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1 Acknowledgments

The ACCA team acknowledges the funds provided to the project by ACIAR, CSIRO and partner institutions. The project's achievements are testimony to the enthusiastic participation of the collaborating partners and stakeholders.

This report synthesizes much hard and dedicated work of many in CSIRO and the partner institutions:

- Bangladesh: IRRI; Bangladesh Rice Research Institute; Bangladesh Agricultural Research Institute; Socio Economic Research and Development Initiative; Bangladesh Agricultural Research Council
- Cambodia: Department of Agricultural Extension; Cambodian Agricultural Research and Development Institute; iDE Cambodia; Svay Rieng Provincial Department of Agriculture
- India: Professor Jayashankar Telangana State Agricultural University (formerly ANGRAU); Livelihoods and Natural Resources Research Institute; Watershed Support Services and Activities Network; Indian Meteorology Department; National Centre for Medium Range Weather Forecasting
- Lao PDR: National Agricultural and Forestry Research Institute; National University of Laos; International Water Management Institute, National Agriculture and Forestry Extension Service; Department of Meteorology and Hydrology; Provincial Agriculture and Forestry Office Savannakhet.
- Consultants: Asian Institute of Technology, University of Queensland, Cam Ag, Emmanuel Santoyo Rio (independent consultant).

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2 Executive summary

Climate change is impacting Asia, with shifts in rainfall patterns, changing temperature regimes and increased climate variability. Since many Asian economies depend heavily on agriculture they are likely to be more affected by climate change, and this will amplify food security challenges.

In general terms, adaptation interventions can be categorised into two broad groups. National and provincial agencies often implement adaptation initiatives primarily based on national scale climate change vulnerability and impact assessments, while at smaller scales practical adaptation interventions occur at the community level, often promoted by NGOs or civil society organisations.

The top-down approach offers strategic insights into sectoral and regional vulnerabilities but provides little information on the resilience or adaptive capacity of sectors and regions, or location-specific context to support household or community level adaptation. The bottom-up approach is constrained by the challenge of scaling household or community level information for broader impact and hence is not easily replicated or taken into the policy domain.

The aim of the Adapting to Climate Change in Asia project (ACCA) was to develop multi-scale adaptation strategies and to demonstrate processes that support policymakers to deliver more effective climate adaptation programs relevant to smallholder livelihoods and food security, and to demonstrate options to build the capacity of farming households to adapt rice-based cropping systems to climate variability and climate change.

To achieve these aims, ACCA addressed the following objectives in four countries – India, Bangladesh, Cambodia and Lao PDR:

1. Adapt and apply available tools/methods to select and assess adaptation strategies for rice-based cropping systems
2. Develop capacity in research and extension processes that support the building of adaptive capacity in rice-based cropping systems
3. Select and evaluate a suite of crop, nutrient and water management adaptation options suitable for provincial level dissemination
4. Derive and disseminate principles and policy recommendations that will enable a more effective design and implementation of adaptation programs at multiple scales

In India, the project aimed to address issues of drought risk, lack of climate information to guide decisions on type and management of crops, rapid rural change with significant social complexity and perceived agricultural labour constraints. The rainfall visualiser, weather-based agro-advisories, farmer climate clubs and Climate Information Centres (CLICs) merged traditional and scientific knowledge of weather, supporting farmers to make decisions as a season unfolds, while recommendations such as a sowing rule and strategic irrigation between crops increased efficiency of inputs and reduced perceived risk.

From an economic perspective, adoption of the project’s recommended soil moisture sowing rule and strategic irrigation of a rainfed cotton crop would result in a gross margin gain of between USD 127/ha and USD 389/ha over existing sowing practices. Using the CLICs as our primary dissemination mechanism, 5% adoption after five years would result in economic benefits shared by at least 400 households in the study districts of Telangana.

Significant policy influence was achieved by the project, including creating the reputation amongst state government and donor agencies of the CLICs as a replicable and locally beneficial agricultural development entity; endorsement by the Indian Meteorological

Department of ACCA’s integrated approach and adaptive improvement to support dissemination of IMD information and forecasts through agro-advisories and the CLICs network.

Encroaching salinity and lack of irrigation are major constraints to agricultural intensification and adaptation in southwest Bangladesh, while social tensions exist around community decision making and adoption of some livelihood options (eg shrimp farming) in the study region of southwest Bangladesh.

Access to existing high quality datasets and a collaborative environment for on-station trials to generate new high quality data meant that the primary focus in Bangladesh was the development and validation of the cropping systems model APSIM. While ongoing farmer engagement, with the intent of developing, evaluating and promoting adaptation practices was not part of the project plan for Bangladesh, systems modelling and social research on adaptive capacity and household typologies suggest opportunities to manage salinity at farmer and polder level. These opportunities and their social and economic influence are being explored in two new ACIAR-funded projects.

Significant policy influence was achieved, including: ACCA outputs underpinning the Comprehensive Disaster Management Program’s work in climate adaptation; enhanced capacity in systems analysis and modelling in Bangladesh and institutional support for continuing this post-ACCA.

The ‘response farming’ approach to addressing seasonal variability was the foundation of ACCA’s adaptation work in Cambodia. This approach assumes that there are a number of options that a farming enterprise can use to make best use of a monsoon period to produce wet season rice, accounting for variability in rainfall (start, duration and amount of rain). These include crop duration and variety, crop sequencing (including double cropping), time of establishment, use of supplementary irrigation, potential for mechanisation or alternative seeding technologies, and pest and fertiliser application times and rates.

Focus groups discussions with farmers suggested that preferred practices were direct seeding, use of short duration rice and double cropping, in response to specific seasonal conditions. Economic analysis suggests a gross margin gain of between USD 328/ha and USD 390/ha over farmer practice. Using the dissemination mechanisms established by the project (iDE’s Farm Business Advisor network, DAE’s training and demonstration initiatives and PADEE’s training and extension activities through SNV, 5% adoption after five years would result in economic benefits to over 1000 households in the focus provinces.

Research was complemented by capacity building of farmers and extensionists in response farming, underpinned by social research to match adaptation options to local adaptive capacity and household livelihoods. In addition, project influence was achieved through informing Cambodian climate policy, informing the design of IFAD’s ASPIRE program, and mainstreaming research results into extension practice through development of technical report as a framework for extension and training.

In Lao PDR, the key adaptation practice promoted by the project was the use of direct dry seeding. In addition to reduced exposure to early season drought and terminal drought stress farmers were attracted mainly by the prospect for reduced costs and labour for production. Planting with the direct seeder is much faster than traditional transplanting methods (one farmer can transplant one hectare in the same time it takes 20 people to transplant using traditional methods).

From an economic perspective, analysis suggests that the gross margin gain of direct seeded rice (that is well managed for weeds) over transplanted rice is USD 150/ha. Using the dissemination mechanisms established by the project (PAFO Savannakhet extension, NAFRI and DAEC training and SNV and IFAD training initiatives), 5% adoption after five years would result in economic benefits to over 1200 households in the two study districts of Outhoumphone and Champhone.

Broader project influence was noted in: expansion of the NAFRI response strategy for climate change through provision of tools, approaches and policy-specific information to understand, monitor and respond to climate events; development of the content and delivery of climate-related extension to include practical training in monitoring and understanding changes in climate; and responding to policy interest in direct seeding by providing a framework for better understanding the benefits and drivers for adoption.

The ACCA network of project teams achieved significant research, community and institutional advances throughout the project, and a range of indicators are outlined for impact and sustainability.

Key operational learnings include:

- Creating an integrated, jointly owned research framework in the early stages of the project is critical for interdisciplinarity.
- Detailed planning and review underpin sound project management, team integration and clarity of institutional and individual roles and expectations.
- Participation and engagement by community and policy stakeholders supports relevance, validation, alignment and sustainability of project outcomes.
- Investing in partnerships within and between project teams and disciplines is an investment in project outcomes, individual development and ongoing collaborations.
- Setting clear aspirations for scaling and sustainability of project outcomes is as important as creating the flexibility to seize opportunities as they arose.

Key research learnings include:

- Self assessments of adaptive capacity reveal recurring indicators across countries, including health, level of education or knowledge, access to irrigation and livestock ownership.
- Household types and livelihoods analysis identified recurring drivers of change, including feminisation of agriculture, labour shortages and rapid rural change.
- A common framework (with a livelisystems approach) can be developed to explore adaptation options, allowing direct comparison between countries.
- APSIM-ORYZA has been comprehensively validated and is performing well in contrasting Asian rice environments, including the ability to dynamically model salinity impacts on rice.
- The range of yields resulting from seasonal climate variability is more significant than under projected climate changes to 2030.
- Adaptation options evaluated in the project are likely to compensate for the detrimental effects of average climate impacts by 2030. Note that ACCA considered incremental climate change, and not extreme events and did not consider impacts beyond 2030.
- For greater relevance and uptake, adaptation practices need to address multiple objectives eg yield, labour and risk reduction.
- A toolkit of management options can help farmers and extensionists better manage climate variability by allowing them to respond flexibly to the progress of a particular season.
- Developing community capacity to relate weather observations to farming decisions (eg with rainfall visualisers and agro-advisories) is important and relatively easy to implement.
- Impredicative Loop Analysis, with a livelisystems foundation is a promising policy and planning tool that integrates social and biophysical aspects of climate adaptation.
- Sustainability polygons are useful visual representations for a range of purposes, including relative environmental effect, potential for maladaptation, the degree to which a practice is ‘Climate Smart’ and a measure of adoption risk.

3 List of abbreviations and acronyms

ACCA	Adaptation to Climate Change in Asia (project acronym)
ACCA-SRA	Shorthand for Small Research Activity LWR-2012-110 (Laos)
ACRC	Agroclimate Research Centre, in PJTSAU (formerly Agromet Cell)
AgMIP	Agricultural Model Intercomparison and Improvement Project
AIT	Asian Institute of Technology
ANGRAU	Acharya NG Ranga Agriculture University, now PJTSAU (India)
ANU	Australian National University
ASPIRE	Agriculture Services Program for Innovation, Resilience & Extension)
APSIM	Agricultural Production Systems Simulator (cropping systems model)
AR	Annual report
AWD	Alternate wetting and drying
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BRAC	Bangladesh Rehabilitation Assistance Committee
BRRI	Bangladesh Rice Research Institute
CAF	Climate Adaptation Flagship (CSIRO)
CARDI	Cambodian Agricultural Research and Development Institute
CAVAC	Cambodia Agricultural Value Chain Program
CCAFS	CGIAR program on Climate Change, Agriculture & Food Security
CCAI	Climate Change Adaptation Initiative
CDMP	Comprehensive Disaster Management Program (Bangladesh)
CEW	Community Extension Worker (Cambodia)
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Center for Tropical Agriculture
CLIC	Climate Information Centre (India)
CLUES	IRRI's Climate Change Affecting Land Use in the Mekong Delta project
CRIDA	Central Research Institute for Dryland Agriculture (India)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSISA	Cereal System Initiative for South Asia
DAE	Department of Agricultural Extension (Cambodia)
DAEC	Department of Agricultural Extension & Cooperatives; formerly NAFES (Laos)
DAFO	District Agriculture and Forestry Office (Laos)
DAS	Days after sowing
DDS	Dry direct seeding
DFAT	Australian Government's Department of Foreign Affairs and Trade
DMH	Department of Meteorology and Hydrology (Laos)
DRD	Department of Rural Development (India)
FAO	Food and Agriculture Organisation
FBA	Farm Business Advisor, associated with iDE (Cambodia)
FCC	Farmer climate clubs (India)
FFS	Farmer Field Schools
FGD	Farmer Group Discussion
GAP	Good Agricultural Practice

GCM	Global Climate Model
GDA	General Directorate of Agriculture (Cambodia)
GHG	Greenhouse gases
HH	Household
IAT	Integrated Assessment Tool (farming systems model)
ICAR	Indian Council of Agricultural Research
ICRISAT	International Crops Research Institute for the Semi-Arid-Tropics
iDE	International Development Enterprises (NGO)
IFAD	International Fund for Agricultural Development
ILA	Impredicative Loop Analysis
IMD	Indian Meteorology Department
IRRI	International Rice Research Institute
IWMI	International Water Management Institute
IWMP	Integrated Watershed Management Program (India)
KII	Key Informant Interview
LADLF	Lao Australia Development and Learning Facility
LMESS	Linear Mixed Effect Statistical System
LNRMI	Livelihoods and Natural Resource Management Institute (India)
MAF	Ministry of Agriculture and Forestry (Laos)
MAFF	Ministry of Agriculture, Fisheries and Forestry (Cambodia)
MRC	Mekong River Commission
MGREGA	Mahatma Gandhi National Rural Employee Guarantee Scheme (India)
MS	Milestone
MTR	ACCA's Mid Term Review, in January 2013
NAFES	National Agricultural and Forestry Extension Service, now DAEC (Laos)
NAFRI	National Agriculture and Forestry Research Institute (Laos)
NARS	National Agricultural Research System
NCMRWF	National Centre for Medium Range Weather Forecasting (India)
NGO	Non-government organisation
NOAA	National Oceanic and Atmospheric Administration
NUOL	National University of Laos
ODA	Official Development Assistance
PAB	Photosynthetic aquatic biomass
PADEE	Project for Agriculture Development & Economic Empowerment (Cambodia)
PAFO	Provincial Agriculture and Forestry Office (Laos)
PAR	Participatory Action Research
PAWC	Plant Available Water Capacity
PDA	Provincial Department of Agriculture (Cambodia)
PDR	(Lao) People's Democratic Republic
PJTSAU	Prof Jayashankar Telangana State Agricultural University, formerly ANGRAU
RKVY	Rashtriya Krishi Vikas Yojana – National Agric Development Scheme (India)
SAARC	South Asian Association for Regional Collaboration
SARCCAB	Support to Agricultural Research for Climate Change Adaptation Bangladesh
SERDI	Socio Economic Research and Development Initiative (Bangladesh)
SLP	South Lao Project

SNV	Netherlands Development Organisation
SRI	System of Rice Intensification
SRFSI	Sustainable and Resilient Farming Systems Initiative
SRL	Sustainable Rural Livelihoods framework
SRMPEP	Sustainable Natural Resource M'ment & Productivity Enhancement Project
TOT	Training of Trainers
UNDP	United Nations Development Program
UQ	University of Queensland
WASSAN	Watershed Support Services and Activities Network (India)

4 Background

Climate change amplifies the challenge of food security. The impacts of climate change in Asia include shifts in rainfall patterns, changing temperature regimes and increased climate variability. Since many Asian countries depend more on agriculture and have less resilient institutions than the developed world, they will be more threatened by climate change. The poorest farmers living in vulnerable areas will bear the brunt of the adverse effects of climate change, especially where policy environments and capacity to respond are weakest.

In recognition of the above, in 2009, ACIAR established a dedicated *Climate Change Initiative,* by implementing two major adaptation projects, one targeting farm level adaptation options in Cambodia, Lao PDR, Bangladesh and India (the ACCA[1] project), and a second project focussing on the Mekong Delta in Vietnam (the CLUES project). The ACCA project was designed as a four country project with a total value of $8.9M, of which $5.5M were ACIAR funds. The project has 21 partner organisations and engaged three consultants to support in-country activities.

In general terms, adaptation interventions can be categorised into two broad groups. As shown in Figure 1, national and provincial entities often implement adaptation initiatives primarily based on national scale climate change vulnerability and impact assessments. While this approach provides strategic insights into sectoral and regional vulnerabilities it offers no information on either the resilience or adaptive capacity of sectors and regions, or a location-specific context to enable household or community level adaptation.

At smaller scales many practical adaptation interventions occur at the community level, usually promoted by NGOs or civil society organizations. This small scale approach is constrained by the difficulty in scaling household or community level information to higher levels (eg provincial or national) and therefore is not easily replicated or taken into the policy domain.

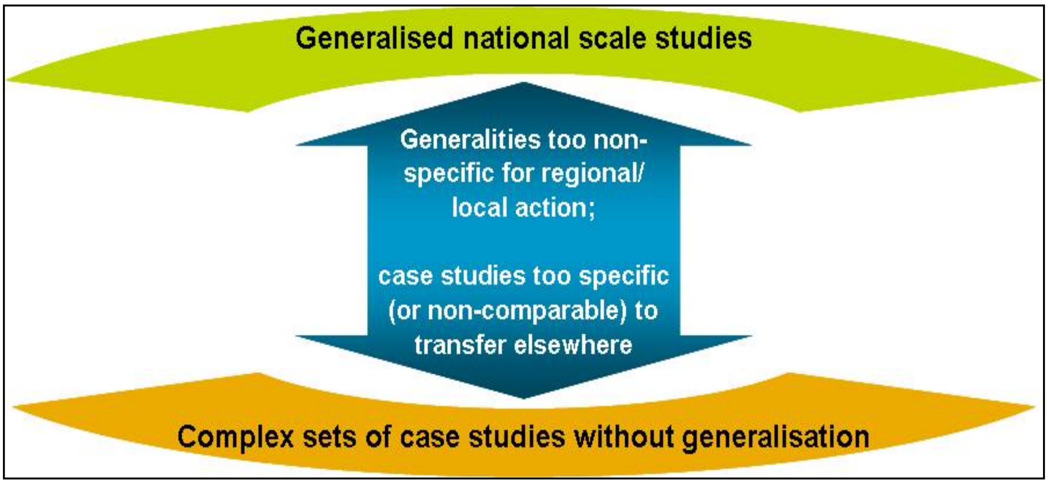

Figure 1. Tension between national level and local level adaptation studies (adapted from Howden et al 2010)

This project demonstrates an approach to bridge these two scales. Our approach includes sufficient complexity at the farming household level to derive credible, locally accepted adaptation options and then generalise these options and test them against future climate

[1] Adaptation to Climate Change in Asia

projections to assess their long term viability and more general transferability to other areas.

This approach meets demand from government and donor organizations for knowledge to support the design of future adaptation programs that are better aligned to local realities. Similarly, there is a widely recognised need by adaptation practitioners (NGOs, agricultural research and extension service providers, farmers) for tested and robust crop and water management options that will outperform existing farming practices under current climatic conditions but that can also be adapted to future climate conditions.

The project commenced in 2010 and is structured as four sub-projects separately covering Cambodia, Lao PDR, Bangladesh and India, with management and technical support provided by CSIRO. The project has developed multi-scale adaptation strategies and demonstrates the processes that enable policymakers to deliver more effective climate adaptation programs relevant to smallholder livelihoods and food security, and to demonstrate options to build the capacity of farming households to adapt rice-based cropping systems to climatic variability.

The collaborating institutions[2] in Cambodia are the Department of Agricultural Extension (DAE), the Cambodian Agricultural Research and Development Institute (CARDI), an NGO, International Development Enterprises Cambodia (iDE Cambodia) and the Svay Rieng Provincial Department of Agriculture (PDA). Project emphasis was on capacity building and conducting social research to assess local adaptive capacity, complemented by targeted testing of adaptation options based on lowland rice-based cropping in Svay Rieng Province, where there is access to groundwater and some surface irrigation water.

In Lao PDR the collaborating institutions are the National Agriculture and Forestry Research Institute (NAFRI), the Department of Agricultural Extension and Cooperatives (DAEC, formerly the National Agriculture and Forestry Extension Service), the National University of Laos (NUoL), the International Water Management Institute, the Department of Meteorology and Hydrology (DMH) and the Provincial Agriculture and Forestry Office (PAFO) in Savannakhet. The focus was on adapting to climate change by improving crop and water management in lowland rice-based systems of two districts in Savannakhet Province (one entirely dependent on rainfall, with a high incidence of drought, the other highly flood prone and with surface water for supplementary irrigation).

The primary focus in Bangladesh was the development and validation of the cropping systems model APSIM based on data from past and ongoing trials by the International Rice Research Institute (IRRI) and additional on-station trials in collaboration with Bangladesh research partners. The main partner in Bangladesh is IRRI, supported by collaborators from the Bangladesh Agricultural Research Council (BARC), Bangladesh Agriculture Research Institute (BARI) and the Bangladesh Rice Research Institute (BRRI). Social research was carried out by the Socio Economic Research and Development Initiative (SERDI), an independent research organisation.

The primary focus in India was piloting the delivery of weather-based agro-advisories in Telangana state (formerly Andhra Pradesh) as an entry point to increase local capacity to manage climate risk and variability and to increase agricultural productivity. The main project partners are the Agroclimate Research Centre (ACRC) within the Professor Jayashankar Telangana State Agricultural University (PJTSAU, formerly ANGRAU), the Livelihoods and Natural Resource Management Institute (LNRMI) and the NGO Watershed Support Services and Activities Network (WASSAN). Associated collaborators are the Indian Meteorology Department (IMD) and the National Centre for Medium Range Weather Forecasting (NCMRWF).

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[2] A complete list of collaborating institutions and the ACCA team members from each institution is provided in Section 11.4.

5 Objectives

1. To adapt and apply available tools/methods to select and assess adaptation strategies for rice-based cropping systems

1.1. Assess adaptive capacity and determine farming systems typologies at local and provincial levels amenable to cropping and water management based adaptation strategies.

1.2. Review literature, source and assess climate data to develop site specific understandings of climate variability and to generate locally relevant climate change projections.

1.3. Develop the capability of APSIM to represent rice-based farming systems.

1.4. Conduct scenario analyses using farmer input (1.1), climate data (1.2) and APSIM (1.3) to identify crop and water management options adapted to variable seasons and climate change.

2. To develop capacity in research and extension processes that support the building of adaptive capacity in rice-based cropping systems

2.1. Train research partners in project research methodologies.

2.2. Improve farmers' ability in case study villages to benchmark and self-assess opportunities for building adaptive capacity.

2.3. Train extensionists and NGO partners to work with farmers in selecting and testing feasible adaptation response options.

3. To select and evaluate a suite of crop and water management adaptation options suitable for provincial level dissemination

3.1. Based on the results of social research (1.1), APSIM scenario analysis (1.4) and farmer participatory planning (2.2) establish a range of on farm experiments to evaluate adaptation options.

3.2. Design and conduct farmer engagement processes to generate farmer-truthed adaptation practices and decision trees to better manage climate variability

3.3. Conduct second series of scenario analyses using APSIM to evaluate additional adaptation practices and climate risk management decision trees determined in 3.2.

3.4. Synthesis of results into a set of technically, financially, socially and institutionally feasible adaptation practices and identification of future research needs.

3.5. Outscaling of technologies and knowledge to selected areas beyond immediate project study sites.

4. To derive and disseminate principles and policy recommendations that will enable a more effective design and implementation of adaptation programmes at multiple scales

4.1. Develop design principles and adaptation strategies to build resilience to climate change at local, provincial and national scales (upscaling).

4.2. Establish advisory panels or utilise existing policy dialogue platforms to channel project outputs developed in 4.1 into climate adaptation policy making.

6 Integration framework and project methodology

Progress in adaptation is predicated on bridging across scales as shown in Figure 1 above. To be effective this bridging needs to be underpinned by an 'adaptation cycle' which is based a ‘reflective analysis-action continuum’ that connects science with society at every step in the process (Meinke et al., 2009).

Accordingly, to make our biophysical and social research more relevant to the process of adaptation it is necessary to embed research approaches within context-specific, participatory dialogues that match the highly contextual needs of decision makers for suitable tools (Meinke et al., 2009). This explicitly requires the research community to engage all stakeholders; from local farming households to the various levels of community, provincial and perhaps national policy making.

The ACCA integration framework is built on this premise and is illustrated in Figure 2. It outlines the flow of individual project activities that generate the outputs and milestones listed in the output tables in Section 4, and how these outputs relate to project outcomes and impacts (i.e. the pathways to impact or the ‘theory of change’ of the project). Also shown are key feedback/iteration loops. We recognise that the immediate sphere of control the project has, i.e. the generation of outputs, which are further devolved into primary outputs (mainly achieved in the three years prior to the midterm review (MTR)) and the synthesised outputs (the main focus of work since that review).

Various stakeholder and policy engagement processes are employed to influence key local and national level policy makers as well as international donor organisations to achieve outcomes that will facilitate scaling of adaptation practices developed by the project and that ultimately magnify the community level impacts (refer to Volume 3, Appendix 1 for details of ACCA’s engagement approach and outcomes).

In the following text we briefly describe the methods underpinning the individual activities.

Our **social research** (activity 1.1 in Figure 2) has two aims. The first is to relate crop and water management adaptation options to diverse livelihood strategies. For this a typology of households was developed in each country, which highlights access to resources, adaptive capacity and livelihood strategies. Using the household types as a filter, we can better understand if and how different agricultural adaptation options are relevant, and for whom. The second aim is to support targeted policy development for adaptation (4.1 in Figure 2) that is informed by the varied capacities and challenges illustrated by the household types.

The household typologies were determined using various methods and data sources such as rapid rural appraisals, detailed household surveys, analysis of secondary data and focus group discussions. These methods varied according to circumstances in each country and recognized partner knowledge and research capacities. A more in depth description of the household typologies approach developed and implemented by the ACCA project is provided by Williams et al. 2013 and 2015.

To complement the household typologies we conducted a household-based assessment of adaptive capacity, drawing on the Sustainable Rural Livelihoods framework first proposed by Scoones (1998) and Ellis (2000). In the community of each case study, a series of self-assessment workshops were facilitated to elicit information on what were perceived to be the constraints and enablers of adaptive capacity, as seen through the lens of individual households. Details on the methods used and how communities scored their adaptive capacity are being prepared for publication (See section 11.3, Paper 1).

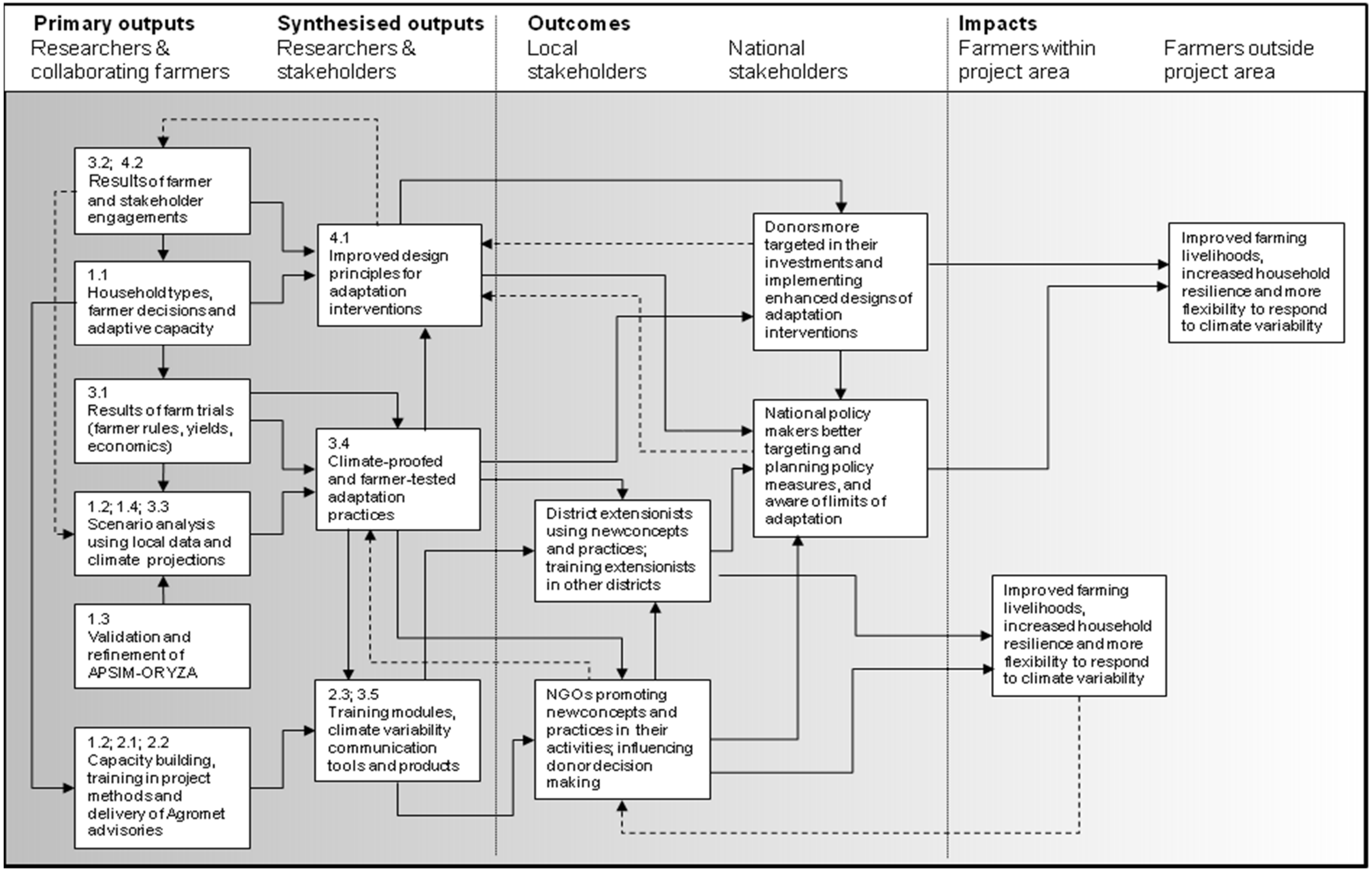


Figure 2. ACCA integration framework, illustrating how key project outputs relate to activities (numbers in output boxes) and how these activities flow into outcomes and impacts ('theory of change')

The **testing of potential adaptation practices on farm** (activity 3.1 in Figure 2) constituted a second major emphasis of the initial work. Choice of practices was determined by a variety of factors but strongly influenced by farmers' preferences canvassed in focus group discussions and informed through activity 1.1. An overview of the adaptation options tested in each country through on farm experimentation is provided in Table 1. The majority of the practices focus on elements of lowland rainfed rice cropping systems (Bangladesh, Cambodia and Lao PDR), whereas in India, there was a stronger emphasis on rainfed cotton and maize.

A critical aspect of being able to conduct the on-ground research in activities 1.1 and 3.1 in particular was the need to train project partners in the key social and on farm research methods early in the project cycle. This was done as part of activities 2.1 and 2.2, through in-country training workshops, on-the-job training and co-development of methods, complemented by Crawford-funded training visits to Australia.

Table 1. Summary of adaptation practices tested on farm and evaluated through scenario analysis using APSIM.

Adaptation practices	On farm testing	Scenario analysis
India		
Improved planting rules for cotton and maize	yes	yes
Strategic irrigation in cotton and maize	yes	yes
Alternate wetting and drying in rice	yes	yes
Alternate furrow irrigation in cotton and maize	yes	no
Spreading irrigation water between rice and cotton	no	yes
Bangladesh		
Improved varieties - saline tolerant	yes	yes
Improved varieties - short duration	yes	yes
Dry season irrigation using pond or stored canal water	yes	yes
High value rabi season crops	yes	yes
Cambodia		
Drum and direct seeding of rice	yes	yes
Rice double cropping	yes	yes
Improved rice varieties – short duration	yes	yes
Improved N management and deep placement of urea	yes	yes
High value dry season irrigated crops (vegetables)	yes	no
Lao PDR		
Drum and direct seeding of rice	yes	yes
Improved varieties - submergence tolerant	yes	no
Improved varieties - drought tolerant	yes	no
Improved N management	yes	yes
'Life saving' irrigation using pond water	no	yes

Benchmarking of farmer practices against current climate variability and evaluating the performance of adaptation practices under future climates was carried out through **modelling** (activities 1.4 and 3.3 in Figure 2), constituting the third main research emphasis in the first three years of ACCA. This requires the parameterisation of a suitable cropping systems model to reflect local soil and crop conditions and farmer management practices using on farm data. To confidently reflect cropping systems for the case study sites, the cropping systems model needed to be able to incorporate farmer decision rules and to be able to simulate long term cropping sequences.

The Agricultural Productions Systems Simulator (APSIM) model was chosen because of its ability to meet these prerequisites. However, at the beginning of the project, the ability of APSIM to simulate rice-based cropping systems was limited, so a major enabling activity in 1.3 was the validation of APSIM-ORYZA across multiple rice environments in Asia, as well as studies to develop specific process routines for salinity.

This work was mainly conducted in Bangladesh and Los Baños, led by IRRI, and has confirmed the ability of APSIM to reliably capture the key climate, crop, soil and management processes of rice-based cropping systems in Asia (Gaydon et al. 2012a; Gaydon et al. 2012b; and Volume 2, Appendix 1), providing the foundation for activities 1.4 and 3.3. Thus tested, APSIM was parameterised at each ACCA project location using local climate, crop and soil data and incorporating local farmer management practices obtained primarily from the on farm research in activity 3.1 and subsequent second iteration of farmer engagement in activity 3.2.

Obtaining location specific climate projections is still a challenge, in particular in countries like Cambodia and Lao PDR, where long term climate records are hard to find and often patchy. While dynamic downscaling of Global Circulation Models can provide long term projections, often spatial resolution of output from such high level models is too coarse to be able to be used for specific sites. Conversely, while some of the statistical downscaling approaches can yield more location specificity if based on reliable historical data, they only provide short term projections (eg until 2030).

A number of approaches were used in ACCA, reflecting availability of high quality historical climate data. For benchmarking current climates and generating future climate projections in Bangladesh, Lao PDR and India, we mainly used the LMESS method to generate location specific projections to 2030 (Kokic et al. 2011), drawing on historical data for the case study locations and using output from two contrasting Global Circulation models (ECHAM5 which is more conservative than GFDLCM2.1 with respect to changes predicted in future climatic scenarios). In Cambodia we have initially taken a fixed scenario approach, while further refining the climate data files through scaling from neighbouring sites in Vietnam.

The first and second series of **scenario analyses** in activities 1.4 and 3.3 using the locally parameterised APSIM helped determine how well current farmer practices perform, in particular with respect to present climate variability, as well as allowing an evaluation of how these practices might perform under future climates. These scenario outcomes of current practice were then contrasted against the performance of new practices such as those listed in Table 1, to assess whether they offered advantages both under present day conditions as well as enabling farmers to improve productivity under changing climates. The results of these scenario analyses were synthesised into a set of more generic adaptation practices, that have been farmer-proofed as well as climate-proofed (activity 3.4 in Figure 2).

In this way a more robust base was provided to decide which current farmer practices and which adaptation practices can be scaled out with confidence through key local stakeholders (activity 2.3 and 3.5 in Figure 2), while at the same time it also underpinned the extrapolation of practices to a broader range of environments. On-ground relevance and evidence of uptake in conjunction with generalised adaptation strategies enabled the team to develop design principles to inform policy makers how to develop future climate change adaptation programs that are better targeted and more effective (activity 4.1 in Figure 2).

Modelling outputs reflecting the adaptation options were represented as sustainability polygons (Ten Brink et al. 1991, Moeller et al. 2014) – a visual summary of how sustainable or climate-smart competing adaptation practices are.

Each sustainability indicator is represented by a relative value from 1 to 0 where 1 is the most desirable outcome (highest or lowest depending on context (eg highest gross margin per hectare or lowest carbon emission per ton of yield).

For a desirable attribute (eg gross margin) the relative sustainability value for any adaptation is calculated as the value of the adaptation divided by the value calculated for the highest among the competing adaptation options. For an undesirable attribute (eg carbon emissions) the sustainability value of an adaptation is calculated by dividing the lowest value among competing adaptations by the value of that adaptation.

When all sustainability indicators are presented in a polygon and equal weighting is assumed for all indicators, the most climate-smart practice would cover the largest area. Ideally the most climate-smart practice will have all values close to 1. However, often this is not the case, requiring the trade-offs between desirable indicators to be assessed. In this sense the sustainability polygons were a tool to enable a more structured assessment of whether adaptation practices are in fact effective and not maladaptive.

The above research approach was fully implemented in Cambodia, Lao PDR and India. In Bangladesh, the focus of the project was to conduct experiments aimed at refining the APSIM model (activity 1.3 in Figure 2), with less opportunity for on farm research. As shown by the multiple feedback loops in Figure 2, the process was inherently adaptive and participatory, like the ‘adaptation cycle’ outlined by Meinke et al. (2009).

Implementation of the ACCA multi-scale bridging concept is reflected in Figure 2 through the generation of adaptation practices relevant at the local scale that can be readily **outscaled** (activity 3.4), and more general design principles that inform policy making to assist in **upscaling** (activity 4.1), and flow through from policy outcomes at the local and national policy levels to eventual impacts at the farming household level.

An important step was sharing an understanding of the process and developing common terminology across the diverse range of partners in the ACCA project. While unified by the aims and general project framework (project ‘theory of change’ illustrated Figure 2), each country team modified the general scaling approach to align with local priorities and opportunities. The scaling process was informed by a methods discussion paper (Williams and Roth, 2013) and a strategic stakeholder engagement approach detailed in Volume 3, Appendix 1. The actual outscaling and upscaling activities are summarised in each of the country results sections 5.1 to 5.4 in this report.

7 Achievements against activities and outputs/milestones

Objective 1: To adapt and apply available tools/methods to select and assess adaptation strategies for rice-based cropping systems

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
1.1	Assess adaptive capacity and determine farming systems typologies at local and provincial levels amenable to cropping and water management based adaptation strategies (all four partner countries)	1. Reports for each country documenting preliminary farming systems typologies in target areas	Mar 2011	COMPLETED. Final reports documenting the household survey data and synthesising the data into household (HH) typologies in each country completed in 2011. These reports provided the basis from which detailed HH types were extracted for each of the four typologies[3]. A common template was applied in all four countries following the methodology described by Williams et al. (2015), aggregating the copious survey data and the results of the adaptive capacity assessment into four headings and matching the HH type to adaptation strategies likely to be relevant to that particular HH type. The templates have been collated in a report provided in Appendix 1 of the 2012 Annual Report, and the data recorded in these reports constituted the basis for Williams et al (2015) and Brown et al in prep (see paper 1 in section 11.3).
		2. SRL household level surveys completed and results documented in a report	Feb 2011	COMPLETED. All four adaptive capacity assessments have been written up in country reports by our partners, one of them in the form of a MSc thesis (Lao PDR). The key constraints to adaptive capacity were extracted and incorporated in the household types discussed above. The results from India, Cambodia and Bangladesh have been presented at conferences in Bangladesh, India and Australia or published (see Khan and Grünbühel 2012; paper 1, section 11.3). A compilation of the results has also been provided in section 3.1 of the midterm review report.
		3. In-depth descriptions of the livelihood trajectories of different household typologies documented (India)	Feb 2011	COMPLETED. The insights gathered by this study indicate that any consideration of adaptation must be carried out within the context of other major drivers of change such as labour shortages, farmers exiting agriculture, feminisation of agriculture, the distortive effect of policies like MGNREGA, and a clear delineation of which farmers are likely to further invest in agriculture. This information has been incorporated into the HH typology developed for India. Policy implications from some of the emerging trends were discussed with key Telangana stakeholders in February 2012 and formed the basis of policy briefs (Activity 4.2, MS3). Data analysis has been completed and eight journal papers have been published (papers 4 to 11 in section

[3] In this report, the term ‘typology’ refers to a set of defined ‘types’. We have generated four household typologies (one in each country), each comprising a number of different household types

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
				11.2).
1.1 cont.	Assess adaptive capacity and determine farming systems typologies at local and provincial levels amenable to cropping and water management based adaptation strategies (all four partner countries)	4. Draft journal paper on SRL as a tool to assess household adaptive capacity	Dec 2011	COMPLETED. A journal paper describing and evaluating the utility of the methodology was initially submitted to *Regional Environmental Change* but it was rejected as being too narrowly focussed. It is now being reworked into a more comprehensive paper not only describing the methodology, but also aggregating the key results and learnings across all case study villages in the all four ACCA countries. Details of this planned paper are provided in section 11.3 (paper 1) of this report.
		5. Draft journal paper: Institutions in development: A theoretical framework to understand stability and change (India)	Jan 2012	COMPLETED. Eight papers covering aspects of agrarian livelihoods, institutions and the rural employment guarantee scheme, have been published by Jakimow et al in a range of journals. These are listed in section 11.3 (papers 4 to 11) of this report.
		6. Provincial level farming systems typologies using secondary data completed and documented	May 2012	PARTIALLY COMPLETED. A greater effort than anticipated was directed to developing a robust set of typologies to provide the basis for scaling HH types to district or provincial scales (MS1). A methodological framework for scaling was initially developed and workshopped with all four partner countries during the annual review and planning meetings Feb-Apr 2012. However, as a result of these workshops it became apparent that suitable secondary data to generate the HH typologies at provincial scales was not available in all cases. At the same time, the results from MS 1-4 across all four countries indicated that there were common adaptation strategies emerging across all four countries, enabling us to take a different approach to mapping of adaptation strategies against HH typologies than originally planned. This led to a redesign of the scaling process as captured in the variation of the project carried out in 2013 and described in a discussion paper prepared by Williams and Roth (2013). A journal paper that develops a generic framework to contrast types across countries is in preparation (Grünbühel et al - See section 11.3, paper 9).
		7. Draft journal paper: Farmers' perceptions of climate change variance amongst different farming households in Telangana	May 2012	COMPLETED. A conference paper was presented at the Australian Agronomy Conference in October 2012. As part of Activity 1.4 / MS6, a journal paper by building on this conference paper has been published (Nidumolu et al, 2015). Furthermore, results from the adaptive capacity analysis in Bangladesh have also enabled an originally unplanned analysis of farmer perceptions to climate change in Bangladesh to be published (Rashid et al. 2014).

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
1.1 cont.	Assess adaptive capacity and determine farming systems typologies at local and provincial levels amenable to cropping and water management based adaptation strategies (all four partner countries)	8. Draft journal paper on utility of SRL In combination with typologies as a tool to assess provincial level adaptive capacity	Apr 2013	COMPLETED. Dedicated data synthesis workshops were carried out in Australia (July 2011 for Lao PDR component), India (August 2011 for India and Bangladesh components) and Cambodia (Sept 2011 for Cambodia and Lao PDR components). The results of the final HH typologies have been published in a journal paper (Williams et al, 2015). However, as discussed under MS6, following the redesign of the approach to HH typologies as a scaling methodology we have instead decided to use Dorward's concept of four *livelisystems* as a unifying framework to compare HH typologies and adaptation strategies across all four countries. This re-analysis of the SRL and HH typology data has been completed and is now being synthesised into a paper by Grünbühel et al. This paper is in an advanced state and due to be submitted in early 2016 (see section 11.3, paper 9).
1.2	Review literature, source and assess climate data to develop site specific understandings of climate variability and to generate locally relevant climate change projections (all four partner countries)	1. Climate input files for APSIM modelling	Oct 2010	COMPLETED. All historical climate datasets have been acquired and compiled into APSIM-ready format. The poor quality of some datasets has necessitated a number of additional tasks. In some cases we have resorted to gridded data (e.g. Indian climate data) to circumvent the problem of large data gaps. We have also used NCEP datasets (NOAA, 2012), which are generated from the reanalysis of observational data and have the advantage that they provide long-term consistent and complete datasets, including parameters such as radiation, which are often not available in the historical records. The disadvantage of NCEP data is that they are produced at a fairly coarse grid scale, and some grid points are quite distant from the field sites in our case study areas. Comparisons between the observational data and the NCEP synthetic historical data indicate high correlations, giving us confidence in the NCEP data.
		2. Characterisations of climate variability documented	Jan 2011	COMPLETED. Overview trend analyses were produced for all countries in 2011. A more in-depth analysis of climate variability has been completed for India (refer to Appendix 4 in Annual Report 2012) and Lao PDR (refer to Appendix 5 in Annual Report 2012). Characterisations of climate variability were also generated by the APSIM modelling conducted for all four countries and expressed in the form of cumulative probability of exceedance functions. In all cases, we found that seasonal climate variability tends to be more significant than the projected changes in climate change. This suggests that finding ways to cope with today's climate variability gives farmers the best chance of protecting against future changes in climate.

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
1.2 cont.	Review literature, source and assess climate data to develop site specific understandings of climate variability and to generate locally relevant climate change projections (all four partner countries)	3. Production of district/provincial level seasonal climate forecasts (India, Lao PDR)	Ongoing in 2010, 2011, 2012	COMPLETED. *India:* Medium range seasonal weather forecasts (2-5 day windows) were prepared and disseminated in the form of Agromet advisories by PJTSAU and local NGO partners to farmers in the three case study villages, twice a week. In each village, farmer climate clubs were established, growing in membership over time. These clubs met fortnightly to discuss the advisories. In Aug-Sep 2011 we conducted a survey of the farmers to evaluate the utility of the advisories. The survey results have been incorporated into a second generation of advisories that were disseminated during the 2012 wet season. Reports on the experience in India are provided in several trip reports and in Appendix 6 of the Annual Report 2012. A repetition of the survey to capture farmer views after the 2012 wet season was undertaken and results documented in a report in early 2013. The Agromet advisories and farmer climate clubs were continued into the 2013 wet season using residual PJTSAU funds, and have now evolved into the development of village Climate Information Centres (CLICs; Activity 3.5, MS3). In the final year dissemination of Agromet advisories was expanded to 33 villages in which CLICs had been established. *Lao PDR:* Building on prototype seasonal and weekly climate forecasts developed by NAFRI and DMH in 2011, which were used to inform policy makers in the Ministry of Agriculture, we attempted piloting Agromet advisories in the 2012 wet season with farmers in the case study villages in Outhoumphone and Champhone. Difficulties in establishing effective delivery mechanisms in Lao PDR resulted in limited dissemination of the Agromet advisories at a village level in 2012. These limitations were partially addressed, enabling NAFRI to continue to prepare and disseminate Agromet advisories in the two case study villages in 2013 and 2014, but still in a limited scale due to resource constraints. We reviewed the process after the 2014 wet season, and drawing on the lessons from India, helped NAFRI design a more effective provision of Agromet advisories beyond the conclusion of the project. This included the use of crop calendar based advisories and the Rainfall Visualiser, in collaboration with SNV in Khammouane Province.
		4. Locally calibrated climate projections prepared as input files for APSIM	May 2012	COMPLETED. A set of climate projections has been produced for all four countries using the LMESS method (Kokic et al., 2011) incorporating observed and NCEP reanalysis data (NOAA, 2012) and output from two CGMS (ECHAM5 and GFDLCM2.1) for a 20 year period centred on 2030. Synthetic historic data have been validated against observational data to ascertain the confidence with which we can use synthetic climate data as the basis for climate projections. Correlations between observational and synthetic datasets are in the order of 80%, with one or two cases of around 60%. A report outlining the process comprises Appendix 7 in the Annual Report 2012 and further details are provided in section 3.3 of the MTR.

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
1.2 cont.	Review literature, source and assess climate data to develop site specific understandings of climate variability and to generate locally relevant climate change projections (all four partner countries)	5. Draft journal paper on local climate projections	Sept 2012	COMPLETED. Preparation of the individual country projections using the LMESS method led to new insights on how to improve the method originally proposed by Kokic et al. 2011. A refinement to the method based on the experiences in the ACCA project was applied to downscaling of climate change projections in the Pacific and published in *Climate Dynamics* in 2013 (Kokic et al, 2013).
1.3	Develop the capability of APSIM to represent rice-based farming systems (mainly Bangladesh; minor activities in Cambodia)	1. Existing datasets compiled for validation tests	July 2010	COMPLETED. Several high quality datasets from IRRI were used in the early stages of ACCA to validate components of APSIM. Use of these datasets has generated two papers (Gaydon et al., 2012a, 2012b). Since then, we have started accessing additional high quality datasets from IRRI and other research institutions across south Asia through both the ACCA and the SAARC-Australia projects. These datasets have allowed us to carry out additional validations of APSIM-ORYZA, confirming the general robustness of APSIM-ORYZA across a wide range of rice-based cropping systems in south and southeast Asia. Combined, the validation tests using datasets of both projects (and also drawing on other datasets in South and Southeast Asia), provided input into the papers generated as part of MS6, as well as being documented in the SAC Monograph published as part of the SAARC-Australia project in April 2014 (Akher et al, 2014).
		2. Supplementary trials to capture AWD dynamics implemented *Note: in the first year, the original planned focus on AWD was modified in Bangladesh to focus on salinity and water table dynamics, and on capturing phenology x N interactions in Cambodia*	July 2010	COMPLETED. *Bangladesh:* in the 2010 wet season, trials were established in Dacope, Satkhira and Gazipur (although the Satkhira data from the 2011 *kharif* were omitted due to prolonged flooding) and repeated through to 2013. The Gazipur trial in particular was well managed, generating high quality datasets enabling rigorous testing of APSIM-ORYZA. In 2013 the Gazipur trial was changed to obtain AWD calibration data. *Cambodia:* the initial CARDI trial set up in 2010 was expanded in 2011 and 2012 into more comprehensive variety x N trials (testing 15 rice varieties and split N applications). Results of the validations using the CARDI datasets provided key input into the paper produced as part of MS6. *Los Banos:* in addition to the above, in 2011 it was decided to initiate a series of controlled salinity trials and glass house experiments at IRRI's Los Banos research farm using savings in the IRRI budget and capitalising on a new post doctoral fellow who joined IRRI to work on incorporating salinity x plant dynamics into the ORYZA model. The salinity trials in Los Banos are now entering the next crop cycle and their results constitute input to MS7-9.

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
1.3 cont.	Develop the capability of APSIM to represent rice-based farming systems (mainly Bangladesh; minor activities in Cambodia)	3. First iteration updated APSIM model with AWD and drought routines ready for use *Note: the original planned focus on AWD was modified in Bangladesh to focus on salinity and water table dynamics, and on capturing phenology x N interactions in Cambodia*	Apr 2011	COMPLETED. The planned integration of the improved ORYZA module into APSIM has proceeded, albeit in a different manner to that originally envisaged. Instead of updating the code in the existing ORYZA module coupled to APSIM (which is laborious), we developed a separate piece of software that was to enable any version of ORYZA to interact with ASPIM. This software, WRAPPER, was developed in Dec 2011. Testing indicated that there are problems wrapping APSIM with later versions of ORYZA which need to be resolved prior to the WRAPPER becoming fully functional. The WRAPPER approach has since become superseded, with the decision to proceed with development of a new rice module using the APSIM_X templates (see MS 7-9) as a result of the project variation in 2013.
		4. Supplementary datasets compiled and used for module validations	Nov 2011	COMPLETED. In Bangladesh wet season 2011 and 2012 data for the two Khulna sites (Dacope and Satkhira) and the Gazipur farming systems trial data were collated and provided to the Bangladesh modelling team for further parameterisation (in conjunction with joint modelling training activities under the SAARC-Australia project). In Cambodia the CARDI on-station trial data for 2011 have also been compiled and used to parameterise APSIM (resulting in Poulton et al 2015; see also MS6).
		5. Second iteration updated APSIM model with refined AWD and drought routines ready for use *Note: the original planned focus on AWD has been modified in Bangladesh to focus on salinity and water table dynamics, and on capturing phenology x N interactions in Cambodia*	Apr 2012	COMPLETED. Parameterisation of the Khulna datasets has been successful. Initial problems where the model was not adequately capturing inundation, salinity and capillary rise, leading to over- and under-predictions of rice biomass at various stages in the growth cycle, have been overcome through improvements to routines in APSIM to address the inundation and capillary rise dynamics, and by including salinity routines in APSIM-ORYZA (using the salinity datasets being generated in Los Banos, MS7-9), significantly improving the model’s performance. Parameterisation of the Gazipur data has been achieved by the Bangladesh modelling team. Rather than Don Gaydon carrying out the parameterisation, it was decided to continue to use the datasets as a parameterisation training exercise for the Bangladesh modelling group. This still requires frequent backstopping to help the team solve problems. In the coming months, Don Gaydon will provide a series of modelling tasks to help the Bangladesh modelling team work more effectively on the Gazipur dataset. It is planned to hold a modelling seminar in Nov 2014 with the Bangladesh modelling team to capture their results and evaluate the capacity building outcomes. In Cambodia the CARDI dataset has been successfully used to parameterise APSIM. APSIM now is capable of running simulations for 15 different rice varieties grown in Cambodia for one of the most representative rice soils (Prateah Lang) and has been validated using on farm data (see also MS6).

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
1.3 cont.	Develop the capability of APSIM to represent rice-based farming systems	6. Draft paper on APSIM-ORYZA validation and application	Aug 2012	COMPLETED. A comprehensive validation of APSIM-ORYZA has been undertaken in conjunction with other projects (SAARC-Australia project) and by accessing a wide range of other datasets. A total of 32 datasets across 12 countries in Asia have been used in this exercise. The results show that APSIM performs very well in most of the diverse rice growing environments of South and southeast Asia. The paper also highlights a few areas requiring further model refinement (e.g. to represent soil structure dynamics under Conservation Agriculture tillage regimes; better evaporation routines). A paper by Gaydon et al. capturing these results is due to be submitted to *Environmental Modelling and Software* in Nov 2015 (Vol. 2, App. 1). The results of the CARDI validation studies have also been summarised in a paper published in 2015 (Poulton et al 2015).
		7. New datasets compiled from field experiments in Bangladesh, and controlled trials and greenhouse experiments in Los Banos	Dec 2013	COMPLETED. As part of the variation to the ACCA workplan agreed in 2013, a reallocation of unspent funds in the IRRI ACCA budget has enabled new field trials and glass house experiments to be set up at IRRI's Los Baños research campus in 2013 and 2014. This was supplemented by validation datasets being generated in the *rabi* season 2012/13 and 2013/2014 through the modification of the original Satkhira trials in Bangladesh, which were changed to accommodate salinity x irrigation treatments. Both datasets have been compiled and for use as input to MS8 and MS9.
		8. Salinity routines coded into ORYZA and APSIM	Apr 2014	COMPLETED. Salinity codes have been developed and incorporated into ORYZA to capture the phenological response to salinity stress. Salinity dynamics already existed in APSIM, but they have now been interfaced with the updated ORYZA. Testing has shown that the salinity response functions are working, and the results of this breakthrough (to our knowledge we have developed the first rice model capable of simulating the effects of salinity) are being widely disseminated through conference and journal papers (See section 11.3 and also App. 2, Vol. 3).
		9. New APSIM rice model produced for integration into APSIM-X	Dec 2014	COMPLETED. The phenology routines within the ORYZA require treatment specific parameterisation of key phenology parameters, limiting the ability to extrapolate the calibrated model to other soil conditions. In agreement with IRRI, we built a completely new rice module with improved phenology, but using the new crop template developed for APSIM_X (next generation version of APSIM), allowing us to work around the issues raised under MS3. Moreover, we have incorporated a rice salinity routine into the crop module, which is the first dynamic salinity crop module for rice. These improvements to APSIM-ORYZA are being extensively published (papers 16-19, section 11.3; see also App. 2, 3 and 4 in Vol. 2).

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
1.4	Conduct scenario analyses using farmer input (1.1), climate data (1.2) and APSIM (1.3) to identify crop and water management options adapted to variable seasons and climate change (Cambodia, Lao PDR, India)	1. Sampling and monitoring protocols agreed and implemented	May 2010, May 2011, May 2012	COMPLETED. Sampling and monitoring protocols were updated where necessary for the 2011 and 2012 wet seasons in all four countries, together with additional training in methods of soil monitoring where required. Monitoring occurred largely as planned, although in some cases not all data were measured due to capacity constraints of partners. An example of the protocols used is provided in Appendix 8 of the 2011 AR.
		2. Calibration datasets compiled and current practices benchmarked	Dec 2010, Dec 2011	COMPLETED. Datasets to calibrate APSIM for farmer field conditions have been obtained and compiled in all four countries for the wet seasons 2011 and 2012. Farmers were interviewed in all case study villages to gather information on actual farmer practices and decisions. Datasets and farmer practices have been used to benchmark APSIM for all sites. Examples of the benchmarking results are provided in Appendix 11 of the Annual Report 2012 and in Section 3.2 of the MTR. Following the variation to the project in 2013, a second farmer engagement process was conducted in 2013 to obtain more farmer feedback. Reported under Activity 3.2.
		3. First phase of farmer climate risk perception questionnaires tested and applied (India)	Apr 2011	COMPLETED. Information obtained from the climate risk perception surveys carried out in 2010 informed the selection of some of the climate risk management options tested as part of activity 3.1. More details are contained in Appendix 4 of the Annual Report 2012 and Section 3.3 of the MTR, as well as a paper by Nidumolu et al (2015).
		4. Improved cropping and water management options derived from scenario analysis	Apr 2011, Apr 2012	COMPLETED. The first iteration of scenario analyses was carried out for all four countries in 2011 and 2012. Results obtained from this iteration of scenario analysis are summarised below and presented more fully in Section 3.5 of the MTR. Following the variation to the project in 2013, a second set of scenario analyses was conducted in 2013 and 2014 to refine these results. This is reported below under Activity 3.3. *India:* strategic irrigation of high-risk, high-return, cotton crops has the potential to achieve significant improvements in yield and yield stability which can be sufficient to justify reducing irrigation to rice (either by implementing AWD or SRI approaches to rice growing or by reducing the land available as paddy). Strategic irrigation will remain an effective adaptation option under the future (2021-2040) climate scenarios modelled. *Bangladesh:* early establishment of both T. Aman and subsequent *rabi* season crops is likely to have potential long-term benefits under both historical and future climates. *Cambodia:* short duration varieties, planted early in the wet season and given adequate levels of N, have potential to increase on farm yields over traditional medium duration rice varieties. The potential to successfully grow two short

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
1.4 cont.	Conduct scenario analyses using farmer input (1.1), climate data (1.2) and APSIM (1.3) to identify crop and water management options adapted to variable seasons and climate change (Cambodia, Lao PDR, India)	4. Improved cropping and water management options derived from scenario analysis Cont..	Apr 2011, Apr 2012 Cont.	duration crops in one wet season is reliant on the early start to the monsoon season, as well as access to sufficient specialised agronomic knowledge, machinery and inputs. *Lao PDR:* while sowing using a direct seeder does not bring significant yield benefits there are, however, cost savings (in required labour and inputs) which are expected to be reflected in forthcoming gross margin analyses. Using supplementary irrigation throughout the growing season increases yields in poor seasons; additional N inputs are required in better years to capture the benefits of the additional water. Similar results have been observed under present day (1971-2011) and a future (2021-2040) climates. The various management options for each country have been documented in trip reports, sections 3.4 and 3.5 of the MTR.
		5. Model output characterising cropping systems risk profiles	Apr 2011, Apr 2012	COMPLETED. Cumulative distribution functions of yields based on long term historical climate records have been generated with APSIM for all main rice-cropping systems and results. A second iteration has been completed in 2013/2014 as part of Activity 3.2. Key results are presented in section 8 of this report.
		6. Climate risk framework linked to APSIM model output and climate risk management priorities ranked (India) – second phase	Apr 2012	COMPLETED. The second stage climate risk perception survey was carried out in late 2011. Analysis of the data and targeted APSIM modelling has enabled us link the risk management framework generated under this milestone with the scenario analysis being undertaken for India. The results have been documented in a number of papers as part of MS8 and MS9.
		7. Charts, pictorials, street plays etc. developed to communicate modelling results to farmers	May 2010, May 2011, May 2012	COMPLETED. A framework to communicate climate information to farmers, where we jointly evaluate with farmers the results of the on–farm trials and the output generated by the scenario analysis in activity 1.4, was developed and applied in 2013 as we consolidated the results of the 2nd iteration scenario analysis and in conjunction with the second series of farmer workshops conducted as part of Activity 3.2. A range of methods conveying modelling results have been used - pictorials and street theatre plays in India, focus group discussions and simple butcher paper charts in Cambodia and Laos.
		8. A series of draft papers documenting results of APSIM and IAT scenario analysis and selected options	Mar 2013	PARTIALLY COMPLETED. Preparation of papers capturing the integrated approach used in ACCA and summarising the results of the scenario analyses across all four countries is at an advanced stage, with submission to high profile journals planned for late 2015 (see papers 6, 7, 10, 11, 12, 15, section 11.3; see also App. 5-7, in Vol 2).

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
1.4 cont.	Conduct scenario analyses using farmer input (1.1), climate data (1.2) and APSIM (1.3) to identify crop and water management options adapted to variable seasons and climate change	9. Draft journal paper – Under-standing climate risk management approaches in rainfed agriculture with implications in a changing climate (India)	Oct 2013	COMPLETED. A conference and a journal paper by Nidumolu et al. have been published (Nidumolu et al, 2014) An additional paper reflecting on the CLICs approach in India is in preparation (paper 13, section 11.3)

Objective 2: To develop capacity in research and extension processes that support the building of adaptive capacity in rice-based cropping systems

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
2.1	Train research partners in project research methodologies (all four partner countries)	1. Partners trained in SRL methodology and surveys tested	Apr-Aug 2010	COMPLETED. Reported in Annual Report 2011.
		2. Partners exposed in workshops to APSIM and scenario analysis and trained in sampling	Apr-Aug 2010	COMPLETED. Reported in Annual Report 2011. Additional training in soil sampling was carried out in India in July 2011. Laboratory protocols and equipment have been improved at CARDI and at NAFRI (through a linked SRA: SMCN/2010/084). Training of a Bangladesh modelling group established in conjunction with the SAARC-Australia project has been ongoing.
2.2	Improve farmers' ability in case study villages to benchmark and self-assess opportunities for building adaptive capacity (Cambodia, Lao PDR, India)	1. Farmer groups established in each case study village	Sep 2010	COMPLETED. *India:* Farmer Climate Clubs (FCC) were established in 2010 and have continued to operate in each of the case study villages; initially each comprising about 25 farmers. In 2012 numbers have grown and the clubs now range between 34 and 52 members. These farmer groups meet on a regular basis, and are the groups engaged to evaluate the results of the field trials and the agro-advisories. In one village the FCC has evolved into a farmer association. *Cambodia:* No formal farmer groups were established in Cambodia, but in each of the three villages, about 40 farmers were involved in field trials in 2011 and 2012. *Lao PDR:* As in Cambodia, no formal farmer groups were established in Lao PDR. In 2011, around 10 farmers were involved in field trials from five villages.

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
2.2 cont.	Improve farmers' ability in case study villages to benchmark and self-assess opportunities for building adaptive capacity (Cambodia, Lao PDR, India)	1. Farmer groups established in each case study village Cont.	Sep 2010 Cont.	Numbers increased to about 15 in 2012 In Cambodia and Lao PDR on farm trials continued in the 2013 wet season through the support of the sister project LWR/2010/110.
		2. Participatory action learning sessions to plan on farm trials carried out at the onset of each monsoon season	Dec 2010, May 2011, Dec 2011	COMPLETED. Focus discussion groups were carried out in each participating village before the wet season, to jointly plan and select treatments to be trialled in on farm experiments. Where required farmer training sessions were also carried out; for example in Cambodia farmers were trained in the use of the drum seeder and in urea deep fertiliser placement; in India farmers were trained in SRI; and Lao PDR farmers were trained in Good Agricultural Practices and the use of the dry seeder. This continued in Cambodia and Lao PDR in the 2013 wet season through the support of the sister project LWR/2010/110.
		3. Farmers accessing and using SCF bulletins for decision making (Lao PDR and India only)	Ongoing during cropping seasons	ONGOING. *India:* District level agro-advisories based on medium range seasonal weather forecasts continue to be prepared and disseminated by PJTSAU and local NGOs twice a week to farmers in the three case study villages. The Farmer Climate Clubs meet regularly to discuss the agro-advisories. To further inform farmer decision-making, a visualisation tool using gridded IMD rainfall data has been developed and is being disseminated to NGOs in Telangana. Upon entering the latitudes and longitudes of a particular location, three graphs are produced that depict wet, normal and dry wet seasons from the last ten years. Using this tool NGOs can print large charts for display in the villages, allowing villagers to plot the current rain gauge data they have observed onto this graph. This provides villagers with a visual impression of where they are in the current season in relation to past rainfall years, and, on the basis of rainfall trends, influence their decision making about adjusting their crop and water management. *Lao PDR:* In 2011 NAFRI piloted a seasonal climate forecasting bulletin, which was targeted at the national Government through the MAF. A process to disseminate farmer level agro-met advisories that builds on this prototype was attempted in the 2012 wet season, but difficulties in establishing effective delivery mechanisms in Lao PDR resulted in limited dissemination of the Agromet advisories at a village level in 2012. These limitations were partially addressed, enabling NAFRI to continue to prepare and disseminate Agromet advisories in the two case study villages in 2013 and 2014, but still in a limited scale due to resource constraints.

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
2.3.	Train extensionists and NGO partners to work with farmers in selecting and testing feasible adaptation response options (Cambodia, Lao PDR, India)	1. Training workshops carried out by DAEs and NGOs	Dec 2010, May 2011	COMPLETED. Training in all three countries was provided to collaborating local extension and NGO partners. In most instances the training was provided by our lead partners in each country (PJTSAU and WASSAN in India; NAFRI in Lao PDR; CARDI and iDE Cambodia in Cambodia). Training focussed on establishing on farm trials, monitoring crop growth, and techniques of eliciting farmer feedback on the treatments tested.
		2. Training materials for train-the-trainer courses in PAR updated in relation to climate adaptation and produced	May 2011	COMPLETED. This activity was delayed until training needs assessments had been completed in each of the three countries, as our extension partners felt that PAR was not the highest priority in their training needs. These training needs assessments were completed in 2012 (an example from Cambodia is provided in Appendix 12 of the Annual Report 2012). In 2013 we worked with the key extension partners in each country (WASSAN in India, DAEC in Lao PDR and DAE in Cambodia) to develop priority training modules and to commence train-the-trainer programs. In 2014 dissemination products and approaches were developed in conjunction with activities 3.2 and 3.5. Material has been compiled and provided to the Climate Information Centers in India, and is being disseminated through DAE training in the PADEE program in Cambodia.

Objective 3: To select and evaluate a suite of crop, nutrient & water management adaptation options suitable for provincial level dissemination - outscaling

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
3.1	Based on the results of social research (1.1), APSIM scenario analysis (1.4) and farmer participatory planning (2.2) establish a range of on farm experiments to evaluate adaptation options (Cambodia = C, Lao PDR = L, India = I)	1. 10 on farm plots established in each case study village in time for monsoon	Jul 2010 (I,C), May 2011, May 2012	COMPLETED. Alongside the HH typologies work, this activity constituted a major effort across ACCA in the first 2.5 years. The 2011 wet season proved to be the first in which the full complement of on farm trials was rolled out. Generally results were very useful and provided several lines of further enquiry into adaptation practices farmers are likely to adopt; these in turn formed the basis for further on farm trials in 2012. A summary of the outcomes of the on farm research is provided in Section 3.4 of the MTR and in section 8 of this report. A challenge that emerged across all three countries after the 2011 wet season is that it is hard to maintain farmer interest in running control plots alongside treatment plots if the improved practices looked promising.

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
3.1 cont	Based on the results of social research (1.1), APSIM scenario analysis (1.4) and farmer participatory planning (2.2) establish a range of on farm experiments to evaluate adaptation options (Cambodia = C, Lao PDR = L, India = I)	1. 10 on farm plots established in each case study village in time for monsoon Cont.	Jul 2010 (I,C), May 2011, May 2012 Cont.	This was alleviated to some degree by emphasising the need to maintain robust controls in the 2012 wet season. Also, in Lao PDR maintaining a sufficiently frequent presence in the case study villages was affected by capacity constraints in 2011. A stronger involvement of provincial and district partners helped NAFRI alleviate these pressures in 2012. *India*: Ten farmer plots were established in each of the three case study villages in Nalgonda, Mahbubnagar and Warangal districts in both wet season 2011 and 2012. Treatments consisted of different irrigation regimes in cotton and maize, testing of different sowing dates, and a comparison of SRI, ANGRAU package and farmer practice in the rice plots. *Bangladesh*: Funding constraints precluded dedicated on farm activities, but links to IRRI'S SARCCAB project allowed pooling of resources and maintaining two on farm trials near Khulna. Adaptation practices included improved rice varieties and alternative *rabi* crops aiming at mitigating salinity risks and earlier planting of *boro* rice to escape terminal drought. *Cambodia*: A wide range of on farm experiments were established in three case study villages in both 2011 and 2012. Treatments comprised drum seeding vs. transplanting; double cropping rice vs. traditional single season rice; farmer seed vs. improved seed; farmer fertility management vs. improved fertility management; and testing of a range of vegetables and to a minor extent, of forages. In total, 40 on farm plots were established in 2011, while 35 plots were established in 2012, with similar treatments. *Lao PDR*: In 2011 on farm experiments were established in four case study villages. Treatments comprised farmer seed vs. improved seed and farmer fertility management vs. improved fertility management. In total, 12 on farm plots were established. A similar number of on farm trials was established in 2012 in five villages, with a greater focus on supplementary irrigation, testing submergence (TDK1-sub1) and drought (TDK11) tolerant rice varieties and testing of early rice establishment using direct seeders. This work continued in Cambodia and Lao PDR through sister project LWR/2012/110, involving a stronger focus on dry direct seeding in Lao PDR (52 farmers in 2013) and an extension of the drum seeding and double cropping rice systems from Svay Rieng to Prey Veng Province in Cambodia (40 sites in 2013).
		2. 10 on farm plots established for dry season crops in case study villages (where there is access to irrigation)	Dec 2010, Dec 2011	COMPLETED. The 2011-2012 dry season saw some on farm research activity in all three countries, but in a more limited intensity than the wet season, due to lack of irrigation in most villages.

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
3.1 cont	Based on the results of social research (1.1), APSIM scenario analysis (1.4) and farmer participatory planning (2.2) establish a range of on farm experiments to evaluate adaptation options (Cambodia = C, Lao PDR = L, India = I)	2. 10 on farm plots established for dry season crops in case study villages (where there is access to irrigation) Cont.	Dec 2010, Dec 2011 Cont.	*India:* In 2011 six farmer plots were established in Nemmani and Gorita, comparing SRI with the ANGRAU rice package and farmer practice. In 2012, in addition to the same intensity of rice plots, one *kharif* maize plot was established in Gorita and 10 *rabi* maize plots in Bairanpally, three of which were intensively monitored. *Bangladesh:* The same sites established in the wet season were continued under irrigation, mainly *boro* rice and cowpeas. *Cambodia:* Some level of irrigated rice and vegetable growing occurred in all three case study villages in both dry seasons, with a total of 16 trials established. *Lao PDR:* Due to capacity constraints, it was decided not to pursue a formal program of on farm experiments in the 2011/12 dry season. Rather, we opted to use the dry season to multiply seed of the submergence tolerant rice variety TDK1-sub1, in order to have sufficient available seed for the 2012 wet season trials to test this variety in flood prone areas of Champhone. For similar capacity constraints no activity was planned for the dry season 2011/12; key collaborators were encouraged to focus on collecting and analysing 2012 wet season results, with a view to more in-depth understanding of these results and ability to prepare for the 2013 wet season.
		3. End-of-monsoon season evaluations documented	Jan 2010 (I,C), Jan2012, Jan 2013	COMPLETED. Meetings with collaborating farmers to evaluate the outcome of 2011 wet season on farm experiments were conducted in Lao PDR in February and April 2012 and in April 2012 in India and Cambodia. Results have been documented in trip reports. Farmer evaluations of the wet season 2012 were also completed as planned in India, Cambodia (see November and December 2012 trip reports) and Lao PDR (see April 2013 trip report).
		4. End-of-dry season evaluations documented	May 2011, May 2012	COMPLETED. The 2010-2011 end-of-dry season farmer evaluation meetings were held in June 2011 in India, and March and May 2011 for Cambodia and Lao PDR, respectively. Key results have been documented in trip reports. The 2012-13 end-of-dry season farmer evaluation meetings were conducted in April 2013 and also reported in trip reports.
3.2	Design and conduct farmer engagement processes to generate farmer-truthed adaptation practices and decision trees to better manage climate variability (Cambodia, Lao PDR, India)	1. Design of farmer engagement process documented	Jun 2013	COMPLETED. Following two CSIRO team workshops in July and August 2012 and in subsequent consultation meetings with our partners during October and November 2012, it was decided to substantially redesign activities 3.2 – 3.4. The redesign commenced during the MTR workshop and was completed through a formal project variation in mid 2013. Following on from discussions held during the MTR to develop general guidelines and a shared understanding of the purpose of

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
3.2 cont.	Design and conduct farmer engagement processes to generate farmer-truthed adaptation practices and decision trees to better manage climate variability (Cambodia, Lao PDR, India)	1. Design of farmer engagement process documented Cont.	Jun 2013 Cont.	activities 3.2, 3.3 and 3.4, all four country teams designed farmer engagement (FE) processes aligned with local needs and conditions. The proposed FE processes ended up differing a bit in each country, reflecting different capabilities and preferred approaches of our partners. Focus group discussions (FGD) were designed for all of the case study villages in Cambodia, India and Lao PDR, with groups stratified along household types, to validate the typologies and to obtain farmer feedback on the adaptation practices tested or conceived. This was followed by in-depth interviews using a key informant interview (KII) process, to elicit farmer decision making rules and to develop additional scenarios to be tested using APSIM. Details on the FE plans in each country have been reported in trip reports in 2013.
		2. Outcomes of 1st farmer engagement process documented	Nov 2013	COMPLETED. *India:* the initial FE process in India entailed a focus group discussion (FGD) process, which was led by Chiranjeevi Tallapragada (LNRMI) in August 2013. Key findings have been documented in a report (section 11.3, report 36) and highlight the importance of multiple mechanisms for information sharing due to high illiteracy; and the challenges of diverting and/or sharing irrigation based on field location and access. Farmers in FGDs who used the 70mm rule had good results, however there is a general preference to get crops in early (take advantage of early rains, risk of missing planting window) despite risks of loss of seed. *Bangladesh:* Whilst initially also planned for Bangladesh (using residual IRRI funds, a subsequent review of IRRI's ACCA component redirected residual funds towards additional work supporting development of salinity routines in APSIM (Activity 1.3, MS7-9) and the farmer engagement process was not fully carried out in Bangladesh. A KII process conducted in April/May 2013 yielded useful data on farmer decision making rules that were subsequently used to re-parameterise the Manager module in APSIM for the Bangladesh scenario analyses. *Cambodia*: the FGD process was conducted in Cambodia in August 2013, facilitated through a consultant (Dr Emmanuel Santoyo Rio) and involving DAE. Results highlight the strong role of risk (cultural, social and financial) in shaping the process of adoption in Svay Rieng. Use of short duration rice varieties and fertiliser (enabling double cropping) was the most popular / commonly used practice. Though there are acknowledged benefits of the drum seeder, including significant labour reduction; reduction in seed use and time saving in crop establishment, focus group participants felt that broadcasting was cheaper and easier. The approach taken and results and conclusions are documented in a report (see report 39, section 11.3).

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
3.2 cont.	Design and conduct farmer engagement processes to generate farmer-truthed adaptation practices and decision trees to better manage climate variability (Cambodia, Lao PDR, India)	2. Outcomes of 1st farmer engagement process documented Cont.	Nov 2013 Cont.	*Lao PDR:* the approach chosen in Lao PDR consisted of a FGD process following training in Good Agriculture Practices given by DAEC and NAFRI prior to the 2014 wet season, and a KII process eliciting farmer views on dry direct seeding. The practice most discussed and implemented was the direct seeder. Households were enthusiastic about the savings in labour for transplanting, however the dry season had contributed to significant weed problems which required ongoing labour and detracted from perceived benefits. Households were keen to experiment in different fields (where weed management may be easier) in the next season. Pesticides were generally not an acceptable weed management option due to health and environmental concerns. Results have been documented in Vol 3, App 2 and the July 2013 trip report.
		3. Outcomes of 2nd farmer engagement process documented	Apr 2014	COMPLETED*. India*: the KII were conducted by the PJTSAU team, in conjunction with Activity 1.4/MS6 in Sept/Oct 2013. Emphasis was on capturing rules that farmers use to decide when to sow, complemented by new rules developed by the ACCA team. It also provided further data on farmer climate risk management and their views on options such as strategic irrigation, underpinning some of the scenarios modelled for India. The results of the India KII were captured in spreadsheets by Murthy et al. *Cambodia*: The KII was conducted in Oct 2013 (Vol 3, App 9) and built on the results obtained in the preceding FGD. It allowed a deeper probing of some of the reasons behind farmer acceptance of adaptation measures such as rice double cropping using drum seeding, improved varieties and better nitrogen management. It also specified trigger points for farmers initiating tillage and nursery and transplanting operations. The subsequent re-parameterisation enabled us to verify the various cropping options being proposed within a 'response farming' framework, and results have been captured in Vol 3, App 3. *Lao PDR*: a second set of KII was performed in Nov 2013, after the collaborating farmers had harvested the test plots. Weed management in the dry seeding systems emerged as a key potential constraint, negating labour savings through avoidance of transplanting. Overall farmers are very receptive and state the labour savings benefits as a major determinant for acceptance of dry seeding (Vol 3, App 4). The interviews also enabled a further specification of farmer planting rules subsequently captured in APSIM .

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
3.3	Conduct 2nd series of scenario analyses using APSIM to evaluate additional adaptation practices and climate risk management decision trees determined in 3.2 (Cambodia, Laos, India)	1. Scenarios and decision tree parameters defined using output from 3.2	Feb 2013	COMPLETED. Results from the farmer engagement processes conducted in Activity 3.2 were used to define a further set of scenarios to be tested using APSIM. In particular, the results of the KII were critical in being able to approximate the farmer decision rules around rice crop establishment, making using of the versatility of APSIM's Manager module.
		2. APSIM reconfigured and Manager module programmed	May 2013	COMPLETED. Final parameterisations of APSIM have been achieved in all four countries. This took longer than anticipated, as it required modelling results to be presented back to our partners, who subsequently reviewed the plausibility of the results, in some cases necessitating further refinements to parameterisations. This has led to an increased ownership of the results, at the cost of a 6-12 month delay in finalisation of the 2nd scenario analysis.
		3. Modelling outputs compiled	Jul 2013	COMPLETED. The second substantive iteration of scenario analyses was initiated in the second half of 2013, based on the results arising from the more extensive farmer focus group discussions and subsequent researcher and NGO workshops in Activity 3.2, as well as plausibility testing with stakeholders. This was a highly iterative process, and interim results were documented in a number of trip reports. Modelling outputs were compiled into a uniform reporting format comprising key performance parameters (yield, total biomass, gross margin, stability of yield) as well as indicators of potential maladaptation (GHG emissions intensity, soil carbon) are presented in the form of sustainability polygons. A complete set of scenario results for India have been compiled into a report (Vol 3, App 5), forming the basis for a series of country specific papers (Hochman et al. for India – Vol 2, App 5-6; Poulton et al. for Cambodia – Vol 2, App 7; Laing et al for Lao PDR – paper 12, section 11.3 and Gaydon et al. for Bangladesh – papers 6, 7, section 11.3) incorporating the results of the second iteration of modelling. These papers are due to be submitted to journals by the end of 2015.
		4. Farmer-appropriate communication products produced	Aug 2013	COMPLETED. This milestone is linked to Activity 3.5 / MS2 and MS3. In India WASSAN have converted some of the modelling results into street theatre plays and pictorials, as well as refining and expanding the web-based information tools made available in the CLICs. In Cambodia, a 'Response Farming' manual has been translated into Khmer by DAE and is being disseminated through the PADEE program.

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
3.3 cont.	Conduct second series of scenario analyses using APSIM to evaluate additional adaptation practices and climate risk management decision trees determined in 3.2 (Cambodia, Laos, India)	4. Farmer-appropriate communication products produced Cont.	Aug 2013 Cont.	In Lao PDR a dry seeding extension manual has been produced as part of sister project LWR/2010/110, and we provided key input into a comprehensive extension manual on direct seeding produced by the IFAD-funded SNRMPEP project.
		5. Draft journal paper: Eliciting and modelling farmer climate risk management	Oct 2013	PARTIALLY COMPLETED. A paper reflecting on the Indian experience and the utility of village Climate Information Centres (see Activity 3.5 / MS3) is prepared for submission in the coming months.
3.4	Synthesis of results into a set of technically, financially, socially and institutionally feasible adaptation practices and identification of future research needs (Cambodia, Laos, India)	1. Results of synthesis workshops documented	May 2014	COMPLETED. *India*: the final synthesis workshop was held with all partners in Jan 2014, resulting in a package of adaptation measures being disseminated through village Climate Information Centres (see Activity 3.5 / MS3). Results have been recorded in a trip report. *Cambodia*: a preliminary workshop was held with the project partners in May 2014, followed by an assessment and endorsement of the 'response farming' package through a technical panel in June 2014, involving a wider range of specialists. A comprehensive report containing detailed crop calendars and crop and soil management practices for a range of adaptation options has been prepared (Vol 3, App 3) and submitted to the relevant directors within the General Directorate of Agriculture, who have endorsed the package to be disseminated via the PADEE program (see Activity 3.5 / MS3). *Lao PDR*: a synthesis workshop was held with all partners in Vientiane in May 2014. Inspired by the 'response farming' package developed by the Cambodian team, the Lao PDR team prepared crop calendars, underpinned by detailed crop and soil management recommendations..
		2. Draft journal paper: Evaluation of farmer engagement process and adaptation practices generated	Jun 2014	PARTIALLY COMPLETED. A PhD thesis by Elizabeth Clarke evaluating the integration approach used by ACCA is in its final stages, with plans to submit two journal papers in early 2016 (papers 2 & 3, section 11.3 of this report).
		3. Draft journal paper: Integrated approach to represent adaptation options using analysis from multiple sources	Jul 2014	PARTIALLY COMPLETED. An invited paper by Roth and Grünbühel published in 2012 in a Special Issue of the *Asian Journal of Environment and Disaster Risk Management* describes the ACCA integration framework and provides early reflections on how well this has worked in Cambodia and Lao PDR (Roth and Grünbühel, 2012). A more comprehensive analysis using Dorwards' *Livelisystems* framework to integrate multiple information sources across all four countries is now being synthesised into a paper following presentations at two conferences. This paper is in an advanced state and due to be submitted in early 2016 (paper 9, section 11.3).

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
3.5	Outscaling of technologies and knowledge to selected areas beyond immediate project study sites (Cambodia, Lao PDR, India)	1. Field days and workshops to expose farmers and extension workers to on farm trials (one each in each case study village, during monsoon and dry season, respectively)	Aug-Oct 2011, Feb-Mar 2012, Aug-Oct 2012	COMPLETED. Field days were organised during the 2011 wet season in all three countries (October 2011 in Lao PDR, November 2011 in India, September 2011 in Cambodia), exposing farmers in the case study villages to the results of the on farm demonstrations. Similarly, field days were also organised during the 2012 wet season in Cambodia and Lao PDR. No formal field days were organised during the dry season, due to the lower level of on farm activity. Outcomes of past field days have been reported in previous annual reports and trip reports. However, additional field days were conducted for the 2013 wet season in Cambodia and Lao PDR to expose farmers to the demonstration trials being carried out during the 2013 wet season in Lao PDR and Cambodia through the companion SRA (LWR/2012/110).
		2. Extension materials for dissemination of preferred adaptation options produced	May 2014	COMPLETED. *India*: WASSAN has produced pictorials and posters depicting the key messages and recommendations arising from our work, including the improved sowing rules, the rainfall visualiser charts, the use and interpretation of Agromet advisories. The same content has also been turned into a street theatre play, which was successfully trialled before the start of the 2013 wet season. Since then, the street theatre has been performed in more than 63 villages in Mahbubnagar, Rangareddy and Nalgonda districts. WASSAN also commissioned the production of a software front-end to access all the dynamic and static information through computers that have been set up in the 33 village Climate Information Centres. *Cambodia*: the ‘Response Farming’ manual has been translated into Khmer by DAE and is being disseminated through the PADEE program, as well as through iDE’s Farmer Business Advisor program. . *Lao PDR*: the discussion paper produced as part of Activity 1.4 / MS6 in conjunction with the sister project LWR/2010/110 (Vol 3, App 4) has formed the basis for extension materials. As a result, a dry seeding extension manual has been produced as part of sister project LWR/2010/110. We also provided key input into a comprehensive extension manual on direct seeding produced by the IFAD-funded SNRMPEP project

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
3.5 cont.	Outscaling of technologies and knowledge to selected areas beyond immediate project study sites (Cambodia, Lao PDR, India)	3. NGOs and Extension services scaling out project results through field days, workshops and train-the-trainer approaches	Jun 2014	COMPLETED. This activity constituted the focus of the project in its final and extension year. Results have been compiled in the stakeholder engagement report (App 1, Vol. 3). *India:* the primary vehicle for outscaling the integrated knowledge package on managing climate variability to have emerged from our work in Telangana is the establishment of village based Climate Information Centres (CLIC; described in more detail in section 8.1 of this report), combining soft and hard infrastructure elements. CLIC piloting constituted the main focus of ACCA in Telangana in the final year. Under the leadership of the NGO partner WASSAN, the team in India has been involved in establishing 33 CLICs in each of the three project districts (Warangal, Rangareddy, Mahbubnagar), supported through the Dept. of Rural Development’s Integrated Watershed Management Program and other state government agencies. Plans to seek institutional support and anchoring the CLIC institutionally to maintain the CLICs beyond the project were initially disrupted by the political changes related to the establishment of the new State of Telangana, but were successfully re-initiated by PJTSAU and WASSAN with the new government institutions in Telangana in 2015. *Cambodia*: Two linked outscaling pathways were implemented. Through NGO partner iDE, entrepreneur input providers (Farmer Business Advisors - FBAs) were trained in the ‘response farming’ package developed by ACCA. Each FBA services 40-50 farmers and to date around 300 FBAs have been trained in ACCA practices. Through extension partner DAE, under the auspices of the IFAD-funded PADEE program, extension workers are being trained in direct seeding and double cropping practices that form part of the ’response farming’ package endorsed by GDA under MS1 of Activity 3.4. Once the PADEE program has been fully rolled out, there is a potential to reach out to 20,000 households across five provinces in Cambodia (see also in section 8.3 of this report). *Lao PDR:* Primary outscaling was through Savannakhet provincial and district level extension services to promote dry seeding as the key climate risk management technology emanating from our work in Lao PDR. In 2013-14, in addition to farmers participating in on farm testing, an additional area of 100 ha was direct seeded in Savannakhet. In 2014-15, this had expanded to 600ha and interest spread beyond the case study districts of Outhoumphone and Champone to other districts in Savannakhet, as well as to Champassak province. We have also been providing project outputs to the IFAD-funded Sustainable NRM Productivity Enhancement Project, which is disseminating direct seeding technology in other in southern Lao provinces. Extension of ACCA results has also occurred with SNV in Khammouane Province (see section 8.4).

Objective 4: To derive and disseminate principles and policy recommendations that will enable a more effective design and implementation of adaptation programmes at multiple scales - upscaling

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
4.1	Develop design principles and adaptation strategies to build resilience to climate change at local, provincial and national scales (upscaling) (all four partner countries)	1. Design of policy engagement process documented	Jun 2013	COMPLETED. Following two CSIRO team workshops in July and August 2012 and in subsequent consultation meetings with our partners during October and November 2012, it was decided to substantially redesign activity 4.1. The redesign commenced during the MTR workshop and was completed through a formal project variation in mid 2013. The first step in this redesign was to develop general guidelines and a shared understanding of the purpose of this activity (i.e what do we mean with upscaling – section 11.3, paper 45). Consequently in early 2013, all four country teams designed stakeholder engagement processes built around a selected set of stakeholders or policies and donor programs to be targeted. With the subsequent re-focussing of the Bangladesh component on developing salinity routines for APSIM, further policy level engagement in Bangladesh has been stopped. In the other three countries, in general terms, we planned for a series of stakeholder workshops after the results of the farmer FGD became available. Progress and stakeholders being targeted have been documented in a stakeholder engagement report (App 1, Vol 3), as well as recorded in numerous trip reports. In addition, Liz Clarke, a PhD student from ANU, has included ACCA as a case study in her PhD to evaluate the strengths and weaknesses of the engagement processes used in 1.1, 1.4, 2.2 and 3.1. She analysed project documents and interviewed ACCA team members. Results of her work were presented at the International Food Security Conference in Holland in 2013 (see list in 11.3), and she is working on a joint paper (papers 2 & 3, section11.3).

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
4.1 cont.	Develop design principles and adaptation strategies to build resilience to climate change at local, provincial and national scales (upscaling) (all four partner countries)	2. Proceedings of 1st set of workshops to engage with policy makers and stakeholders on adaptation strategies	Feb 2014	COMPLETED. *India*: rather than conduct workshops, the preferred mode in India has been to conduct a series of bilateral briefing sessions with key stakeholders, e.g. the India Meteorology Dept. (in relation to changes to the Agromet advisory system), the Special Commissioner for Rural Development (for support to pilot 15 CLICs through the DRD Integrated Watershed Development Program; mainstreaming climate adaptation extension and training into watershed development programs), and the Secretaries of Agriculture and of Panchayati Raj, for institutionalising the maintenance of CLICs. Meeting notes are provided in trip reports. *Cambodia:* Two workshops to expose policy makers to key adaptation strategies and policy recommendations have been conducted in Nov 2013 and May 2014 (the latter as part of ACIAR's Rice Policy Dialogue). These focussed on conveying the concept of building farming household resilience and giving farmers tools to manage climate variability through response farming. We also exposed stakeholders to the concept of incremental *versus* transformational adaptation (Roth et al 2014). *Lao PDR*: A workshop involving mainly provincial stakeholders (who have carriage of on-ground extension in Savannakhet) on dry direct seeding was held in Savannakhet in July 2013. This has been supported through additional bilateral briefings, primarily to the Director General of the Dept. of Agriculture, with emphasis in helping develop an Agromet advisory system in Lao PDR, as well as providing policy briefs on dry direct seeding in support of the Lao PDR government push for intensification and drought proofing of lowland rice production. The results of these meetings have been recorded in a number of trip reports.
		3. Consolidated design principles and policy recommendations for adaptation strategies documented in a report	May 2014	COMPLETED. Preliminary design principles were presented by Roth et al at the First Global Conference on Research Integration and Implementation in Sep 2013 (see paper 73, section 11.3) and a preliminary set of policy recommendations are documented in a paper presented at the ACIAR Rice Policy Dialogue workshop in Phnom Penh in May 2014 (Roth et al 2014). The ACCA project was also used as a case study in a CSIRO funded strategic project conducting a meta-analysis on R4D design principles.

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
4.1 cont.	Develop design principles and adaptation strategies to build resilience to climate change at local, provincial and national scales (upscaling) (all four partner countries)	4. Proceedings of 2nd set of workshops to engage with policy makers and stakeholders on adaptation strategies	Jun 2014	PARTIALLY COMPLETED. *India*, An evaluation of the CLIC pilots was conducted in March-April 2015, coinciding with a policy and stakeholder workshop with the Depts. of Rural Development, Agriculture and Panchayat Raj. The CLICs evaluation has been documented in a report (section 11.3, paper 37), while the results of the policy workshop have been documented in trip reports. *Cambodia*: Design principles for adaptation programs and opportunities to disseminate ACCA results were discussed in bilateral meetings with the project management team of the new IFAD ASPIRE program (Agriculture Services Program for Innovation Resilience and Extension) in Aug 2015. ASPIRE (and the UNDP) have already drawn on some of the ACCA outputs (climate resilient agriculture, double cropping of rice; response farming) in the design of their new programs. *Bangladesh:* Stakeholder policy workshops as in the other countries are not planned, but a modelling symposium was conducted in Apr 2015 that showcased results of scenario modelling. The primary target audience was senior research managers of BARC, BRRI and BARI, with a view to strengthening institutional support for modelling in these organisations, consolidating earlier work of the SAARC-Australia project. *Lao PDR:* Originally we had planned to conduct a policy workshop with our partner NAFRI, in conjunction with a LADLF funded policy integration project aimed at mainstreaming direct seeding into the MAF policy process. Budgetary cuts by DFAT to its program in Laos resulted in the LADLF support to NAFRI being withdrawn, and the workshop could not proceed. NAFRI have plans to conduct the policy workshop in late 2015 out of their own resources, and the project leader has committed to attend this workshop.
		5. Draft journal paper on adaptation strategies and socio-economic/biophysical integration methodology	Aug 2014	INITIATED. A paper by Roth et al. is in preparation for submission to *Mitigation and Adaptation Strategies for Global Change* in early 2016. This paper will bring together the lessons learnt from the ACCA project and reflect on how these learnings can be applied in future adaptation research.

NO	ACTIVITY	OUTPUTS/MILESTONES	COMPLETION DATE	COMMENTS
4.2	Establish advisory panels or utilise existing policy dialogue platforms to channel project outputs developed in 4.1 into climate adaptation policy making (all four partner countries)	1. Key stakeholders and policy makers identified and engaged through advisory committees or policy dialogue platforms	Nov 2010	COMPLETED. The stakeholder engagement plans prepared during 2011 have been regularly reviewed and updated through 2012 (see App 1, Vol 3 for details)
		2. Routine briefings and workshops conducted	Apr 2011, Apr 2012, Apr 2013, Apr 2014	COMPLETED. Regular briefings with key stakeholders have been carried out by the project leader, the deputy project leader and some of the local team coordinators during most of the visits by CSIRO team members. Formal stakeholder workshops were held in Bangladesh (February 2012), in India (in conjunction with ACIAR's Water Forum project, in Nov and Dec 2012), Cambodia (April 2012; Nov 2013, May 2014) and in Lao PDR (July 2013). Details of the stakeholders briefed and the content of the briefings have been provided in relevant trip reports and the stakeholder engagement report (App 1, Vol 3). Main policy, donor and NGO stakeholders engaged include: *India*: National Rainfed Area Authority; Indian Council of Agricultural Research; Indian Meteorology Dept.; Telangana Departments of Rural Development, Agriculture, Panchayati Raj. *Bangladesh*: Bangladesh Agricultural Research Council; Comprehensive Disaster Management Program; Dept. of Agricultural Extension; Dept. of Environment – Climate Change Office; BRAC; FAO. *Cambodia*: General Directorate of Agriculture; Climate Change Office; Svay Rieng Dept. of Agriculture; Asian Development Bank; UNDP; IFAD; FAO; SNV (Netherlands development agency); the Cambodia Agricultural Value Chain Program (CAVAC - AusAID/DFAT). *Lao PDR:* Dept. of Agriculture; Mekong River Commission; AusAID/DFAT; IFAD; UNDP; SNV; Savannakhet Provincial Agriculture and Forestry Office.
		3. Annual policy briefs produced and disseminated to stakeholders, policy makers and donors	Apr 2011, Apr 2012, Apr 2013, Apr 2014	COMPLETED. Policy briefs were prepared and distributed to key policy stakeholders in all four countries. Three policy briefs were produced and distributed in India, two policy briefs in Lao PDR and one policy brief in Bangladesh and Cambodia. The first two policy briefs prepared for India are included in Appendix 13 of the Annual Report 2012.

8 Key results and discussion

8.1 India

Country focus

The primary focus in India was piloting the delivery of weather-based agro-advisories in Telangana (formerly part of Andhra Pradesh) as an entry point to increase local capacity to manage climate risk and variability and to increase agricultural productivity. This was underpinned by an extensive program of participatory on farm research to test sowing rules and strategic irrigation (primarily in cotton), complemented by an in-depth social study of household livelihood strategies and adaptive capacity.

Telangana was chosen to link to the work of ACIAR’s cluster of water and climate change related projects, but also because rainfed areas of Telangana are characterised by a very variable climate with high incidence of drought.

The main project partners are the Agroclimate Research Centre (ACRC) within Professor Jayashankar Telengana State Agricultural University (PJTSAU, formerly ANGRAU), the Livelihoods and Natural Resource Management Institute (LNRMI) and the NGO Watershed Support Services and Activities Network (WASSAN). Associated collaborators are the Indian Meteorology Department (IMD) and the National Centre for Medium Range Weather Forecasting (NCMRWF).

Site information

The case study villages are in three districts in the Telangana state in south India: Warangal, in the Central Telangana agro climatic zone, Nalgonda and Mahbubnagar in the Southern Telangana Zone (Figure 3). Paddy rice, cotton and maize are the key *kharif* (monsoon) crops in these villages. Paddy rice is grown under irrigated conditions mostly using groundwater pumped from bore-wells. Cotton and maize are mostly rainfed. The average holding size in the area is ~2 ha with predominantly smallholder farmers.

Figure 3. Location of study villages

Natural endowments for agriculture vary considerably between the three villages. Bairanpally (Warangal district) village has better soil and water resources than Gorita (Mahbubnagar district), and Nemmani (Nalgonda district) villages, where resources are more limited.

Bairanpally has a mean growing season rainfall of 910mm, with very productive soils (mainly Vertisols or black soils) and more substantial ground water based irrigation resources. Gorita and Nemmani have growing season rainfalls of 615 mm and 600 mm respectively and both have ground water based irrigation resources that are confined to Vertisols in drainage depressions. Upland soils are mainly poorer, red granitic Alfisols and Ultisols.

Cropping calendar

Monsoon season cropping in Telangana has traditionally focussed on the growing of mainly rainfed cotton and maize on red, granitic soils (Ultisols), and irrigated rice on Vertisols.

For cotton, sowing usually takes place into tilled fields after sufficient rainfall has fallen in June/July. Sowing rules differ and are discussed in more detail later. Planting beyond July is usually not undertaken. Cultural practices include weeding, and where there is access to irrigation, furrowing and irrigation. Harvesting of cotton is by hand and takes place in several pickings during November to December. Yields of seed cotton in purely rainfed conditions are highly variable and range between 1 – 4 t/ha.

Nurseries for rice are established and land preparation commences in June using irrigation water, with transplanting in July. Rice is only viable where there is a secure supply of ground water, which is supplemented in August/September. Manual harvesting takes place in October to November. Yields range between 4 – 6 t/ha.

	June				July				Aug				Sep				Oct				Nov				Dec			
Crop stage / Week	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Sowing					■	■	■																					
Square bud										■																		
Blossom												■	■															
Boll														■														
Harvest																				■	■	■	■	■	■	■		

Figure 4. Crop calendar for traditionally planted cotton in Central and Southern Telangana.

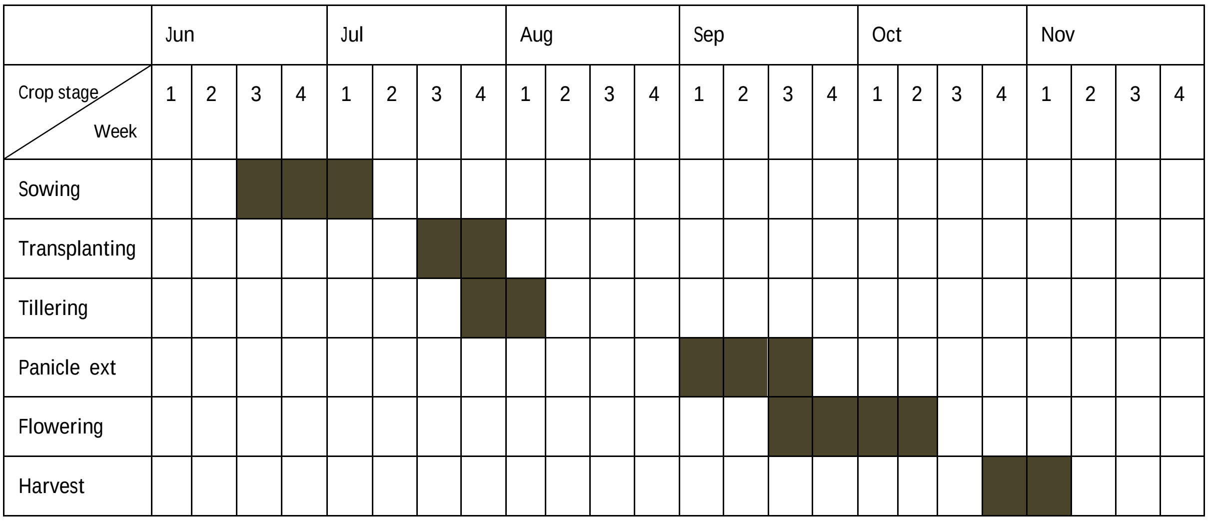


Figure 5. Crop calendar for traditionally planted rice in Central and Southern Telangana.

Household types

Household types have been developed from the study of six villages: Mucherla and Bairanpally (Warangal), Gorita and Ammapally (Mahbubnagar) and Nemmani and Chowdampally (Nalgonda). These types are summarised in Table 2.

The caste system in India has been significant in defining the types, which are distinct from those identified in the other ACCA countries. Scheduled castes (SC), backward castes (BC), and other castes (OC) are social categories used to provide equitable benefits across castes. SCs are considered the most disadvantaged group; traditionally these are mostly landless labourers; however some have been assigned covenanted land by the government. Land size is usually very small, soil quality is poor and they have no access to groundwater (though there are some government programs to support digging bore wells).

BCs are a slightly better off, but still economically disadvantaged; traditionally they have been denied access to education. Over the past few decades they have become more politically assertive given their majority share of the population. Traditionally, BCs are rooted in agriculture as they used to take care of the lands of landowning castes (eg Brahmins).

OCs are the most advantaged group. They usually own land and businesses and engage in a diversity of occupations. Previously they were landlords but over time holdings have decreased in size: many families have sold off land or have divided properties due to inheritance. This caste has mostly moved into high paid and high profile jobs but often own land as absentee landlords.

Other key variables in defining the types in Telangana are land ownership; soil quality and irrigation access and access to other non-agricultural livelihood options through access to productive assets (eg small business).

Table 2. Summary of household types, India

Type	Key characteristics	Key constraints
1	Landless SC/BC wage labourers.	Low and unequal wages; poor healthcare; limited options for diversification and risk mitigation
2a	Marginal and small; SC/BC ; no irrigation; poor soil quality	Lack of irrigation access; market access/fair prices; access to credit and information
2b	Marginal and small; SC/BC farmers; limited irrigation; poor soil quality	Risk of bore-well failure; time / labour available for agriculture; access to credit and information.
2c	Marginal and small OC farmers with no irrigation and poor soil quality	Irrigation access; succession planning
2d	Marginal and small OC/BC farmers with good irrigation and poor soil quality	Time / labour available for agriculture; access to quality inputs; market access / fair prices; soil quality
3	Marginal and small farmers with other productive assets, access to irrigation and varied soil quality	Division of labour; household labour availability; non-farm business viability linked to demand by other households
4	Marginal and small BC/OC farmers with good access to irrigation and good soil quality	High input cost; low market prices; small land area
5a	Medium and large BC/OC farmers with no direct access to irrigation and poor soil.	Poor soil quality; lack of irrigation; labour shortages / high cost of labour; risk of heat stress / food shortages for livestock
5b	Medium and large BC/OC farmers with limited irrigation and poor soils	Irrigation; labour costs; input costs; low market prices; availability of fodder crops
6	Medium and large BC/OC farmers with mixed access to irrigation and varied soil type	Cost of labour; cost of inputs
7	Medium and large BC/OC farmers with good access to irrigation and good quality soil	Declining profits and increasing costs; high labour costs and labour shortages

Livelihood trajectories

In India, the ACCA project had an opportunity to conduct a deeper analysis of rural change. Research was conducted to understand the trajectories or likely trends of farming households to guide consideration of appropriate adaptation strategies. The research found that all households were diversifying their livelihoods, but into different types of activities. The smaller the land category, the more marginal secondary livelihood activities, and the more attractive agriculture (own land) becomes. While men across categories have diversified out of agriculture, women face additional constraints in entering alternative occupations. Agricultural labour remains an important part of women's livelihood portfolios. These factors have led to a feminisation of agricultural labour (both own-cultivation and wage labour).

The viability of agriculture is a balance between size and investment in (household) labour resources. Large farms have the resources to invest in agriculture, while the attractiveness of other investment options means that many farmers may not fully utilise their land. For medium farms, resources are being increasingly diverted into education, which is seen as a more secure path to maintain a standard of living and class status. Unlike large landholders, many do not have the capital to invest in both agriculture and education, resulting in a drop in agricultural investment. Small and marginal farmers overcome some of these problems by investing more family labour, thereby reducing input costs. For these farmers, wage labour or the guaranteed rural employment system (MGNREGA, or Mahatma Gandhi National Rural Employee Guarantee Scheme) are important livelihood activities, but a desire to reduce dependence on this income means that they are generally reluctant to sell their land. At the same time, they are less able to invest in the input intensive agriculture that is a feature of agriculture in Nemmani and Gangapur. Pressures such as dowry, health and education expenses have meant the loss of land, or more commonly, its partial sale. Households across social classes were found to be investing in education, but with different ability to convert that education into better livelihood activities in line with access to resources (see paper 7, section 11.2 for an in-depth discussion of this topic).

On farm research

On farm experiments with rice, cotton and maize crops were designed to compare proposed adaptation ideas with current farmer practice by splitting a field into two parts. These fields were monitored by sequential measurement of soil water and mineral nitrogen status, crop growth stages, above ground dry matter and grain or cotton yields at harvest. Experimental replication was to be achieved by more than one farmer trialling the same innovation in the same village over two to three seasons.

However, the main purpose of on farm experiments was to test, demonstrate and prompt discussion on the practicalities of the proposed adaptations, rather than to provide experimentally rigorous evidence that they were superior to current practice. At the end of each season, village discussions about these trials and farmers' overall experience of the season were facilitated. Such discussions led to more adaptation ideas and to design of more on farm trials in the coming season.

On farm research in this study has focussed on rice and cotton crops grown on red and black soils in three participating villages – Bairanpally, Nemmani and Gorita. The principal concern for farmers was the reduction of risk in rainfed cotton and maize, both at the time of crop establishment (eg loss of seedlings due to dry spells after sowing) and within season drought periods. In the first case, the interventions tested included alternative sowing rules, while in the latter case, the use of strategic irrigation ('life saving' irrigation) was tested by diverting limited amounts of irrigation water from rice paddies to cotton.

The main issues identified with paddy rice production were the inefficient use of water from tube wells and inefficient use of fertilisers and agricultural chemicals. Farmers in the three villages trialled the 'PJTSAU Package' - a package of recommendations that is reflected in the agro-advisories produced by PJSTAU from IMD forecasts and distributed to villages to support farm management, based on medium term forecasts. In the village of Nemmani, two farmers also trialled a modified System of Rice Intensification (SRI) method which reduced the amount of water used (effectively an alternate wetting and drying method - AWD).

Modelling adaptation practices

Four adaptation practices were explored during the project: sowing rules, strategic irrigation of rainfed crops, reduced irrigation of rice and reduced area for strategic irrigation of rainfed crops. A detailed compilation of results is provided in Appendix 5, Volume 3; here we present key results.

Sowing rules

The question about when farmers sow rainfed crops started as a conversation between researchers. It seems that while some farmers will sow these crops as soon as the monsoon season officially breaks (defined by IMD as two consecutive days where rainfall exceeds 2.5 mm), local agronomic data suggests that a cumulative rainfall of 50 to 75 mm might be more appropriate. Surveys and discussions with farmer climate clubs established by the project and facilitated by local NGOs in each village confirmed that a wide range of practices exist in the three case study villages and that re-sowing of seed is a common problem.

The sowing window for rainfed crops such as cotton and maize is between 1 June and 17 July. If sowing criteria are not met by 17 July, the crop is not sown. Given this sowing window, four variations to the sowing rule were suggested:

1. Sow at 'onset of monsoon' following IMD's definition ie 2 consecutive days in which daily rainfall >= 2.5mm (referred to as 2 day rule)
2. Sow when cumulative rainfall equals or exceeds 75 mm (accumulated over 4, 7, 10 or 14 days) (referred to as 75mm rule)
3. Sow when cumulative rainfall equals or exceeds 50 mm (accumulated over 4, 7, 10 or 14 days) (referred to as 50mm rule)
4. Sow when soil moisture in top 15 cm is at 50% plant available water capacity (PAWC) in black soils or at 66% PAWC in red soils (referred to as soil moisture rule).

For Gorita, sowing rule 3 (50mm rule) was the most successful in reducing the risk of seedling failure at the smallest cost in terms of missed sowing opportunities under the historical climate scenario. The scenario modelling suggests that this rule also represents the most successful adaptation under both the ECHAM5 and GFDLCM21 scenarios for 2021-2040.

In the case of Bairanpally[4], sowing rule 3 (sowing rule 3 with a 7 day start) was most successful in reducing the risk of seedling failure at the smallest cost in terms of missed sowing opportunities under the historical climate scenario. It was also the most successful adaptation under both the ECHAM5 and GFDLCM21 scenarios for 2021-2040.

Strategic irrigation of rainfed crops

Strategic irrigation of primarily rainfed crops such as cotton and maize was suggested, applying the following rules:

Apply 50 mm when soil moisture falls below 50% of PAWC subject to:

- at least 14 days between irrigations
- maximum of 3 irrigations per season
- for cotton, start irrigations at 30 days after sowing (DAS) and stop at 120 DAS
- for maize, start irrigations at 14 DAS and stop at 21 days after anthesis.

Strategic irrigation of cotton crops in each of the three case study villages increased the yield probability distribution throughout the entire range of yield outcomes. In particular, the probability of yields below 2 t/ha was dramatically reduced. This trend was true for the historical record as well as the ECHAM5 and GFDLCM21 scenarios for 2021-2040. For both the rainfed and strategically irrigated crops, the differences in the distribution of simulated yields between the historical record, the ECHAM5 and the GFDLCM21 scenarios was small relative to the range of yield outcomes due to year to year variability (Figure 6).

Water is a limited and dwindling resource in the study area, so irrigation of rainfed crops must come from savings made by reduced irrigation of paddy rice. This can be achieved

[4] For most analyses, Nemmani results were between Bairanpally and Gorita results and are not shown in this section for brevity. See Appendix 5-6, Volume 2 for more detailed information.

by either reducing the per hectare irrigation through measures such as alternate wetting and drying (reduced irrigation of rice) or by reducing the area sown to rice.

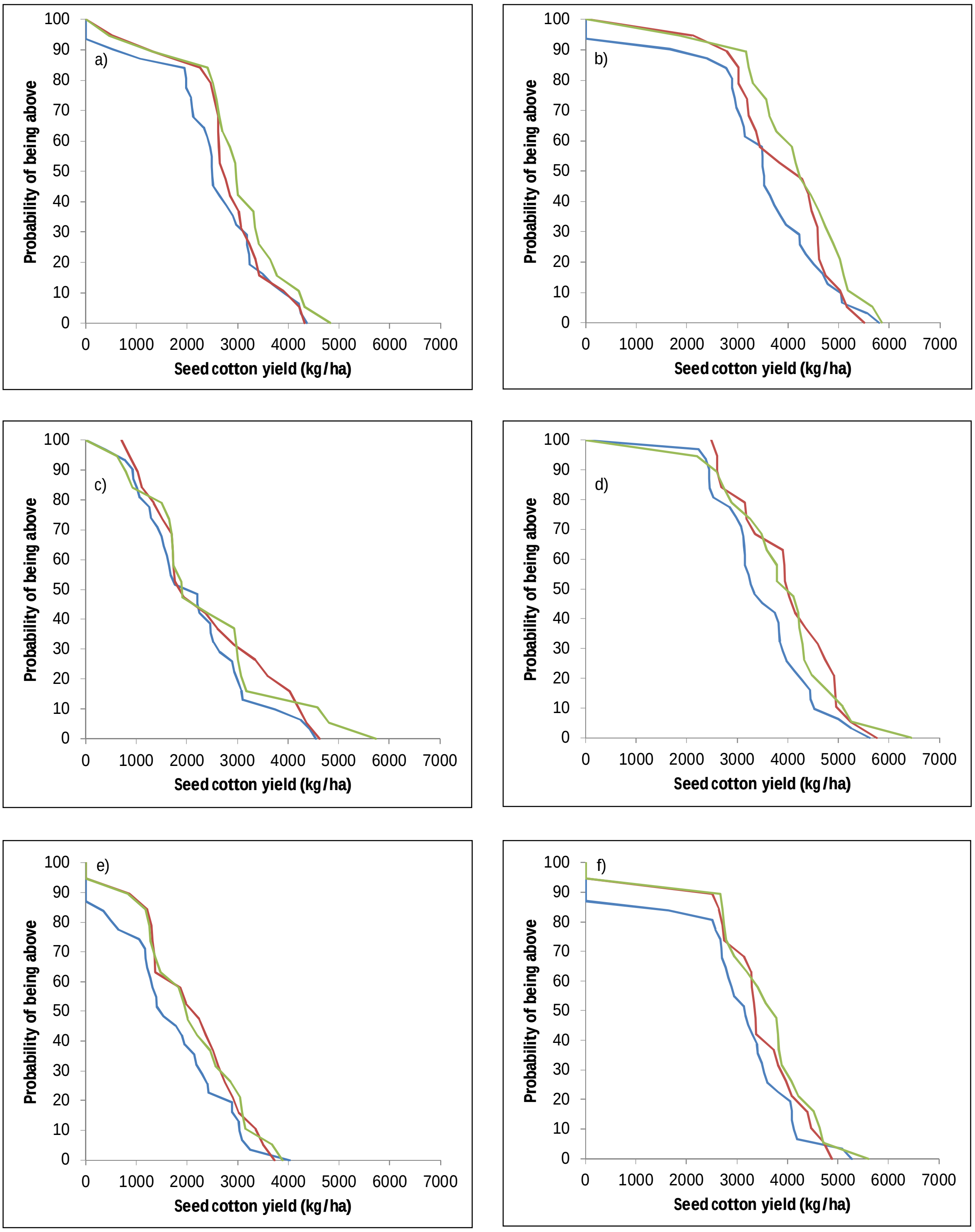


Figure 6. Seed cotton yield response (probability of exceedance) of crops sown using the soil moisture sowing rule for rainfed crops (left hand side) and strategically irrigated crops (right hand side) at Bairanpally (top) Gorita (middle) and Nemmani (bottom). Blue lines represent historical record (1978-2009); green represents ECHAM5 projection (2021-2040) and red represents the GFDLCM2.1 projection (2021-2040).

Reduced irrigation of rice

Paddy rice sowing was simulated for all scenarios according to the following farmer rule:

- Start nursery on 7 June.
- Transplant seedlings at least 25 DAS when cumulative rainfall exceeds 35 mm.
- If minimum rainfall (35 mm) had not fallen in 50 days at Bairanpally, sow at 50 DAS.
- If minimum rainfall (35 mm) had not fallen in 60 days at Gorita, sow at 60 DAS.

Farmer irrigation practice was identified as aiming to maintain a pond depth of 10 cm by irrigating every second day to top up the pond to 10 cm if required (scenario Irrig-1). Three alternative adaptations were proposed:

1. Irrig-2: Maintain 5 cm pond depth – irrigate every day to top up pond to 5 cm if required
2. AWD1: Alternate wetting and drying - irrigate to 5cm when pond depth reaches 0cm
3. AWD2: Alternate wetting and drying - irrigate to 5cm two days after pond depth reaches 0cm.

The current practice (Irrig-1) was compared with the three proposed adaptations in terms of their grain yields, gross margins and net water use.

The three reduced irrigation adaptations were evaluated against current farmer practice in terms of their rice yields, their gross margins and the net water use. Net water use, a measure of the contribution to the depletion of groundwater resources is calculated as irrigation minus drainage beyond the root zone. These comparisons are shown for Bairanpally and Gorita fields in Figure 7.

In the Bairanpally simulations, consistent differences were observed in the amount of net water used in the alternative irrigations (Irrig 1 > Irrig 2 > AWD1 > AWD2). The median difference between the Irrig 1 (current farmer practice) and the AWD2 option represents a saving of about 120 mm/ha or 28% of farmer practice. Small positive differences in yield were observed in response to reduced irrigation (AWD2 > AWD1 > Irrig 2 > Irrig 1) and these yield gains were reflected in improved gross margins (bottom of Figure 7) as both water and electricity are fully subsidised. While the reduced irrigation option is beneficial for production gross margin and net water usage, it requires more management effort by farmers.

In the Gorita simulations, consistent differences were observed in the amount of net water used in the alternative irrigations (Irrig 1 > Irrig 2 = AWD1 > AWD2). The median difference between the Irrig 1 (current farmer practice) and the AWD2 options represents a saving of about 100 mm/ha or 26% of farmer practice. In contrast with Bairanpally, small negative yield and gross margin differences were observed in Gorita in response to reduced irrigation (Irrig 1 > Irrig 2 > AWD1 > AWD2). Hence there is a trade-off in Gorita between conserving groundwater resources and gross margins. This, in addition to the management effort required to properly implement AWD is likely to limit the uptake of this option by most farmers.

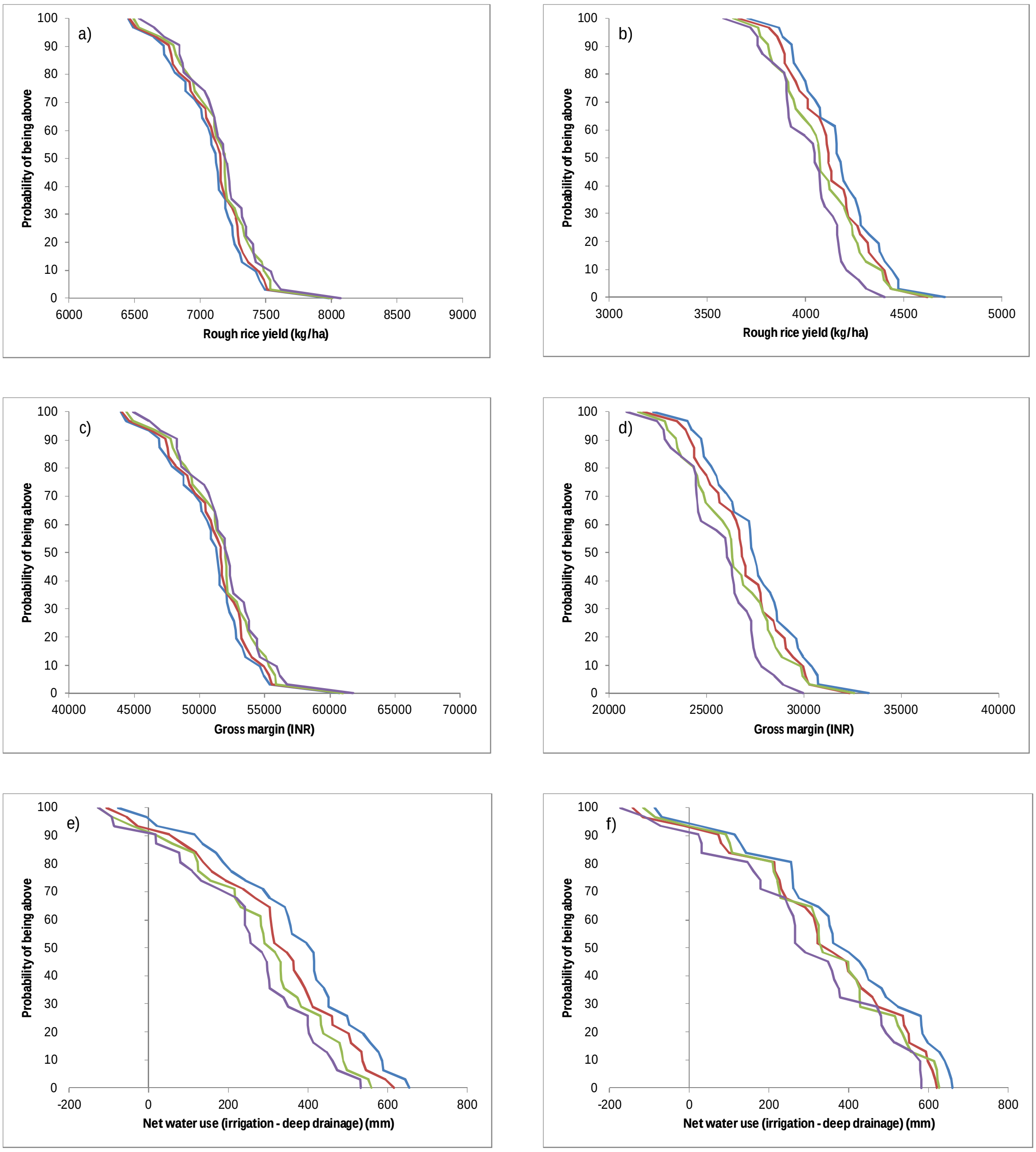


Figure 7. The impact of irrigation rules ("irrig1" blue lines, "irrig2" red lines, "AWD1" green lines, "AWD2" purple lines) on rough rice yield (kg/ha) (top), gross margin (INR) (middle) and net water use (bottom) in Bairanpally (left) and Gorita (right).

Reduced rice area for strategic irrigation of rainfed crops

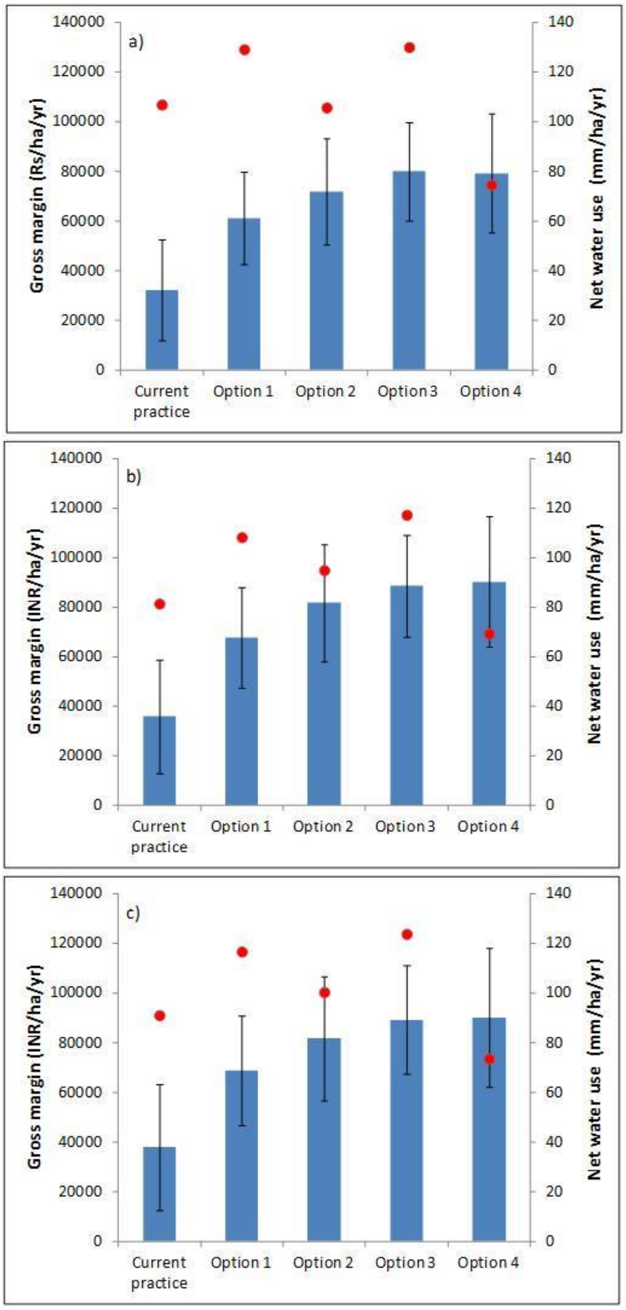
Options investigated for sourcing water for strategic irrigation of rainfed crops from reduced paddy area varied by household type and particularly by farm size. We considered three representative households:

- A small farm with 5 acres (2 ha) of which 2 acres were paddy and 3 acres were cotton or maize;
- A medium farm with 8 acres (3.2 ha) of which 2 acres were paddy and 6 acres were cotton or maize;
- A large farm with 15 acres (6.5 ha) of which 3 acres were paddy and 12 acres were cotton or maize.

For all farm types we assumed the Rice Irrig-2 (maintain 5cm pond depth) and rainfed cotton using the starting soil moisture sowing rules as the current practice. A minimum of 0.2 hectares of rice was retained in adaptation scenarios to ensure self sufficiency for a family of 5 people.

The results in general clearly show that reducing the area under rice, and using the water for strategic irrigation of cotton or maize has economic benefit.

Figure 8 presents the results for the small farm case in Gorita. Reducing rice from 0.8 ha to 0.6 or 0.4 hectare results in an increase of average profitability by about 50% by changing from current practice to option 2. Similarly, average irrigation per hectare per season is reduced with reduced area under rice.



Note on Options

Current practice:
0.8ha irrigated rice, 1.2ha rainfed cotton

Option 1: Use water saved to strategically irrigate cotton
0.6ha irrigated rice, 1.4ha cotton

Option 2: Use water saved to strategically irrigate cotton
0.4ha irrigated rice, 1.6ha cotton

Option 3: Use water saved to strategically irrigate cotton with unlimited no. of irrigations.
0.4ha irrigated rice, 1.6ha cotton

Option 4: Use water saved to strategically irrigate cotton
0.2ha irrigated rice, 1.8ha cotton

Figure 8. Gross margin (blue bars) and net water use (irrigation-recharge, red dots) for adaptation options used on small farms at Gorita growing rice and cotton for a) baseline climate (1978-2009), b) future climate ECHAM5 (2021-2040) and c) future climate GFDL CM2.1 (2021-2040).

Sustainability analyses

For each adaptation option, comparisons of different outputs were made to understand tradeoffs and impacts in the form of sustainability polygons (Ten Brink *et al.* 1991, Moeller et al. 2014). These polygons allow for comparison of multiple indicators as a summary of considerations for sustainability/efficiency of adaptation options. Here we focus on results for the application of the sowing rule for cotton, and strategic irrigation of cotton. Full details, including comparisons for other practices and crops can be found in Volume 2, Appendix 5-6.

a) Sowing rules for cotton (Gorita and Bairanpally)

Modelling highlighted the 50mm in 7 days and soil moisture sowing rules as having the most optimal sowing opportunity versus crop failure tradeoffs (above, see also Appendix 5-6, Vol. 2). Figure 9 compares the yield, gross margin, yield stability, gross margin stability, N_2O and C emissions of cotton for these rules against the 2 day rule (current recommendation) for Gorita (left hand side) and Bairanpally (right hand side).

For cotton crops in Gorita using observed weather data, no single sowing rule had the highest result for all sustainability indicators though differences were relatively small (all indicators being greater than 0.84) (Figure 9a). For cotton crops in Gorita using future ECHAM5 generated weather data, the 50 mm rule had highest or equal highest vales for all sustainability indicators (Figure 9c). Compared with historic results, ECHAM5 cotton scenarios in Gorita resulted in higher yields and GM outcomes and lower emission results at the expense of less stability in yield and GM outcomes (Figure 9a,c). Compared with the observed cotton simulation scenarios, the indicators for the soil moisture and 50 mm rules were more sustainable under the GFDL CM2.1 scenario with the exception of carbon emissions which were slightly higher (Figure 9a,e).

For cotton crops in Bairanpally using observed weather data, the 2 day rule had lower sustainability values than the soil moisture and the 50 mm in 7 days rules, which were approximately equal to each other for all indicators. (Figure 9b). Using future ECHAM5 generated weather data, the 2 day rule had lower sustainability indicator values than the soil moisture and the 50mm in 7 days rules which were approximately equal to each other for all indicators. The same indicators that were lower for the 2 day rule in the observed weather data simulations were even lower for the ECHAM5 scenario (Figure 9d). Using future GFDL CM2.1 scenario, the 2 day rule becomes less sustainable for each of the indicators (Figure 9f).

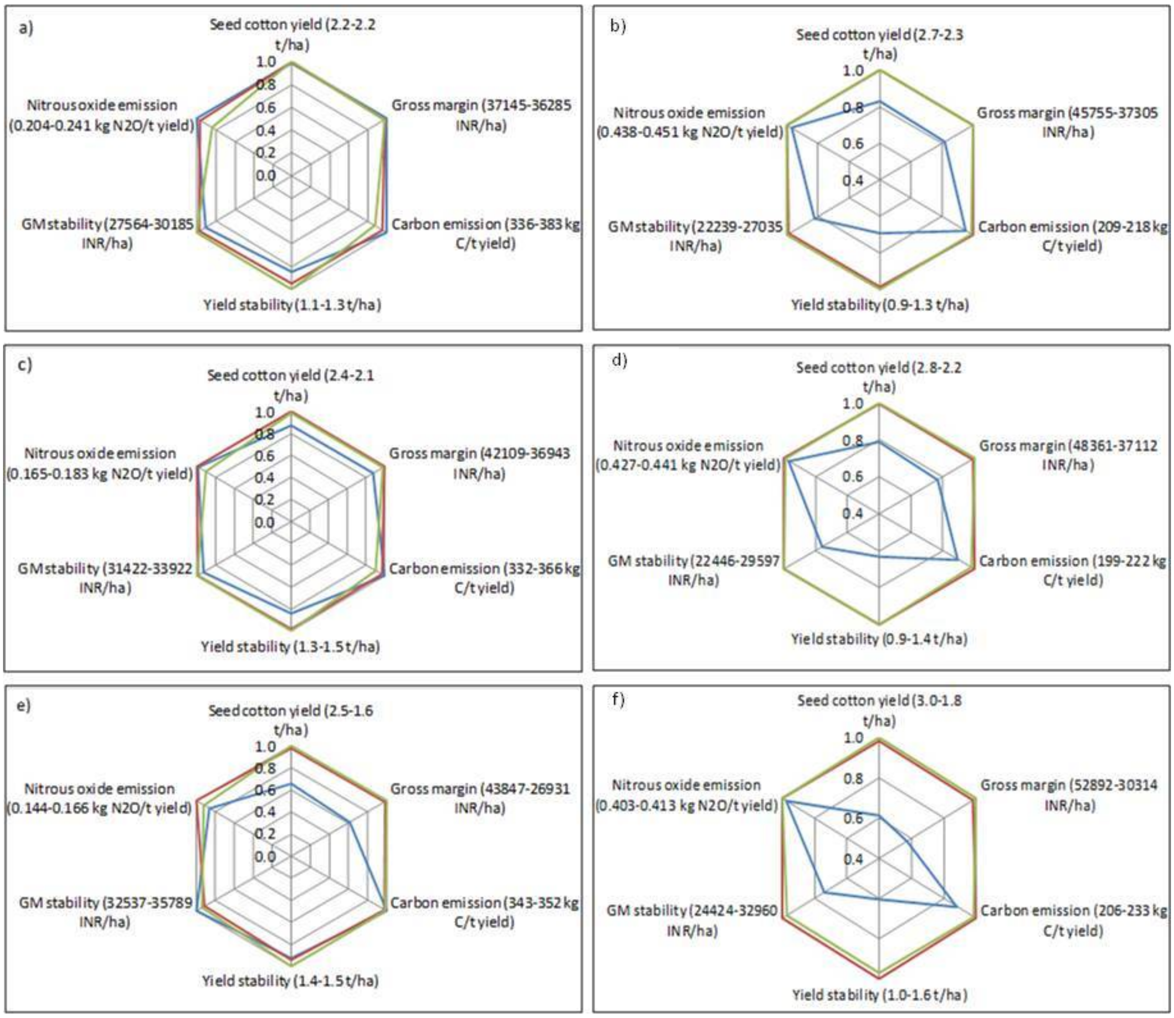


Figure 9. Comparison of yield, gross margin, yield stability, gross margin stability, N_2O and C emissions of cotton crops grown using the 2 day sowing rule and the remaining two sowing rules with optimal tradeoffs between sowing opportunity and seedling failure at Gorita (left) and Bairanpally (right) for a) and b) baseline climate (1978-2009), c) and d) ECHAM5 future climate (2021-2040), and e) and f) GFDL CM2.1 future climate (2021-2040). Blue lines represent 2 day sowing rule, red lines represent 50mm sowing rule and green lines represent soil moisture sowing rule for a)-f). Ranges for each variable are shown in parentheses[5].

Figure 9 shows that for each of the climate scenarios in Bairanpally, there is a tendency for sowing rules that improve yield outcomes to also improve the whole set of sustainability outcomes. However, in Gorita the relative positions of the various sustainability indices for each of the sowing rules varied with climate scenarios such that a clear win-win rule could not be identified.

[5] Each sustainability indicator is represented by a relative value from 1 to 0 where 1 is the most desirable outcome - highest or lowest depending on context (eg highest gross margin per ha or lowest carbon emission per tonne of yield). See Volume 2, Appendix 5-6 for more details.

b) Strategic irrigation of cotton (Gorita and Bairanpally)

A comparison of sustainability polygons for the three climate scenarios for Gorita (Figure 10 a,c,e) shows that all sustainability indicators for the strategic irrigation adaptation were superior for each of the three climate scenarios.

In Bairanpally (Figure 10b,d,f) similar results were obtained regardless of the climate scenario: seed cotton yields, gross margin, carbon emissions and nitrous oxide emissions were all improved by strategic irrigation while yield stability and GM stability were marginally worse with strategic irrigation.

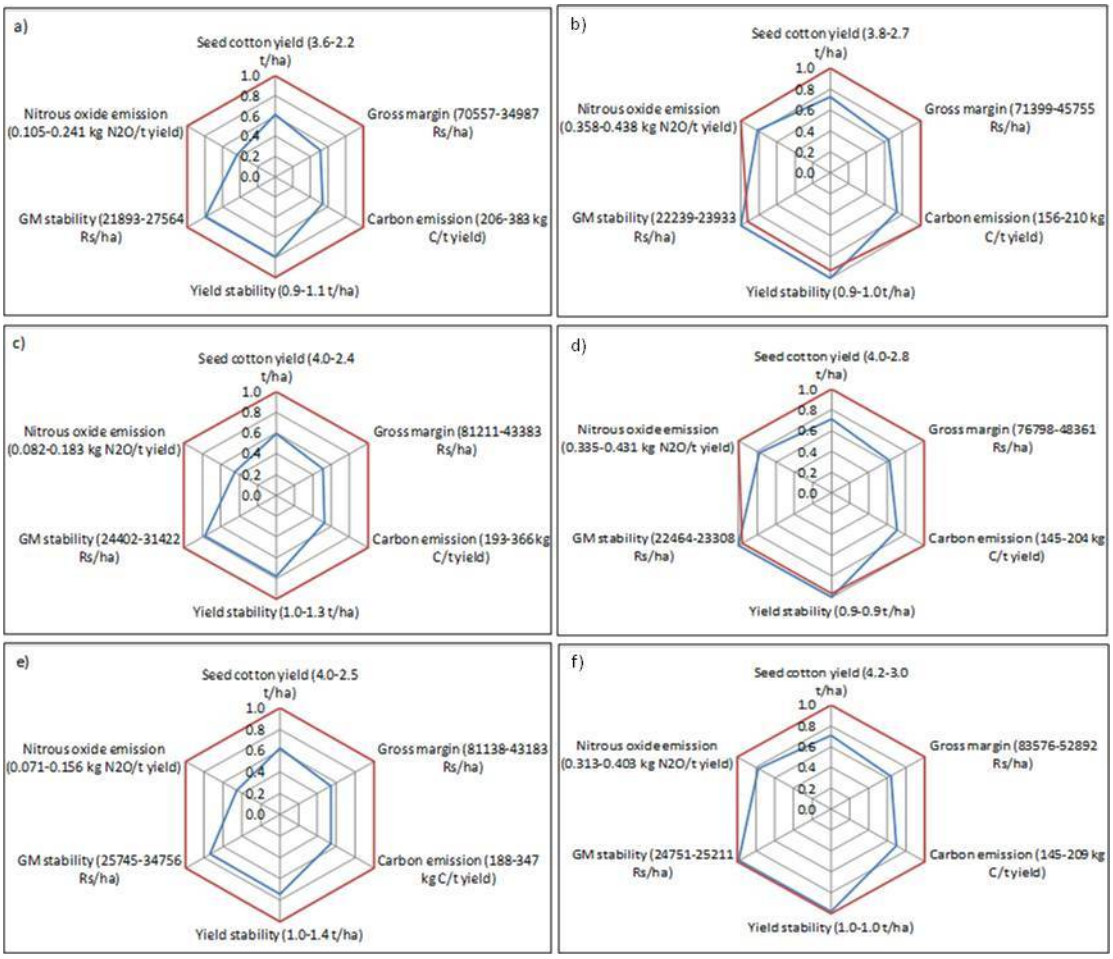


Figure 10. Comparison of yield, gross margin, yield stability, gross margin stability, N_2O and C emissions of rainfed and strategically irrigated cotton grown using the soil moisture sowing rule at Gorita (left) and Bairanpally (right). for a) and b) baseline climate (1978-2009), c) and d) ECHAM5 future climate (2021-2040), e) and f) cotton using GFDL CM2.1 future climate (2021-2040). Blue lines represent rainfed crops, red lines represent strategically irrigated crops. Ranges for each variable are shown in parentheses.

The sustainability polygons for strategic irrigation of cotton for each of the three climate scenarios tend to show that the adaptations that improve yield outcomes also tend to improve the whole set of sustainability outcomes (Figure 10). However this is not always the case, with sustainability polygons for reduced irrigation of rice showing clear tradeoffs, for example between yield, yield stability, gross margin and gross margin stability and emissions of nitrous oxide and carbon emissions (data not shown, refer to Appendix 5-6, Vol. 2)[6].

Participatory climate risk assessment with farmers

Climate risk assessment in cropping is generally undertaken in a top-down approach using climate records while critical farmer experience is often not accounted for. In the present study, farmer experience of climate risk is integrated in a bottom-up participatory approach with climate data analysis. Crop calendars (Figure 4 and Figure 5) were used as a boundary object to identify and rank climate and weather risks faced by smallholder farmers. A semi-structured survey was conducted with experienced farmers whose income is predominantly from farming. Interviews were based on a crop calendar to indicate the timing of key weather and climate risks.

The simple definition of risk as consequence × likelihood was used to establish the impact on yield as consequence and chance of occurrence in a 10-year period as likelihood. Farmers' risk experience matches well with climate records and risk analysis. Farmers' rankings of 'good' and 'poor' seasons also matched up well with their independently reported yield data. On average, a 'good' season yield was 1·5–1·65 times higher than a 'poor' season.

The main risks for paddy rice were excess rains at harvesting and flowering and deficit rains at transplanting. For cotton, farmers identified excess rain at harvest, delayed rains at sowing and excess rain at flowering stages as events that impacted crop yield and quality (Table 3). The risk assessment elicited from farmers complements climate analysis and provides some indication of thresholds for studies on climate change and seasonal forecasts. The results of the present study show the importance of integrating farmer's knowledge and experience to provide important bottom-up feedback to the agromet advisories on climate risk assessment and management (Nidulomu et al. 2013).

Table 3. Climate risk assessment by farmers and link to crop calendars

Village	Crop	Crop Stage	Climate event	Farmer experience (in last 10 yrs) (years)	Impact on yield (%)
Gorita	Cotton	Sowing	Deficient rain	1-3	-20 to -40
		Blossom	Excess rain	2	-20 to -60
		Harvest	Excess rain	3-4	-20 to -30
	Paddy Rice	Transplanting	Deficient rain	5	-30
		Flowering	Excess rain	2-4	-10 to -15
		Harvest	Excess rain	2-5	-10 to -35
Bairanpally	Cotton	Sowing	Deficient rain	1-4	-20 to -45
		Blossom	Excess rain	5	-20 to -25
		Harvest	Excess rain	2-5	-10 to -30
	Paddy Rice	Transplanting	Deficient rain	3-4	-30
		Flowering	Excess rain	2-5	-10 to -20
		Harvest	Excess rain	1-4	-10 to -25

[6] It was not possible to include all results as part of this report. It was decided to focus on sowing rules, as one of the most easily adoptable practices to the broadest set of farmers, and cotton, as the main dry season crop.

Integration: Building farmers' capacity to observe and act on climate information

One aim of this project was to build village farmers' capacity to respond to various climate risks by providing timely information on their local weather, by creating an environment that allows them to more readily interpret this information and by developing management strategies for coping with climate variability.

This project used a participatory approach to build capacity to observe and act on climate information. The approach was trialled in three villages in the Telangana region and comprises four linked and evolving components:

1. Formation and development of village or farmer climate clubs
2. Preparation and dissemination of agromet advisories
3. Village level meteorological data recording and reporting
4. Participatory development of a seasonal rainfall visualisation tool.

The research undertaken in the ACCA project in India focused on on farm adaptation strategies and climate risk assessment and management. These activities were closely aligned with the participation of the members in the farmer climate clubs which were formed as a part of the project. There was demand from farmers and stakeholders to consolidate the outcomes and outputs of project activities in a way that farmers could consult on various farm management activities. This demand catalysed the development of the Climate Information Centre (CLIC) concept.

Climate Information Centres

The Climate Information Centre was developed as a one-stop information centre that consolidates information from a range of sources. It is a computer based off-line (with links to on-line) information system that generates the rainfall visualiser (described below), and maintains a database of information related to agriculture, livestock, fisheries and machinery, packaged for easy access. The CLIC system started with the outputs from ACCA but has grown to be a repository of information – with visuals, videos, narrations and animations on varied subjects related to agriculture that are easily accessible to farmers (see Volume 3, Appendix 6).

Software to support the CLIC was developed and is being maintained by WASSAN. The software is designed to accommodate both predictive information (such as is currently available via agromet advisories) and static information that can be accessed in context of the dynamic information. For example, if the agromet advisory warns of the likely damage that could be expected from a particular pest or disease in the coming five days, then the user is able to dynamically link to static information about that pest or disease, what are the thresholds for economic damage and how it might be controlled.

The CLICs are managed by trained facilitators who support equitable access for farmers and seek to make information available to everyone within the *Gram Panchayat* (village geographic boundary).

Key components of the CLICs developed and tested through ACCA include:

a) Agromet advisory

The weather forecast of the IMD is processed by PJTSAU into an agriculture oriented advisory provided to a local NGO twice a week. It is now presented in a visual format that farmers can make sense of easily. The agromet advisories are generally pasted in public locations, broadcast over loud speakers or disseminated through other mechanisms. This advisory was modified based on user-feedback surveys as part of the ACCA activity (See Appendix 6 of the Annual Report 2012).

b) Rainfall Visualiser

This is the cumulative rainfall measured locally and plotted onto a graph where farmers can view rainfall data in terms of emerging season scenarios and compare them with the occurrences in the near past. The graph shows:

1. A plot of the current and accumulated rainfall data to date. Rainfall in the village is measured from a rain gauge set up in the village and measurements are recorded by a dedicated NGO facilitator/farmer identified and trained for the purpose.
2. Contrasts between this season's rainfall with a) recent 'wet' and 'dry' years and b) the last season, and their trajectories over the season from the last 30 years of rainfall data from IMD.
3. The probability of 'finish', or the probability of the final total rainfall to be expected in the season (highest and lowest) based on historical data

c) Secure sowing

This helps farmers to decide on the right sowing time to secure proper germination and growth. The 50 mm rule described earlier is one example.

d) Strategic irrigation

In prolonged drought spells, this secures the crop and increases water productivity (see previous section)

e) Pests and disease management

This links weather observations to the incidence of pests and diseases and helps farmers to be prepared and to take appropriate remedial actions, supporting judicious use of chemicals. This information is sourced primarily from PJSTAU.

CLICs were first launched in 2013 in each of the three project villages. Focus group discussions were held from July-October 2013 to capture initial feedback on the suite of practices described above and the general approach taken by the CLICs, which was used to refine the approach and information provided.

Expansion of the number of CLICs was made possible through WASSAN's Watershed program, as well as additional funding from RKVY.[7] In August 2015, 33 CLICs were in operation.

An evaluation of the CLICs was undertaken in 2015, based on a survey of 330 farmers; and qualitative focus group discussions in 8 CLICs villages. The evaluation considered aspects such as the use of CLICs (frequency of visits); farmer perceptions on usefulness of information; changes in knowledge and practice due to CLICs visits and satisfaction with the CLICs as a source of information; and compared two 'original' ACCA villages with the experiences of six more recently established CLICs. It is still very early to measure the impact of the CLICs, however the evaluation highlighted farmer preference for video based information. Farmers responded more favourably regarding the usefulness of pest and weather information compared to other packages.

Two important aspects can be highlighted when comparing across the villages. Firstly, the CLICs operator is critical in facilitating access and understanding of the farmers. Where farmer responses were unfavourable, problems in reliability and accessibility of the operator had been reported.

Secondly, the responses imply that for some of the packages, such as rainfall visualiser and agromet advisory, a longer-term relationship is required that fundamentally shifts from

[7] Rashtriya Krishi Vikas Yojana - National Agriculture Development Scheme

information provision to farmers, to farmer engagement with information. Responses from Bairanpally, where farmers have a longer history of engagement with these concepts indicated a higher value or perception of usefulness compared to other villages.

Considering the CLICS and adaptation practices against the household types, it is logical to consider that households with good access to irrigation (4 and 7) are the most able to implement practices such as critical or alternate row irrigation. However households with sufficient water had the least incentive to do so. These practices take additional time compared to current practices and diversion of water saved (e.g. from paddy to cotton) was not always practical for farmers given the lay-out of fields, irrigation infrastructure and reliability of power supply.

Literacy and time to access the bulletins were an issue for many households who relied instead on local NGO staff (working with the project) or other farmers to pass on key information. Though a relevant issue for all types, this is particularly an issue for SC and BC farmers in Type 2 a, b and d.

Labour dynamics were prominent in the India case, with targeted government schemes to retain labour in rural areas perceived by larger land owners (Type 7) to drive up the cost of labour and exacerbate shortages, while forming a vital income source for otherwise precariously placed landless labour (Type 1) (Jakimow et al., 2013). Although labourers are not directly involved as participants in the project, their involvement in agricultural wage labour means they influence and are directly affected by agricultural adaptation strategies, especially as they relate to labour saving or new skills for cultivation.

Engagement outcomes

Stakeholder plans for India were developed in 2011 to guide and prioritise engagement activities. A summary is given in Table 4. Investment in stakeholder engagement has been documented in trip reports, annual reports and in the stakeholder engagement report that appears as Appendix 1 in Volume 3.

Table 4. Summary of stakeholder engagement in India

Stakeholder group	Engagement objective	Stakeholders
Project team	Cohesion; capacity	**PJTSAU; LNRMI; WASSAN; IMD; CSIRO**
Farming community	Adoption; collaboration	**Farmers in study villages; farmers in CLICs villages**; farmers in other villages
Research community	Science exchange; access to data; common approach	CRIDA; NCMWRF; IWMI; **ICRISAT**; IITM; CCAFS; **other ACIAR projects;** general
District/local govt	Local relevance; dissemination	**Village Gram Panchayats;** District Collectors
State govt	Policy or planning influence; relevance; dissemination	Dept Agriculture; **Dept Rural Development**; Dept Environment; **Dept Panchayati Raj**; Irrigation Command Area Devt; WALAMTARI
National govt	Policy or planning influence; relevance; support	**Ind Meteorology Department; Ind Council Agric Research;** National Rainfed Area Authority; NABARD

Regional agencies, donors, NGOs	Dissemination; collaboration	RRA network; **WASSAN NGO network**

Note: Stakeholders with significant interaction listed only. Bold text indicates the stakeholders with whom ACCA had the most traction (towards the relevant engagement objective) at the end of the project.

Many engagement outcomes are described elsewhere in this report. For example, team cohesion and capacity building are described in capacity impacts (Section 6), while science exchange is covered in the publications list (Section 8). Two engagement outcomes are summarised here - adoption and dissemination of project practices and policy and program influence – as these will form the foundation of the project's sustainability and impact in the region.

Adoption and dissemination of project practices

Significant mechanisms for dissemination of ACCA information and practices to Indian farmers are summarised below and in Table 5. Note that some overlap exists.

a) *Dissemination through CLICs*

As discussed elsewhere in this chapter, 33 CLICs had been established by the end of the project; three original CLICs, 18 CLICs in villages associated with WASSAN's Watershed Program and 12 CLICs through Rashtriya Krishi Vikas Yojana (RKVY), the Federal and State funded National Agriculture Development Scheme to increase growth in the agricultural sector. The Indian project team estimate that around 8000 farmers now have access to ACCA results and practices across the 33 CLICs villages.

Currently, project teams are focussed on maintaining the current suite of information centres beyond the end of the project, rather than on significantly increasing the number of CLICs. The longevity of the CLICs is largely dependent on securing ongoing salary for the CLIC operator, who is critical in facilitating access to information and enhancing farmer understanding and decision making. Progress thus far includes:

- Funding for continuing the WASSAN village CLICs is currently under negotiation with the Departments of Rural Development and Panchayati Raj.
- Six of the WASSAN CLICs have been linked to an Integrated Business Service Centre model, being established by the District Collector of Mahbubnagar and are likely to continue.
- RKVY CLICs are funded to the end of 2016, after which funds will be sought from the village farmer groups. PJTSAU will continue to provide technical support.
- In Warangal district, a Farmer Producer Organisation is interested in funding and running the Bairanpally CLIC, with support from WASSAN.
- Another CLIC has recently been sponsored by a local area member of parliament, with concomitant federal funding for 5 years.
- Interest has been expressed by NABARD in outscaling CLICs beyond the project. A number of funding models have been discussed, including incorporation in NABARD's infrastructure development portfolio

b) *Dissemination through media and community engagement*

In addition to delivering agricultural information through CLICs, ACCA practices and approach (eg sowing rules, strategic irrigation approach, rainfall monitoring and comparison) were incorporated into existing PJTSAU and new dissemination mechanisms. These include:

- PJTSAU uses local television and radio stations to broadcast its agro-advisories once or twice a week during the growing season. Theoretically, this gives 5.5 million farming households access to ACCA information.
- 2500 farmers currently receive PJTSAU's agro-advisories by SMS and/or email.
- Telugu language posters containing ACCA recommendations have been created and delivered by WASSAN to all 8,700 villages in Telangana.
- Three WASSAN watershed villages trialled a connection with local schools (500 students each) to deliver ACCA and agro-advisory messages at school assemblies to create awareness in students' families.
- PJTSAU's local exhibition exposed around 50,000 people to the agro-advisory and ACCA approaches.
- Video shows based on agro-advisories were organised in 12 villages, with around 100 farmers attending each show.

c) Training farmers and agricultural officers

Training packages were delivered throughout the project, particularly in the later years. Some training was project specific and some formed part of broader training initiatives in Telangana. ACCA practices that focus on monitoring weather and tailoring farm management practices accordingly were central to this training.

Significant training outcomes delivered by the PJTSAU team include: 1600 district level agricultural officers; 120 farmers in RKVY project villages; 150 farmers aged 18-35 years, as part of the Young Progressive Farmers program; and 60 farmers from the State Farmers Federation.

The PJTSAU team also conducted training programs for university staff working in agriculture. So far, there have been 12 training programs with around 25 staff in each. In addition, there are plans to incorporate the CLICs approach into the Agriculture Diploma (a two year course after Year 10 of secondary school) of 20-25 Polytechnic Colleges, which will reach around 1200 students each year.

Table 5. Summary of current and potential dissemination of ACCA practices in Telangana State, India.

Disseminating group	Current reach	Potential reach (3-5 years)
CLICs	CLICs established in 33 villages across Telangana; Indian project team estimate around 8000 farmers now have access to ACCA information.	12 RKVY CLICs have State funds to 2016. 8 CLICs have other funding secured. Funding for 12 WASSAN CLICs under negotiation with DRD, DPR and NABARD
Media and community engagement	2500 farmers receive weekly SMS Posters distributed to 8700 villages 1200 farmers view video shows 1500 school children informed	Likely that SMS, local media and pamphlet mechanisms will continue after project; continuity of other mechanisms unclear.

	Possible weekly media exposure of 5.5 million households	
Training farmers and agricultural officers	1600 district level agric officers 120 RKVY farmers 150 Young Progressive Farmers 60 Farmers Federation farmers 300 PJTSAU agric researchers	Difficult to predict which training channels will continue beyond the project. Plans to include CLICs in Agriculture Diploma of 20-25 Polytechnic Colleges, reaching 1200 students annually.

Note that these are estimates of possible exposure to ACCA components, not estimates of adoption.

Policy and program influence

Despite major political upheaval in the last two years of the project, ACCA can report influence in several important areas:

a) Mainstreaming CLICS

The adaptive and integrated approach taken by the project has resulted in the CLIC's reputation as a replicable and locally beneficial agricultural development entity. In 2013, there were three pilot CLICs; by mid 2015, there were 30 more active CLICs. Although the software, hardware, content and training have now been tested and distilled, the system allows for adjustments to be made to meet local information and delivery needs.

Despite alignment with departmental initiatives and opportunities to expand the CLICs network, the project teams have not yet found an ongoing institutional home for CLICs in state departments. Consequently, the Indian teams have refocussed efforts on embedding the CLICs concept in non-governmental initiatives and have also been successful in attracting funding from diverse sources who see their value – from farmer organisations to the national agricultural bank.

In addition, discussions are underway to incorporate the CLICs concept into the CCAFS program's Climate Smart Villages initiative and the MSSRF's Village Knowledge Centres initiative.

b) IMD support for agro-advisories

The ACCA project has directly supported IMD's mandate for the preparation and delivery of medium term weather forecasts (3-5 days) nationally, and the production and dissemination of agro-met advisories at district level, in collaboration with relevant state agencies (eg PJTSAU).

ACCA has provided a trial of agro-advisories that marry IMD forecasts with management recommendations that encompass variation in farm enterprise across multiple districts. In addition, new methods of delivery (eg via SMS, CLICs and email) and presentation (eg pictorial rather than textual, to account for literacy) were tested based on user evaluation.

IMD have endorsed ACCA's integrated approach and adaptive improvement and is supportive of IMD information and forecasts being disseminated through agro-advisories and the CLICs network. PJTSAU is working with IMD on documentation, development of training material and options for replication beyond Telangana.

8.2 Bangladesh

Country focus

Accessibility to existing high quality datasets from IRRI and a comparatively easier environment to generate new high quality data meant that the primary focus in Bangladesh was the development and validation of the cropping systems model APSIM. The development and validation was implemented with data from past and ongoing trials by IRRI and additional on-station trials in collaboration with Bangladesh research partners. Bangladesh was different to the other three countries in the project, in that detailed farmer-consultation was not undertaken in the development of adaptation options.

Social research into determinants of adaptive capacity was conducted in the southwest of Bangladesh (Khulna district), recognised as climatically one of the most vulnerable areas. However, due to budget constraints the same level of activity in on farm research as in the other three countries was not planned, but through linkages with other IRRI projects, we conducted some limited on farm research in Khulna.

The main partner in Bangladesh is IRRI, supported by collaborators from the Bangladesh Agricultural Research Council (BARC), Bangladesh Agriculture Research Institute (BARI) and the Bangladesh Rice Research Institute (BRRI). Social research was carried out by the Socio Economic Research and Development Initiative (SERDI), an independent research organisation.

Site information

Two contrasting locations were chosen for the experimental work in Bangladesh. The Gazipur site located on the BARI/BRRI campus near Joydepur was selected because it allowed well controlled on-station experiments to be set up, and provided a non-saline soil environment to validate APSIM-ORYZA. The second set of sites was in the Khulna district, one site in Dacope *upazila*, the other on the BARI regional research station near Satkhira. Here we established on farm trials under saline soil conditions.

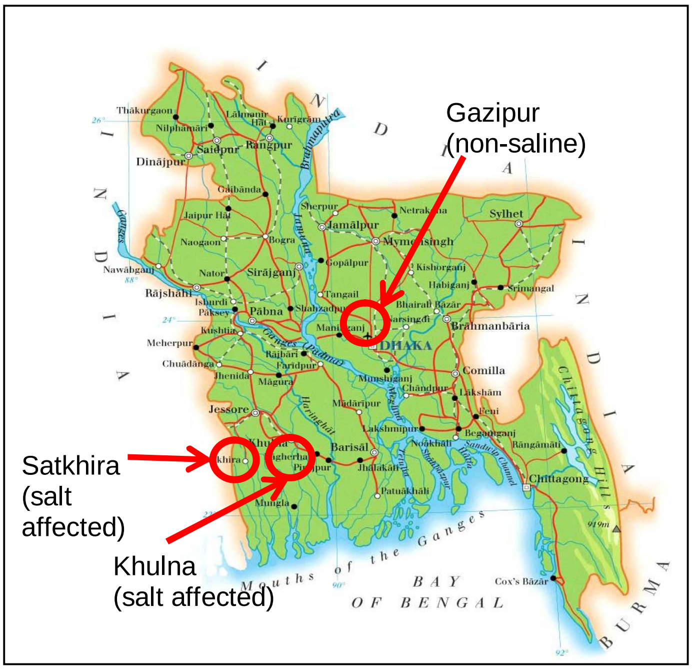


Figure 11. Study sites in Bangladesh

The social research was carried out in two contrasting villages, one with a higher exposure to salinity and with a lower capacity to adapt (Laxmikhola), the second having a lower exposure to salinity and more cropping options because of a lower level of salinity (Kismatfultola).

Kismatfultola located in Batiaghata upazila is subsistence-oriented. Rice is grown as a household staple and any surplus is sold. In the dry season, households may do small areas of dry season cropping, raise livestock or breed fish, though limited fresh water constrains most agricultural activities.

Laxmikhola in Dacope upazila has until recently been dominated by the shrimp industry. Shrimp production, which uses saline or brackish water in ponds, has increased soil salinity in agricultural fields to a point where it becomes unfeasible to grow rice any longer, thus creating major problems of food security. As a result some farmers had returned to rice production to safeguard their livelihood portfolios and their subsistence base. In the five years since the project started, there is evidence that farmers in some areas of Khulna have developed strategies to reduce soil salinity problems in shrimp (Kabir et al 2015).

Cropping calendars

Typical cropping sequences for the Gazipur area are shown below. In the Khulna area, the most typical cropping sequence still is a single rainfed crop of *T. Aman* (the main *kharif* or wet season rice) rice followed by fallow. Where there is some access to (surface) irrigation water, this may be followed by a *boro* rice crop in the dry (or *rabi*) season, or some irrigated vegetable crops (T1 in Figure 12). T1 represents the most widespread cropping sequence.

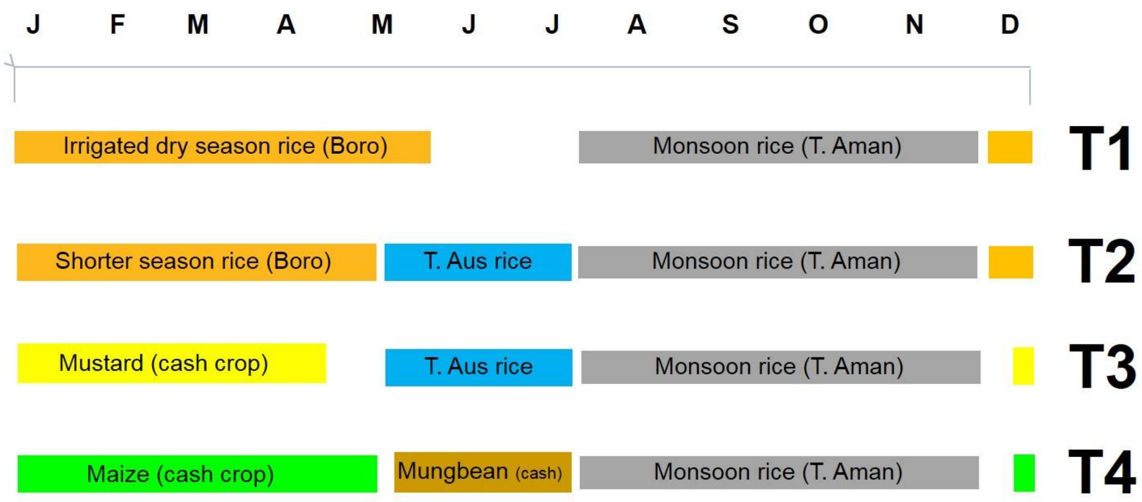


Figure 12. Cropping calendar representation of options explored in the non-saline Gazipur region, Bangladesh.

Household types

Household types in Bangladesh have been derived from the two coastal villages in Khulna district described above. Key variables for defining types in Bangladesh have been (a) extent of soil and water salinity, which severely constrains options for agricultural production; (b) access to urban and regional centres, which limits households' ability to access markets and labour opportunities; (c) wealth ranking which summarises eg access to land, information, access to credit, savings and literacy.

Table 6. Summary of household types, Bangladesh

Type	Key characteristics	Key constraints
1	Type 1: Better off households, affected by moderate salinity, well connected to regional centre.	Soil and water salinity
2	Medium households, affected by moderate salinity, well connected to regional centre.	Soil and water salinity; water availability for irrigation; limited alternative options to agriculture; cost and increasing requirements for inputs
3	Poor households, affected by moderate salinity, well connected to regional centre.	Untimely rain; increasing salinity; high input cost; feed shortages for livestock; time / labour constraints
4	Landless households, affected by moderate salinity, well connected to regional centre.	No access to land; dependence on communally held natural resources; limited employment opportunities within the village
5	Better-off households, affected by high salinity, poor connection to regional centre.	Soil and water salinity; availability of fodder; access to market/price for goods
6	Medium households, affected by high salinity, poor connection to regional centre.	Water salinity; access to fresh water; high input costs; low yield; market access (poor transport)
7	Poor households, affected by high salinity, poor connection to regional centre.	Soil and water salinity; price and availability of fodder
8	Landless households, affected by high salinity, poor connection to regional centres.	Lack of local demand for labour; access to loans; price and availability of fodder

Crop diversification is easier for households in Types 1 and 5, who have generally better access to government institutions and information, which facilitates access to improved inputs (including varieties) as well as the skills, financial and land resources to implement alternatives. The medium and disadvantaged household types achieve lower yields than advantaged farmers due to poor capability to adopt better equipment and practices. Polder management, which helps manage fresh/salt water flows, is managed at a community level, however the needs of larger land holders (i.e. Types 1 and 5) are prioritised (Khan & Grünbühel, 2012).

Model development

The primary focus of the ACCA work in Bangladesh was the development and validation of the cropping systems model APSIM. In the early phases of ACCA, this entailed the validation of the POND module to reflect the changes in soil carbon and nitrogen dynamics as the soil environment transitioned between aerobic (dryland) and anaerobic (ponded) conditions, and capturing the input of organic matter and fixed nitrogen through algae. This was followed by a more widespread validation across multiple sites. In the third and current phase of model development, we concentrated on developing rice-crop salinity response routines within both the ORYZA2000 rice model and in the APSIM-ORYZA model. ORYZA2000 was incorporated into the APSIM framework in 2006, and a summary of changes implemented to the original ORYZA2000 model has been reported

(Section 11.3, paper 25).

Simulating carbon and nitrogen dynamics during transitions between flooded and non-flooded soils

The APSIM model was designed to simulate diverse crop sequences, residue/tillage practices and specifications of field management options. However, it was previously unable to simulate processes associated with the long-term flooded or saturated soil conditions encountered in rice-based systems, primarily due to its heritage in dryland cropping applications.

To address this shortcoming for use in rice-based systems, modifications were made to the APSIM soil water and nutrient modules to include descriptions of soil carbon and nitrogen dynamics under anaerobic conditions. We established a process for simulating the two-way transition between anaerobic and aerobic soil conditions occurring in crop sequences of flooded rice and other non-flooded crops, pastures and fallows. These transitions are dynamically simulated and driven by modelled hydraulic variables (soil water and floodwater depth).

Our assumptions included a simplified approach to modelling oxygen transport processes in saturated soils. The improved APSIM model was tested against diverse, replicated experimental datasets for rice-based cropping systems, representing a spectrum of geographical locations (Australia, Indonesia and the Philippines), soil types, management practices, crop species, varieties and sequences. The model performed equally well in simulating rice grain yield during multi-season crop sequences as the original validation testing reported for the stand-alone ORYZA2000 model simulating single crops (n = 121, R^2 = 0.81). This suggests robustness in APSIM's simulation of rice-growing environments and provides evidence of validity of our modifications and practicality of our assumptions.

Aspects of particular strength were identified (crop rotations; response to applied fertilisers; the simulation of bare fallows), together with areas for further development work (simulation of retained crop stubble during fallows, greenhouse gas emissions). These model improvements have been published in a paper which was awarded the *European Journal of Agronomy's* 'Paper of the Month' award for September (Gaydon et al. 2012).

Simulation of algal inputs into rice systems

Photosynthetic aquatic biomass (PAB; algae and other floodwater flora) is a significant source of organic carbon (C) in rice-based cropping systems. A portion of PAB is capable of fixing nitrogen (N), and is hence also a source of N for crop nutrition. To account for this phenomenon in long term simulation studies of rice-based cropping systems, APSIM was modified to include new descriptions of the biological and chemical processes responsible for loss and gain of C and N in rice floodwater.

We used well-tested algorithms from CERES-Rice, together with new conceptualisations for algal dynamics, in modelling the contribution of PAB to maintenance of soil organic C and soil N-supplying capacity in rice-based cropping systems. We demonstrated how our new conceptualisation of PAB growth, turnover, and soil incorporation in flooded rice systems facilitates successful simulation of long-term soil fertility trials, such as the IRRI Long Term Continuous Cropping Experiment (35+ years), from the perspectives of both soil organic carbon levels and yield maintenance.

Previous models have been unable to account for the observed maintenance of soil organic C in these systems, primarily due to ignoring inputs from PAB as a source of C. The performance of long-term rice cropping system simulations, with and without inclusion of these inputs, was shown to be radically different. Details of these modifications to APSIM-ORYZA are presented in detail in Gaydon et al. (paper 3, section 11.2), together with evidence that the model is now a useful tool to investigate sustainability issues associated with management change in rice-based cropping systems.

General validation of APSIM-ORYZA

In addition to using the high quality dataset generated in Gazipur (one of three validation datasets that allow for validation of multi-year crop sequences), the comprehensive validation of APSIM-ORYZA was undertaken in conjunction with other projects (SAARC-Australia project) and by accessing a wide range of other datasets. A total of 32 datasets across 12 countries in Asia have been used in this exercise. The results show that APSIM performs very well in most of the diverse rice growing environments of South and Southeast Asia. The paper also highlights a few areas requiring further model refinement (e.g. to represent soil structure dynamics under Conservation Agriculture tillage regimes; better evaporation routines). The paper by Gaydon et al. capturing these results is currently undergoing internal CSIRO review and is due to be submitted to Environmental Modelling and Software (Volume 2, Appendix 1).

Defining and testing a salinity response function

The objective of this major activity was to improve the cropping system model APSIM-ORYZA to account for salinity stress and reliably represent the performance of rice production systems under salt stress conditions. A salinity module has been developed by incorporating a new algorithm to compute soil salinity dynamics in the solute component of APSIM and to simulate the consequent rice crop responses through physiological processes related to water deficit and ion toxicity. The improved model was validated with field observations and their performance to represent rice production under salinity stress was estimated.

A greenhouse experiment was conducted at IRRI Los Baños in 2011, with four salinity levels and three rice varieties of differing salinity resistance. Two seasons of field experiments were completed in 2012 to calibrate the model, with four salinity levels, three replications and sub-plots of N application rate. Two seasons of validation experiments were undertaken on two project sites with naturally occurring salinity issues: Infanta in the Philippines and Satkhira in Bangladesh. Three scenarios of irrigation management were imposed on three replications.

APSIM-ORYZA (and the IRRI-Wageningen rice model ORYZA2000) now possesses a capability to simulate rice crop response to salt stress. The model captures varietal differences in salt tolerance, as well as responding to different temporal increases or reductions in salt stress (seasonal salt dynamics), and the interactions with N and water stress. Figure 13 illustrates the crop response function.

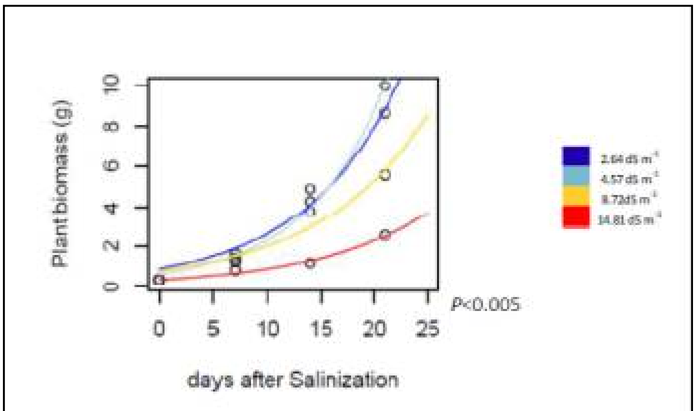


Figure 13. Example of crop biomass response with time to different salinity levels.

Two years of independent model validation experiments have now been successfully completed in two naturally-occurring saline rice growing areas with uncontrolled seasonal salt dynamics (Satkhira, Bangladesh and Infanta, Philippines; year one simulated results shown in Figure 14 for Infanta).

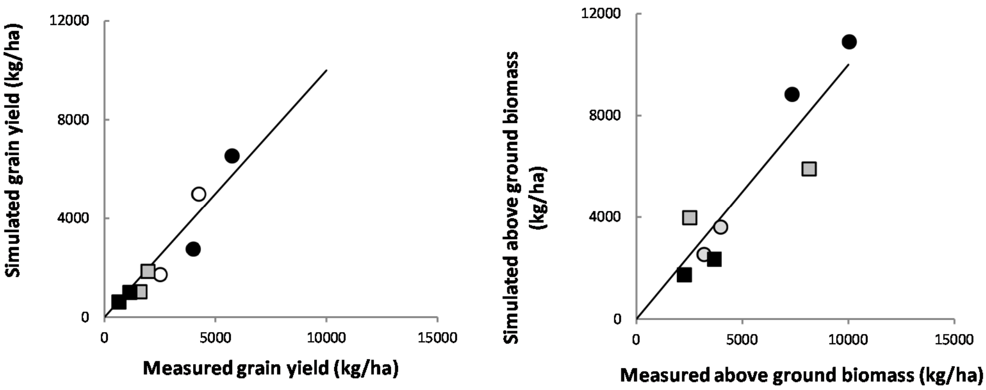


Figure 14. Performance of the model in simulating the crop production under different salinity levels at Infanta, Philippines (2013).

The ability of the APSIM soil modules to simulate seasonal dynamics of salt in the soil is obviously critical to simulation of system performance, quite independent of the confidence in the rice-crop model salinity response. Figure 15 illustrates the performance of APSIM in simulating the soil salinity dynamics for Satkhira, Bangladesh for the saline and non-saline treatments in 2013. At both Infanta and Satkhira, the second year's field data is still being received and validation simulations finalised.

Results of this activity were presented at the International Rice Congress, Bangkok, October-November 2014 (see conference papers 53, 67 and 68, section 11.3) and a number of manuscripts have been submitted for consideration (Volume 2, Appendices 2-4).

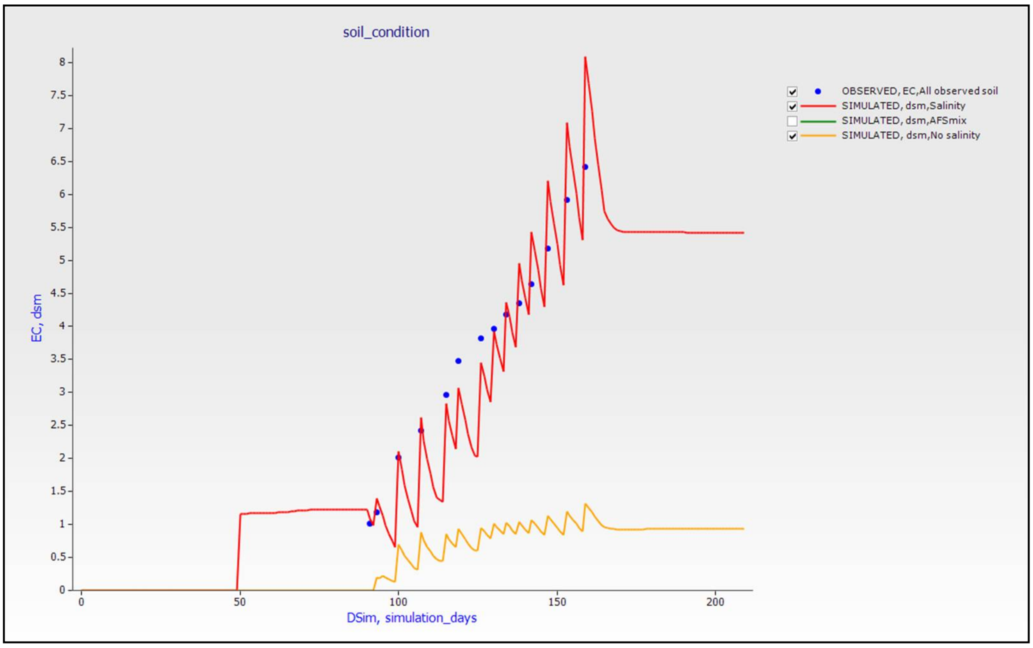


Figure 15. Ability of APSIM to simulate soil salinity dynamics.

Development of rice crop module for APSIM

A rice crop module for the new APSIM_X version is planned for coming years, allowing simulation of rice-base crop production systems under current climate and future conditions by integrating additional formalism or libraries specific for rice into the Plant 2 Structure of the new APSIM_X farming systems model, which is currently under development. This avoids the ongoing need to manually upgrade the ORYZA module within APSIM.

The framework was based on a generic crop template which aims to provide flexibility in the choice of detail and complexity in the representation of the system. The official release of the prototype of this framework was August 2014 with different major crops e.g. wheat, barley, potatoes, however full functionality will not be available until 2017-18.

Modelling scenarios – examples of APSIM-ORYZA applications in Bangladesh

A number of scenario analyses have been performed with the aim of evaluating options to manage salinity through earlier establishment (Dacope and Satkhira) and increase cropping intensity (Gazipur). Results are discussed briefly below (for more detail see Akhter et al. 2014, paper 1, section 11.2; and Gaydon et al in prep, Volume 2, Appendix 1 and Radanielson et al in prep, Volume 2, Appendix 2-4).

Managing salinity – Dacope and Satkhira sites

In the southern saline-affected coastal regions of Bangladesh, earlier maturing wet season (*T. Aman*) rice crops (or earlier established *T. Aman* rice crops) allow earlier establishment of the following *rabi* crops (such as cowpea or irrigated *boro* rice). This resulting earlier second crop establishment is expected to increase the chance of successful harvest before soil salinity levels in the *rabi* season have built up to toxic levels. Earlier establishment of the *rabi* crop will also decrease the likelihood of waterlogging problems from early wet-season rains. The APSIM model has been used to examine the long-term production risk associated with such changed establishment dates, using both historical weather data (1961-2009) and also projected future climate data (2020-2040; using the ECHAM5 and GFDLCM21 GCMs, locally downscaled using methods of Kokic et al. 2011).

The scenarios examined were:

- A range of *T. Aman* sowing dates (day 170 to day 230, at 10 day intervals), particularly examining the effect on *T. Aman* grain yield. Both a 'local' *T. Aman* variety and an improved (BR23) variety were simulated.
- For each *T. Aman* sowing date, *rabi* season crops were subsequently sown and the average performance and variability in their grain production similarly examined. This provided simulated performance at a range of sowing dates for the following crops:
    - Relay-sown cowpea (established earlier by sowing directly into wet *T. Aman* stubble)
    - Sequentially-sown cowpea (typical current practice)
    - Sequentially-sown *boro* rice (typical current practice)

Each of these sowing-date scenarios was simulated using historical climate data for Khulna (1961-2009) and also with projected future climate data (2020-2040 using both GCMs). The soils and crop parameterisations were for Parchalna, Dacope *upazila*.

Figure 16 shows the simulated performance of crops for different sowing dates in Khulna, using historical data. The green (dark) columns correspond to sowing dates in our ACCA experiments at the site.

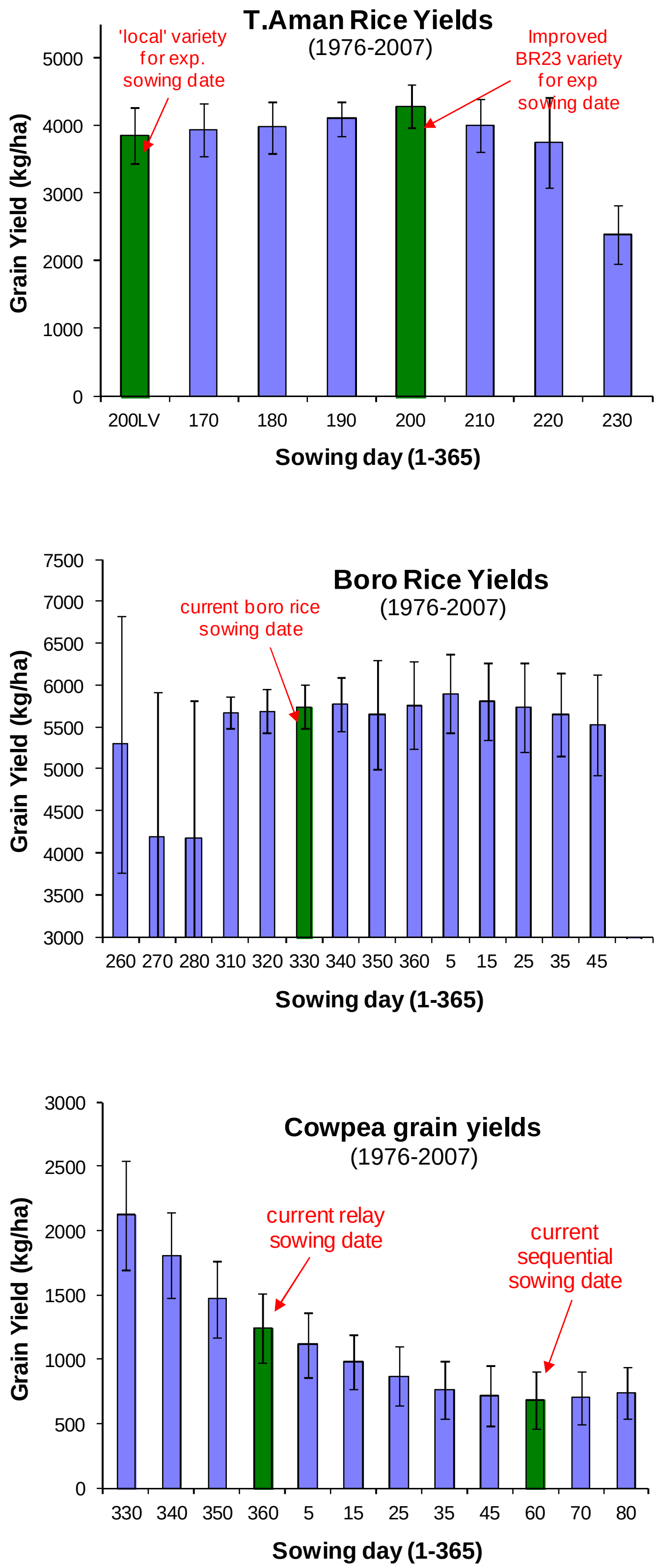


Figure 16. Simulated effect of sowing date on yield performance of (top) *T. Aman* rice, and subsequent *rabi* season crops in rotation, (middle) *boro* rice; and (bottom) cowpea, using HISTORICAL climate data. The columns illustrate average grain yields (1961-2009) whilst the error bars illustrate the variability in production (one standard deviation either side of the average).

The key results in Figure 16 are:

For *T. Aman* rice (Figure 16 top)

- BR23 outperforms the local *T. Aman* variety, and always finishes markedly earlier.
- The experimental sowing dates for BR23 were shown to be optimum timing for maximising *T. Aman* yields, but not necessarily for maximising system yields (ie the *T. Aman* and the following *rabi* crop). For example, cowpea would have yielded much more if sown earlier, whereas the *T. Aman* would not have been greatly affected – leading to greater system grain yield).
- Sowing BR23 later results in sharply decreasing yield likelihood (finishing water stress). Sowing earlier shows a much less significant decrease in yield result.

For *boro* rice (Figure 16 middle)

- Sowing *boro* rice a month or more earlier would result in significant potential yield reductions, due to low temperature sterility.
- Sowing *boro* rice 2-3 weeks either side of the current planting date does not greatly affect yield.

For cowpea (Figure 16 bottom)

- The success of cowpea cultivation in Dacope is very dependent on time of sowing – 'relay' is considerably more advantageous than 'sequential'.
- This graph only shows water-limited potential cowpea yield (no salinity effects yet). Increasing salinity levels with time will make this trend even sharper, exemplifying the benefits of earlier sowing.

Figure 17 shows the same graphs using projected future climate data. Only graphs for the GFDLCM21 GCM (the more extreme future) are shown. They key points are:

For *T. Aman* rice (Figure 17 top)

- Increased yields overall, no effect on optimum sowing date, or the relative effect of sowing earlier.

For *boro* rice (Figure 17 middle)

- The penalty for sowing earlier is removed (warmer conditions now overcome the low temperature sterility problems associated with earlier historical sowings).
- The optimum sowing date is clearly changed in the future, with earlier sowings likely to give advantages.

For cowpea (Figure 17 bottom)

- No change predicted regarding cowpea sowing date effects, just expected yield increases in future.
- The best results with cowpea still occur with sowing as early as possible.

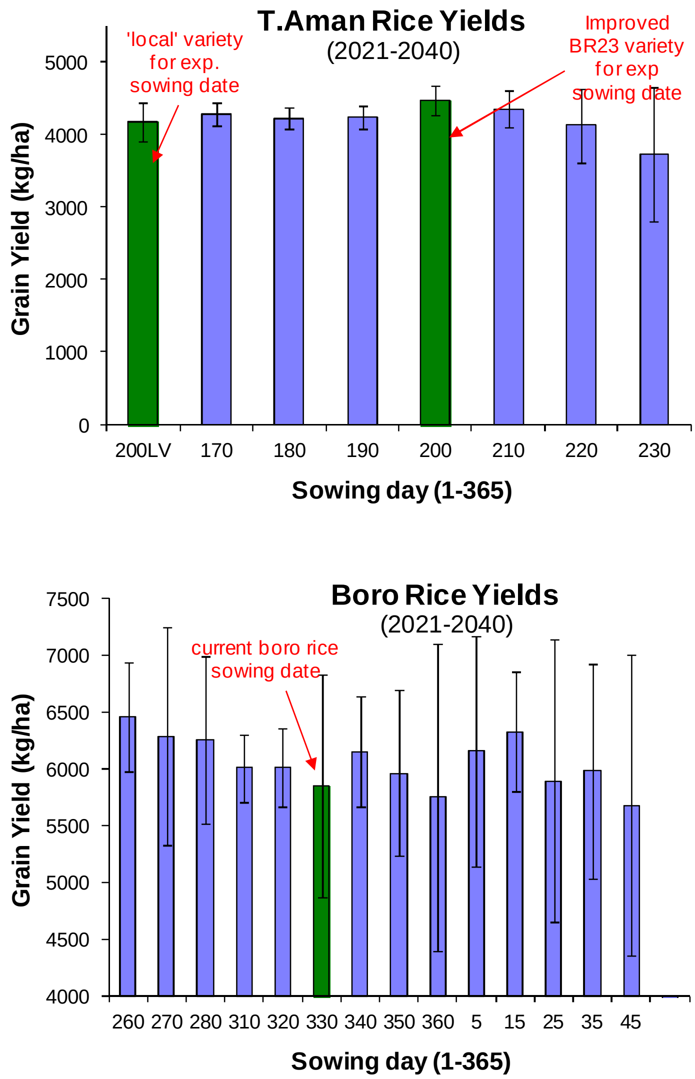


Figure 17. Simulations (as per Figure 16) using FUTURE (2020-2040) climate data. Model outputs using only the GFDLCM21 GCM (more extreme future climate) shown.

In summary, earlier establishment of both *T. Aman* rice and subsequent *rabi* season crops has been shown to be possible in the southern cropping districts of Khulna (Manoranjan Mondal, pers. comm.) and this analysis has shed some light on the potential long-term benefits of this strategy under both historical and future climates. According to Mondal, many farms/villages have the possibility to store enough fresh water to allow earlier establishment of the rice nursery crop, so that transplanting to the main field can occur immediately upon commencement of the monsoon, rather than the current practice of commencing the nursery phase upon the start of the monsoon. This could potentially allow up to a 30 day time advantage in early sowing, and avoid submergence of the crops at young stages.

At the tail end of the *T. Aman* crops, Mondal has also demonstrated that up to 75% farmer per village locations are capable of artificially draining tail-end water from the *T. Aman* fields through judicious use of low-tide levels and polder gates. Although this would require significant community co-ordination of the process (use of the gates by the community etc.), if implemented it could allow a further 14-30 day gain in the earliness of establishing the following rabi crop.

This modelling scenario analysis has illustrated the potential gains in crop production that are possible if such practices (early *T. Aman* establishment, improved high-yielding short-season *T. Aman* variety, plus early *T. Aman* drainage at harvest) could be implemented. Clearly under both historical and likely future climates, this would give farmers a considerably greater confidence of crop success, and add the increased resilience of having a much greater chance of a second (*rabi*) crop in this primarily single-crop environment.

Increasing cropping intensity – Gazipur

Our aim in Gazipur was been to evaluate options for increasing cropping intensity, using a combination of field experiments and modelling. The Bangladesh team focussed on a range of researcher-identified, best-bet, multi-crop sequences. Scenarios explored in Gazipur were (see also Figure 17 above):

- **T1:** Boro rice – Fallow - T.Aman rice (control)
- **T2:** Boro rice -T.Aus rice -T.Aman rice
- **T3:** Mustard - T.Aus rice - T.Aman rice
- **T4:** Maize – Mungbean - T.Aman rice

Scenarios were compared based on grain yields and gross margins (from an irrigated perspective and also total applied water). Water productivity was defined as profit earned per millimetre of water applied.

Figure 18 illustrates the grain yields simulated for each of the cropping system scenarios investigated, under both historical and project future climates. Figure 19 and Figure 20 illustrate these results converted into gross margin (GM) and total water productivity (WP_T = GM / (irrigation + rainfall).

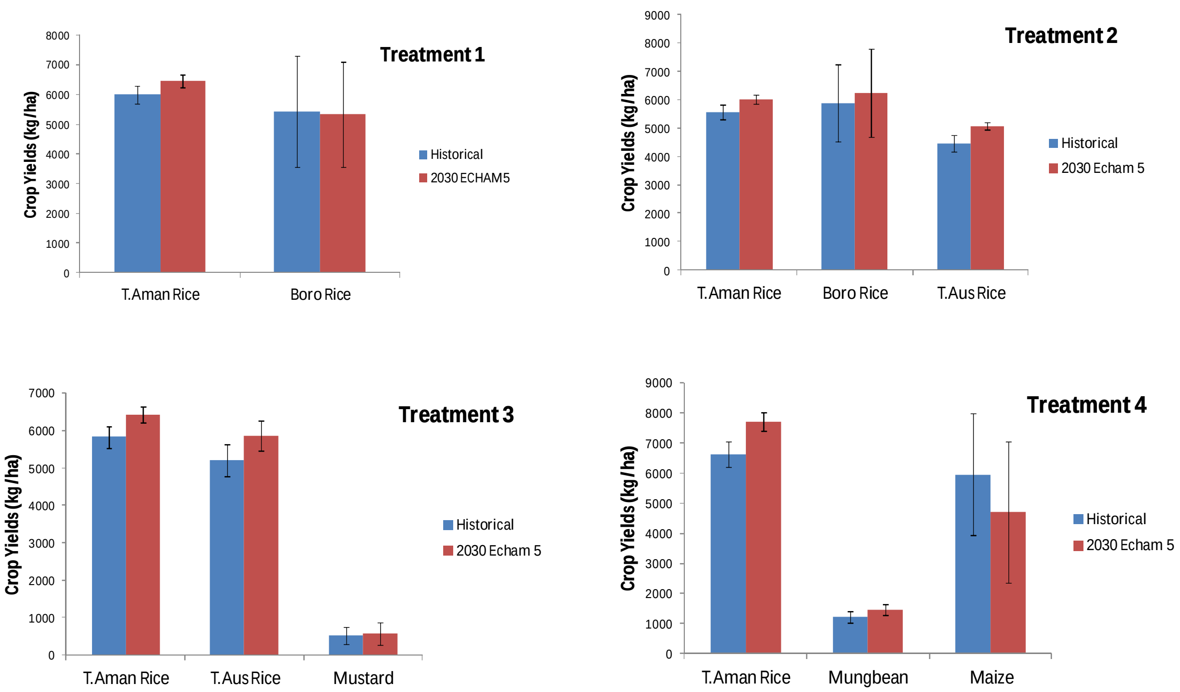


Figure 18. Grain yields associated with each of the investigated cropping systems scenarios (T1-T4)

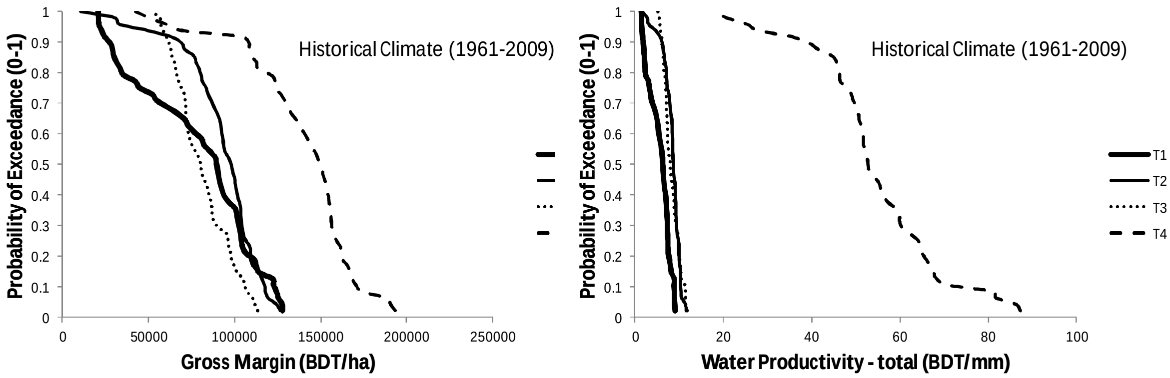


Figure 19. The comparison between options for Gross Margin and also for WP_T for adaptation options T1-T4, under a historical climate.

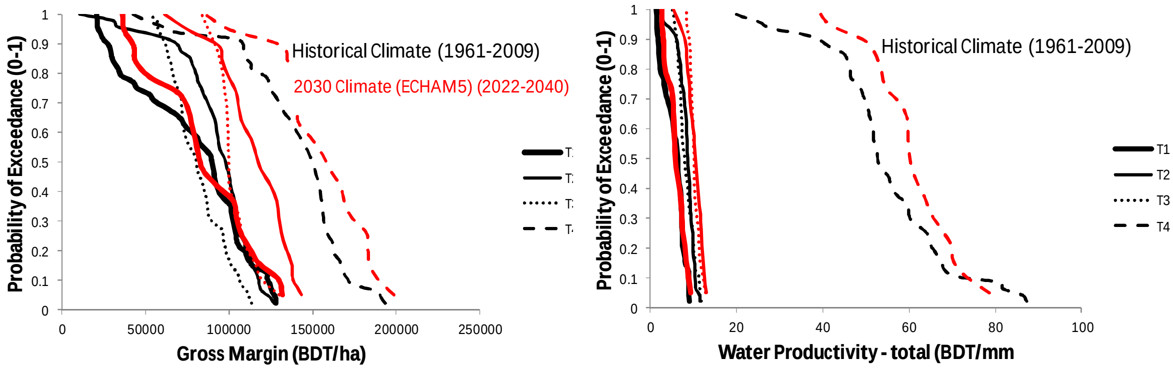


Figure 20. The comparison between options for Gross Margin and also for WP_T for adaptation options T1-T4, under the project future 2030 climate (ECHAM5).

Results indicate that cropping intensification can be successfully achieved in central Bangladesh under current weather patterns (as represented by the historical climate), and that increased gross margins and water productivity result. But given tight timelines for achieving successful 3-crop systems in any part of the world, it's all about choosing the right varieties, timeliness, and smart agronomy (sowing dates, practices etc).

Simulations indicate that these intensification strategies would provide similar benefits under projected 2030 climates. In fact they were shown to have enhanced value over current practices, in a future climate.

The most successful strategies for increasing profit and water productivity of those investigated, involve substantial use of crops other than rice. Their value is tied to market suitability and a range of other pertinent research questions arise for the people of Bangladesh. How sensitive are the results to changes in costs/prices? What about food security concerns?

Bangladesh is marginally food secure, and this is based on rice production. Reductions in rice production could have wider implications, and more research at a national scale is required before a recommendation to any group of farmers is given. Research into implications and requirements at a policy level, via facilitation of seed supply, irrigation laws, policy on rice production requirement, and marketing assistance for new products are also clearly warranted.

Full sustainability polygons have not yet been developed for the Bangladesh for the following reasons. Gross margins presented are preliminary and are currently the subject of a John Allwright Fellowship funded PhD dissertation by Jahangir Kabir (UQ). Results will be compiled and published separately as part of Jahangir's thesis. This analysis is also yet to incorporate the studies on greenhouse gas emissions which are included for the other three countries. This will represent an important consideration, and will be the subject of a journal paper in preparation with Jahangir and other members of the Bangladesh ACCA team.

Engagement outcomes

Stakeholder plans for Bangladesh were developed in 2011 to guide and prioritise engagement activities. Explicit scaling activities for Bangladesh ceased in 2012, in favour of a stronger country focus on model development. Initial and subsequent engagement is summarised in Table 4.

Investment in stakeholder engagement has been documented in trip reports, annual reports and in the stakeholder engagement report that appears as Appendix 1, Volume 3.

Table 7. Summary of stakeholder engagement in Bangladesh

Stakeholder group	Engagement objective	Stakeholders
Project team	Cohesion; capacity	**BARI; BRRI; SERDI; IRRI; CSIRO**
Farming community	Adoption; collaboration	Participating farmers in Dacope and Satkhira
Research community	Science exchange; access to data; common approach	**BARC**; BRAC; BIDS; CIMMYT; CPWF, **CSISA**; **SARCAAB project**; **other ACIAR projects;** general
Upazila govt agencies	Local relevance; dissemination	Dept Agricultural Extension
National govt agencies	Policy or planning influence; relevance; support; dissemination	**Comprehensive Disaster Management Program**; Bangladesh Water Development Board; Dept Agricultural Extension; Climate Change Cell; Dept Meteorology
Regional agencies, donors; NGOs	Dissemination; collaboration	FAO; UNDP; DFAT; ActionAid; Practical Action; BRAC

Note 1: Stakeholders with significant interaction listed only. Bold text indicates the stakeholders with whom ACCA had the most traction (towards the relevant engagement objective) at the end of the project.

Note 2: A review in 2012 shifted the emphasis in Bangladesh from farmer engagement and explicit scaling activities to further refinement of the APSIM cropping model and subsequent institutional capacity building through ACCA and the sister project LWR/2010/033.

Adoption and dissemination of project practices

As noted earlier, the primary focus for ACCA work in Bangladesh was model development and capacity building, which was achieved with ACCA and the SAARC-Australia project.

As project-related engagement with farming communities in the target regions of Khulna ceased in 2012, no explicit dissemination strategy for project practices was initiated. However, some scaling of ACCA practices has occurred (or is projected to occur) by connections with other projects and initiatives working in the same or similar districts. These include:

- The Bangladesh component of CSISA, through connections with IRRI and key staff who were formerly in the ACCA project
- The farm scale components of the CPWF in southwest Bangladesh, through IRRI researchers and the CGIAR Water, Land and Ecosystems program
- Co-investment with IRRI's SARCCAB project for on farm trials near Khulna using ACCA adaptation practice options
- The new ACIAR project on cropping systems intensification in salt-affected areas of coastal southern Bangladesh (LWR-2014-073)

Policy and program influence

The nature of engagement with decision makers in policy and regional programs changed significantly during the project. After 2012, discussions shifted from climate variability and community adaptation to building institutional capability in farming systems modelling. ACCA's target stakeholders changed from departments and programs with carriage for climate change and adaptation to those charged with research capacity and planning.

Despite these disruptions, ACCA can report influence in a number of agencies.

Briefings with the Comprehensive Disaster Management Program (CDMP) yielded early policy influence through discussions on how ACCA outputs could underpin the CDMP's work in climate adaptation. The recognised entry point was upazila level preparation of Disaster Management Plans that explicitly address disaster risk reduction, preparedness, recovery and adaptation. CDMP's recommendation was for collaboration on a pilot study, formalised by a Memorandum of Understanding with IRRI.

One of the most significant legacies of ACCA and SAARC Australia is the enhanced capacity in systems analysis and modelling in Bangladesh (and other SAARC countries) agricultural research institutes. There is now a critical mass of active modellers, working across institutional boundaries, training and mentoring new researchers.

Engagement through direct and sustained interactions and awareness workshops has led to enhanced institutional support for modelling from NARS chiefs and the aspiration of the BARC Chairman to establish greater modelling capacity within BARI and BRRI.

Another projected policy outcome is the intent that modelling will be increasingly be used to inform policy making – particularly around trade-offs and evaluation of options to adapt to changes in climate - in the agricultural research institutes of Bangladesh. This will lead to more balanced decision making and targeted use of research funds.

8.3 Cambodia

Country focus

The emphasis for Cambodia was on targeted testing and dissemination of adaptation options in lowland rice-based cropping areas of Svay Rieng Province, such as direct seeding, use of short duration rice varieties, and improved nitrogen management. Svay Rieng was selected because it is one of the least developed of the lowland rice areas in Cambodia, but at the same time harbours potential for adaptation because there is access to groundwater and some surface irrigation water.

The research focus was complemented by capacity building of farmers and extensionists in response farming, underpinned by social research to match adaptation options to local adaptive capacity and household livelihoods. Links to existing initiatives such as iDE's Farmer Business Advisor program, and strong local support from a proactive Director of the Provincial Department of Agriculture were additional reasons for working in Svay Rieng.

The collaborating institutions in Cambodia were the Department of Agricultural Extension (DAE), the Cambodian Agricultural Research and Development Institute (CARDI), the NGO International Development Enterprises Cambodia (iDE Cambodia, latterly Lors Thmer) and the Svay Rieng Provincial Department of Agriculture (PDA).

Site information

Project teams worked closely with households in three villages in Svay Rieng province. Koul village (Svay Ang commune) and Kbal Damrey (in Svay Yea commune) share similar rainfed farming systems. Koul has access to irrigation from a canal; however water supply is unreliable and only accessible to those households with land adjacent to the canal. At the start of the project, Kbal Damrey had no formal irrigation system, with a small number of households having access to groundwater tube wells. Since then, a canal has been built in Kbal Damrey, though access and reliability of supply will remain an issue for households further from the canal.

Chea Ressey is characterised by a recession rice system, in which the main rice crop is grown in the flood waters as they recede at the end of the monsoon season. Only those households with larger land areas are able to focus on agriculture. The local river delineates the border with Vietnam, and strong relationships have been built between farmers in Chea Ressey and Vietnamese traders and farmers. Seed and other inputs flow into Cambodia, while harvest and labour flow into Vietnam. These households are often poor and stuck in cycles of debt with Vietnamese lenders. Most rely on external income from wage labour.

Cropping calendar

Wet season rice production in Svay Rieng province has traditionally focussed on the growing of local varieties of medium duration lines that mature in 130-140 days. Seedling nurseries are established and land preparation commenced once the monsoon is well established. Commonly, the seedling nursery is established in June, with transplanting in July. Where available, irrigation water from ponds, canals or tube wells is used to supplement rainfall during dry periods which often occur in August/September. Yields have been relatively low (between 2 and 2.5 t/ha), as a result of genetically inferior varieties, low levels of nutrition and poor agronomic practice.

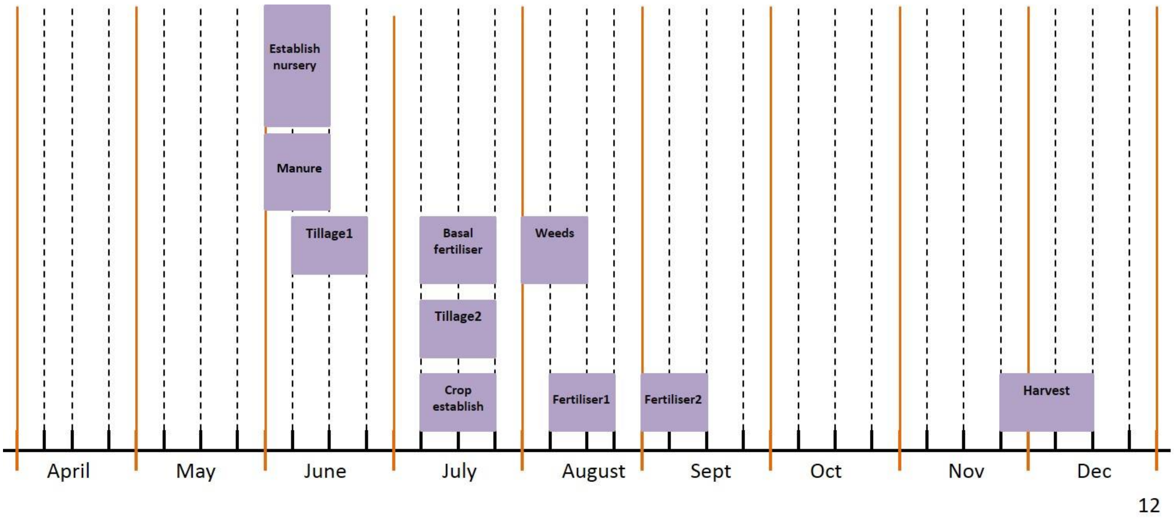


Figure 21. Crop calendar for traditionally planted wet season rice in Svay Rieng Province. Note that the shaded area is the window of opportunity for a specific task.

While farmers are able to meet their household needs in most years, social research suggests that this is becoming more difficult due to the increasingly variable climate, particularly the impacts of drought and floods on production, and social and economic factors that include the effect of rural migration on agricultural labour supply.

Household types

Household types were developed based on Agro-Ecological Assessments (a series of rapid rural appraisal tools such as wealth ranking and community mapping) and workshops with the broader project team. Household types were developed according to four key factors: type of farming system; access to land; access to irrigation; and labour (Table 8).

Recession rice (types E and F) has different cycles, land tenure arrangements and is characterised by limited but fertile land resources in proximity to the main irrigation canal or river. Situated on the border to Vietnam the farm economy is intricately connected to communities on the other side. Seed and other inputs, as well as harvests and labour are transferred across the border.

By contrast, types A – D share similar systems marked by different access to supplementary water, which provides some protection against risk of drought and options for vegetable production. Households with sufficient land remain focused on agriculture and continue improving/maximising productivity with potential to diversify into other activities. Those with insufficient land keep farming to reduce food pressure but divide labour between subsistence farming and wage labour.

Table 8. Summary of household typology, Cambodia

Type	Key characteristics	Key constraints
A	Small, rainfed farmers with no irrigation and high levels of migration.	Small land size; high debt levels; limited capital to access inputs / equipment
B	Large, rainfed farmers with limited irrigation.	Access to irrigation
C	Small, mainly rainfed farmers with limited irrigation and high levels of migration.	Access to water; small land area; high commodity prices; small land area; high commodity prices
D	Large mainly rainfed farmers with access to canal irrigation.	Limited water in the canal; lack of control over canal water; high commodity prices
E	Small recession rice farmers with no irrigation.	Dependence on wage labour; dependency on Vietnamese traders and use of VN504 variety; indebtedness
F	Large, recession rice farmers with no irrigation.	High competition for labour / labour shortage; dependency on relationship with Vietnamese traders (though farmers themselves do not perceive this as a constraint)

On farm research

A participatory approach was used to investigate options to increase the flexibility of the cropping system to meet ongoing production challenges, acknowledging that there cannot be a ‘one size fits all’ solution, due to the differing aspirational goals and livelihood trajectories of individuals. Consequently, on farm research explored a range of potential opportunities, anticipated to meet the needs of a broad range of livelihood types.

These vary from the small subsistence farmer wishing to grow sufficient rain-fed rice to meet food security requirements and using surplus family labour in off-farm enterprises, to those who see farming as their main enterprise and are interested in optimising production through the adoption of modern techniques. These techniques include the use of genetically superior, modern, short and medium duration rice varieties, supplementary irrigation, better crop nutrition and agronomic practice and the use of mechanisation to reduce labour demands.

As a result of successful small scale on farm research in the 2010 wet season there was heightened interest in the study villages of Kbal Damrey and Koul to continue research. As a consequence, in 2011 and 2012, 65 on farm trials were conducted comparing farmer practice to potential systems interventions including the variation of crop timing, the use of short duration rice varieties, increased fertiliser and the introduction of alternate crop establishment technologies.

Figure 22 provides an example of the seasonal timing of an on farm trial and the typical layout and treatments tested. In 2013, as a result of the success of these trials, iDE expanded research to Prey Vang province where 56 farmers from 32 villages participated in on farm research.

The rationale behind this program was that: a) there were opportunities for higher yields with the improved varieties; b) there was potential, in some seasons, to increase production through the growing of two short duration crops to make better use of rainfall and soil moisture resources; c) current crops were nutritionally limited; and d) there were opportunities to reduce labour input with technologies such as drum seeding.

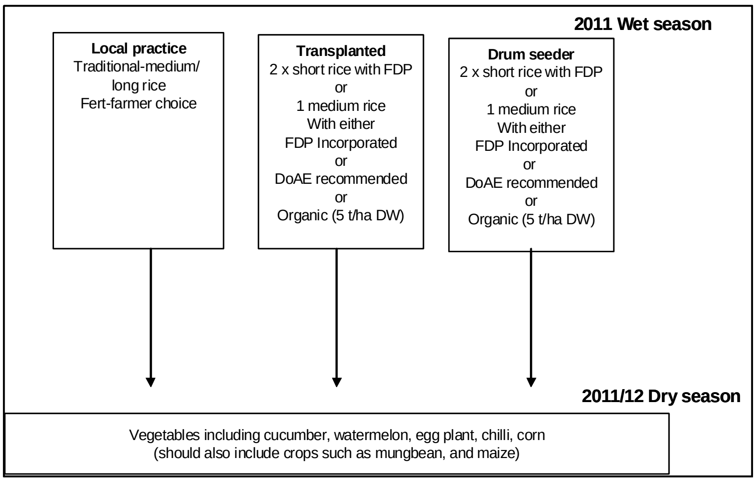


Figure 22. On farm research trial design used at Koul and Kbal Damrey during the 2011 wet and 2011/12 dry seasons

Table 9. Summary of results of adaptation practices tested on farm in Svay Rieng and Prey Veng provinces in 2012 and 2013.

	Seasonal yield		**Seasonal gross margin**	
	Median	**Mid 50%**	**Median**	**GM Mid 50%**
	(kg/ha)	(kg/ha)	(USD/ha)	(USD/ha)
Late monsoon (2012)				
Farmer Practice	1900	1600-2100	(90)	(180)-(10)
1 x short (early)	2700	2100-3100	(20)	(100)-125
2 x short	4900	4700-5700	10	(110)-255
1 x medium	1900	1600-2400	170	130-370
Early monsoon (2013)				
Farmer Practice	3200	2800-3800	120	(30)-320
1 x short (early)	3800	3000-4400	250	70-360
1 x short (mid)	3700	3200-4200	400	340-420
2 x short	6500	5800-7100	500	330-600
1 x medium	3400	3100-3500	300	250-350

Notes: Yield is seasonal production in kg/ha at 14% moisture. Gross margin figures include labour inputs. Figures in brackets indicate negative gross margins (ie the farmer loses money from adopting these practices).

The research results being compared in Table 9 for 2012 and 2013 seasons show the variation that can be expected in yield between systems interventions, and how the most successful seasonal intervention is likely to change between seasons as a result of climate variation.

Where there is an early start to the monsoon (2013), two short-duration crops will achieve high seasonal production and economic return. It can be seen also, that under the same seasonal conditions, the growing of a single short or medium duration, genetically superior variety will result in good economic returns. These somewhat counter-intuitive results are a result of the differences in labour and input costs associated with the growing of one or two crops and the impact of crop establishment timing on yield and input costs (particularly insect and weed control).

For a late-starting monsoon season (2012), Table 9 shows that growing a sequence of two short-duration, genetically superior crops is not the best option due to a reduction in overall seasonal yield, combined with increased labour and input costs associated with the production of two crops. On farm research suggests that the best option in a late-starting season is to grow a modern, medium duration, direct seeded crop, established in June/July. In the two seasons being compared, it can be seen that all of the systems interventions are superior in yield and income to farmer practice.

These results indicate that prior knowledge of upcoming seasonal conditions, or the ability to respond to seasonal conditions as they occur, particularly in the early monsoon period, are crucial to the success of the proposed interventions. As seasonal climate forecasting is currently unreliable in Cambodia, a combination of the results of on farm research and simulation modelling were used to develop a planting rule, based on early season paddy moisture condition which could be used to trigger wet season rice cropping.

It was suggested that the risks were sufficiently low for the farmer to commence land preparation and rice establishment when there was >5mm of water on the paddy surface for at least three days. The meeting of this condition then provided the farmer with the confidence to respond, with that response conditional on the timing of occurrence. If the conditions of the rule are met early in the wet season (eg in May), then the farmer should consider planting an early planted, short duration variety; and if conditions continue to be favourable, a second crop later in the season. However, if paddy conditions are not met until the end of May or into June, then the farmer should consider other options including the establishment of a mid-season, short, or medium modern variety.

Drum seeding was embraced by communities early in the collaboration - not because of higher yields but because of the savings in labour. Farmers indicate that to transplant a crop takes 24 person days/ha compared to 2 person days/ha for drum seeding. However continuing adaptation has occurred with many farmers now opting for a cheaper direct seeding option of hand broadcast as a direct response to the cost of investing in a drum seeder. What farmers have not done is revert to crop transplanting, even though the use of direct seeding does bring with it increased weed management costs.

Another pinch point in growing sequential rice crops is the transition time between crops 1 and 2. In 2011 inexperienced researchers took 21 days to transition from crop 1 to 2. In many cases, this resulted in the failure of the second crop due to terminal moisture stress. However in 2012 this period was reduced to 11 days, lowering the risk of crop failure. In 2013, lead farmers were able to reduce the transition down to seven days.

Studies in Chea Ressey village focussed on the production of recession rice. Similar technologies to those described above were used in the production of irrigated dry season crops, although it was more difficult to gain traction in this village due to the pervasive influence of Vietnamese traders on the local farming community.

Social research indicated that the farmers of this area were amongst the poorest in the district - not because of poor productive potential but because of the high debt levels associated with the closed production systems promoted by traders which included the provision of credit to grow the Vietnamese rice variety 504, all crop inputs and purchase of the crop.

Modelling scenarios

While on farm research was essential in testing the logic of particular system changes, it was not possible to undertake field-based research for a period of sufficient length to experience all potential climatic variation. Crop modelling, based on long term regional meteorological records (rainfall, temperature, radiation) and local soil information provided a longer term context. Simulation of crop production (in this case rice) provided an assessment of seasonal productivity over a longer timeframe, and an estimate of associated production risk. Comparison of on farm data and the simulation output for the same years enabled testing for 'sensibility' of particular interventions at relatively low cost.

Adaptation strategies targeting a 'response farming' approach to the prevailing wet season conditions were evaluated with the aim of improving efficiency of use of the natural resources, particularly water. Response farming assumes that there are a number of ways in which the monsoon period can be used to produce rice, with particular options better suiting particular climatic conditions. Simulated scenarios evaluated the traditional farmer practice with a number of potential adaptation options for a baseline climate period (1978-2011) and for projected future climates (2021-2040).

Scenarios evaluated in the final modelling iterations:

1. Rainfed transplanted, local medium maturation variety established early to mid-wet season with no applied nitrogen fertiliser (farmer practice 1).
2. Rainfed transplanted, local medium maturation variety established early to mid-wet season with 20 kg/ha of applied nitrogen fertiliser (farmer practice 2).
3. Rainfed transplanted, modern medium maturation variety established early to mid-wet season with 50 kg/ha of applied nitrogen fertiliser (adaptation option 1).
4. Rainfed direct seeded, modern medium maturation variety established mid-wet season with 50 kg/ha of applied nitrogen fertiliser (adaptation option 2).
5. Rainfed direct seeded, modern short maturation variety established June with 50 kg/ha of applied nitrogen fertiliser (adaptation option 3).
6. Rainfed direct seeded, modern short maturation variety established early wet season (May) with 50 kg/ha of applied nitrogen fertiliser (adaptation option 4).
7. Rainfed double crop sequence of short duration, direct seeded rice sown early (crop 1) and mid-wet season (crop 2) with 50 kg/ha of applied nitrogen fertiliser (adaptation option 5).
8. Double crop sequence of short duration, direct seeded rice sown early (crop 1) and mid-wet season (crop 2) with access to supplementary irrigation with 50 kg/ha of applied nitrogen fertiliser (adaptation option 6).

Based on farmer group discussions, a set of management rules describing traditional farmer practice and adaptation options of direct seeding of short and medium maturing rice varieties under rainfed and irrigated conditions were specified in the APSIM Manager for evaluation of the five scenarios described above. The APSIM Manager module was configured to respond to a series of event triggers controlling timing of crop establishment, cultivation, fertiliser application, harvesting and opportunity for a second crop

An example of the APSIM Manager Logic used to trigger these events in response to seasonal conditions is presented in Table 10 (using 1979 as an example), reflecting one of the strengths of the APSIM model in being able to simulate farmer specified management rules.

Parameters used to calculate the gross margins (GM) for each scenario are provided in Table 11. These data allow for estimates of order or magnitude for GM and variability of GM, as in reality rice prices and most productions cost vary with each season and certainly have not remained constant over the long term modelling period.

Table 10. Results of event based manager logic responding to the season and seasonal climatic conditions (rainfall), using the 1979 season and scenarios 2, 3, 5 and 8 as examples. Timing of modelled actions and events for each of four treatments is presented.

Date	Medium-single-transplant-rainfed (farmer practice 2) in-crop rainfall = 1207mm	Modern-medium-single-transplant-rainfed (adaptation option 1) in-crop rainfall = 1207mm	Short-single-direct-rainfed (adaptation option 3) in-crop rainfall = 1109mm	Short-double-direct-irrigated (adaptation option 6) in-crop rainfall = 1207mm
1-May-79				Irrigate pond to 20mm
2-May-79				First ploughing
7-May-79				Add manure
9-May-79				Second ploughing
				Direct seed IR66
11-May-79				Apply fertiliser 25kg N
23-Jun-79	Pond depth >20mm	Pond depth >20mm	Pond depth >20mm	
	First ploughing	First ploughing	First ploughing	
24-Jun-79	Seedling nursery established	Seedling nursery established		
27-Jun-79	Add manure	Add manure		
29-Jun-79				Apply fertiliser 25kg N
30-Jun-79			Add manure	
8-Jul-79			Second ploughing	
			Direct seed IR66	
10-Jul-79			Apply fertiliser 25kg N	
26-Jul-79	Transplant Phka Rumduol	Transplant Phka Rumduol		
27-Jul-79	Apply fertiliser 20kg N	Apply fertiliser 25kg N		
15-Aug-79				Maturity
18-Aug-79				Harvest 3.82 t/ha
19-Aug-79				Third ploughing
23-Aug-79				Forth ploughing
				Direct seed IR66
25-Aug-79				Apply fertiliser 25kg N
27-Aug-79			Apply fertiliser 25kg N	
22-Sep-79		Apply fertiliser 25kg N		
13-Oct-79				Apply fertiliser 25kg N
14-Oct-79			Maturity	
17-Oct-79			Harvest 4.42 t/ha	
17-Nov-79	Maturity	Maturity		
21-Nov-79	Harvest 0.99 t/ha	Harvest 1.56 t/ha		
30-Nov-79				Maturity
4-Dec-79				Harvest 5.2 t/ha

Table 11. Average rice prices and production costs used to calculate gross margins of the scenarios 1-3 and 7-8.

		Rainfed							Irrigated	
	All	Farmer practice 1	Farmer practice 2	Option 1	Option 2	Option 3	Option 4		Option 5	
							Short (1st)	Short (2nd)	Short (1st)	Short (2nd)
		0 N	20 N	50 N			50 N	50 N	50 N	50 N
	$/kg	$/ha	$/ha	$/ha			$/ha	$/ha	$/ha	$/ha
Rice price	0.25									
Seed (rice)		45	45	45	90	90	90	90	90	90
Fertiliser		0	50	125	125	125	125	125	125	125
Pesticide		63	63	63	82	51	82	51	82	51
Labour		292	292	360	181	181	195	195	195	195
Other costs		0	0	0	0	0	0	0	20	20

Obtaining good quality, long term climate data for modelling purposes was challenging in Cambodia, due to the fact that all climate date sets had significant gaps, and data for Svay Rieng was patchy. Hence, the approach to generating climate input files for APSIM required some additional steps, described here.

An input long term climate file (composite) was collated for the period 1980-1994 based on daily maximum and minimum temperature for Phnom Penh and rainfall for Prey Veng (11.483 N, 105.333 E) and Kampong Cham (1982 & 1990 only). A second baseline climate file for 1978-2011 was generated from daily observations at Tay Ninh, Vietnam and down-scaled global climate model (GCM) data utilising a Linear Mixed-Effect State-Space (LMESS) modelling methodology (Kokic et al., 2011).

Rainfall, temperature and radiation data from the on-farm automatic weather stations and local climate data were correlated with the LMESS baseline data on a monthly basis and presented on a long-term mean monthly basis (Figure 23a). Original LMESS rainfall for Tay Ninh was adjusted on a monthly basis to correlate long-term daily rainfall trends with the observed long-term seasonal rainfall pattern (Figure 23b). LMESS future daily climate files (2021-2040) were generated for the IPCC A2 emission scenario for downscaled GFDLGM21 and ECHAM5 GCM modelled outputs.

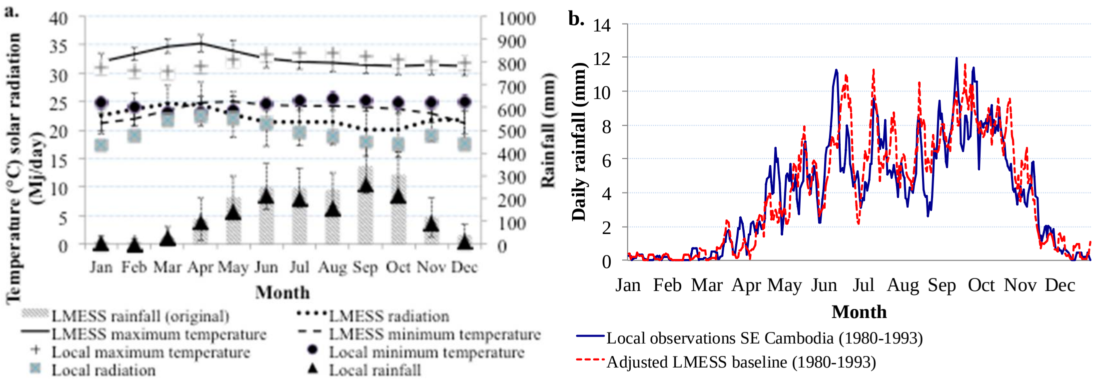


Figure 23. (a) Mean monthly seasonal maximum and minimum temperature (°C), solar radiation (Mj d-1) [lines] and total rainfall (mm) [bars] for LMESS baseline climate (Tay Ninh) from 1997 to 2011 compared with observations from Phnom Penh (symbols) from 1980 to 1993. Vertical whiskers represent standard deviation around the mean for the LMESS data values. (b) Five day running mean rainfall values for local observations (SE Cambodia) and adjusted LMESS baseline rainfall at Tay Ninh for 1980-1993.

Rice yields showed a very strong response to the adaptation scenarios tested. Figure 24 suggests that all adaptation options significantly increase yields when compared to farmer practice. Both farmer practices result in crop failures about 15% of seasons, while addition of modest amounts of nitrogen fertiliser in farmer practice 2 effectively doubles yield. The median yield of 2t/ha modelled compares well with the average farmer yields observed in the on-farm research. While significantly increasing yields beyond those of farmer practice 2 (primarily nitrogen driven), some adaptation scenarios (options 1, 2 and 3) still lead to crop failures in about 5-10% of seasons. The only adaptation option with a single rice crop that reduces the risk of crop failure to about 0% is option 4, where farmers are assumed to direct seed a modern short duration variety established later (June) with 50 kg/ha of applied nitrogen fertiliser.

From the results of the FGD conducted in late 2013, it transpired that farmers were moving towards option 3 as one of their preferred options, but establishing rice through broadcasting seed rather than through the use of the drum seeder. This is despite the modelling suggesting that some years in option 3 (direct seeded short duration rice established in May) may result in failed crops. However, this is compensated by option 3 achieving the highest yields in 80% of the instances (Figure 24). Adaptation 5 (the rainfed double cropping option) can only significantly outperform all options in favourable years (about 5% of years). Not shown here is adaptation option 6 when irrigation is available to establish crops or bridge within season dry spells, where simulation results suggest a significant decrease in risk and the highest annual yields (>9 t/ha).

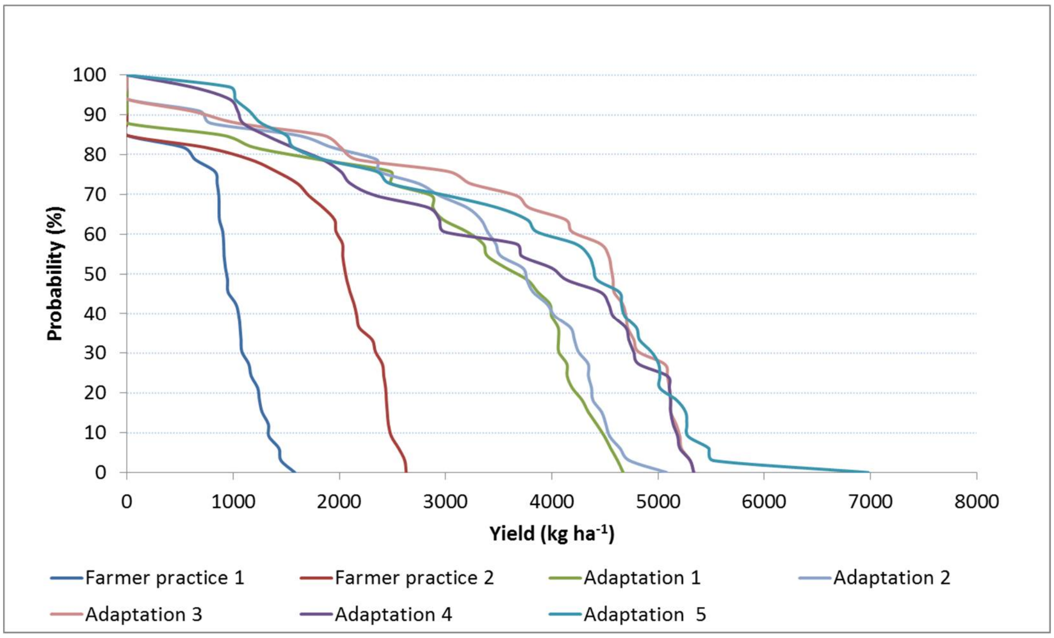


Figure 24. Rice yield responses (probability of exceedance) for rainfed rice cropping options (scenarios 1-7), for current baseline climate 1978-2011.

Relative ranking of gross margins (including labour costs) of farmer practices and adaptation results follow a similar pattern as for yields, with two main exceptions (Figure 25). Adaptation 3 is the most economically attractive option, but the single crop option planted a little later in the wet season (option 4) results in a high GM, as does the option 2 and the double cropping option 5.

However, all scenarios suggest that farmers are making a loss in 15–30% of seasons, while farmer practice 1 has a negative GM in all seasons. For farmers producing rice for home consumption who have no viable alternatives to deploy labour for wage earning, this may be less relevant. Conversely, farmers that factor in the opportunity costs of labour are likely to proceed with low risk, higher return options such as adaptations 2 and 3.

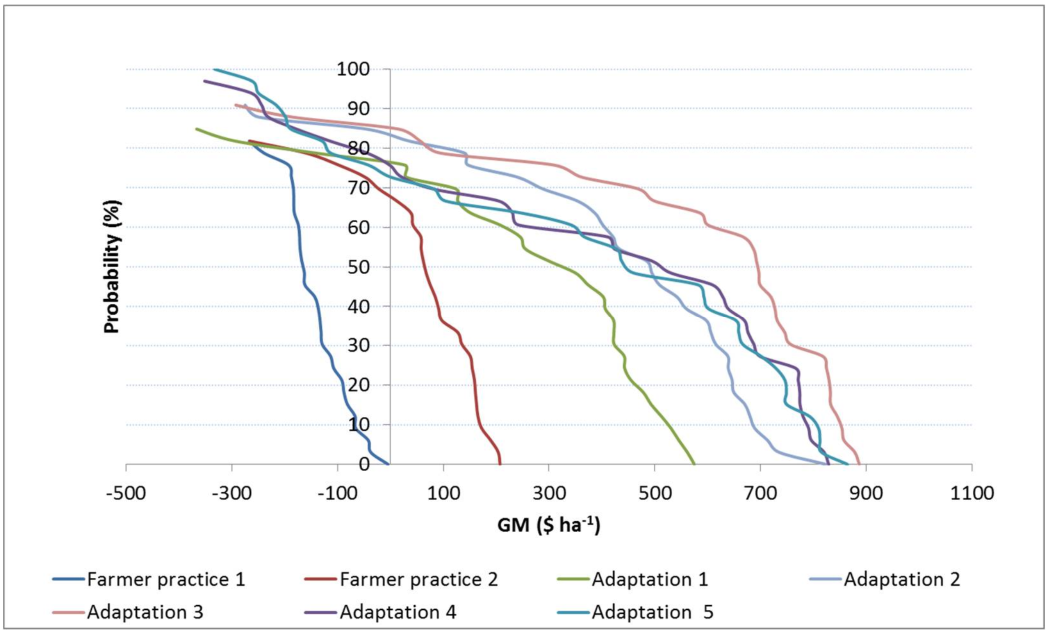


Figure 25. Gross margin responses (probability of exceedance) for rainfed rice cropping options (scenarios 1-7), for current baseline climate 1978-2011.

A comparison of average rice yields for farmer practice, and the tested adaptation options for baseline and future (ECHAM5 and GFDL GM2.1) climates is presented in Figure 26a. Comparing current farmer practices (left columns in Figure 26a) against improved practices (middle columns in Figure 26a) suggests that simple improvements to crop management such as choice of short duration varieties, better nitrogen management and crop husbandry, can generate yield increases that will offset yield reductions as a result of climate change. However, system performance remains modest, and we regard this as an incremental adaptation.

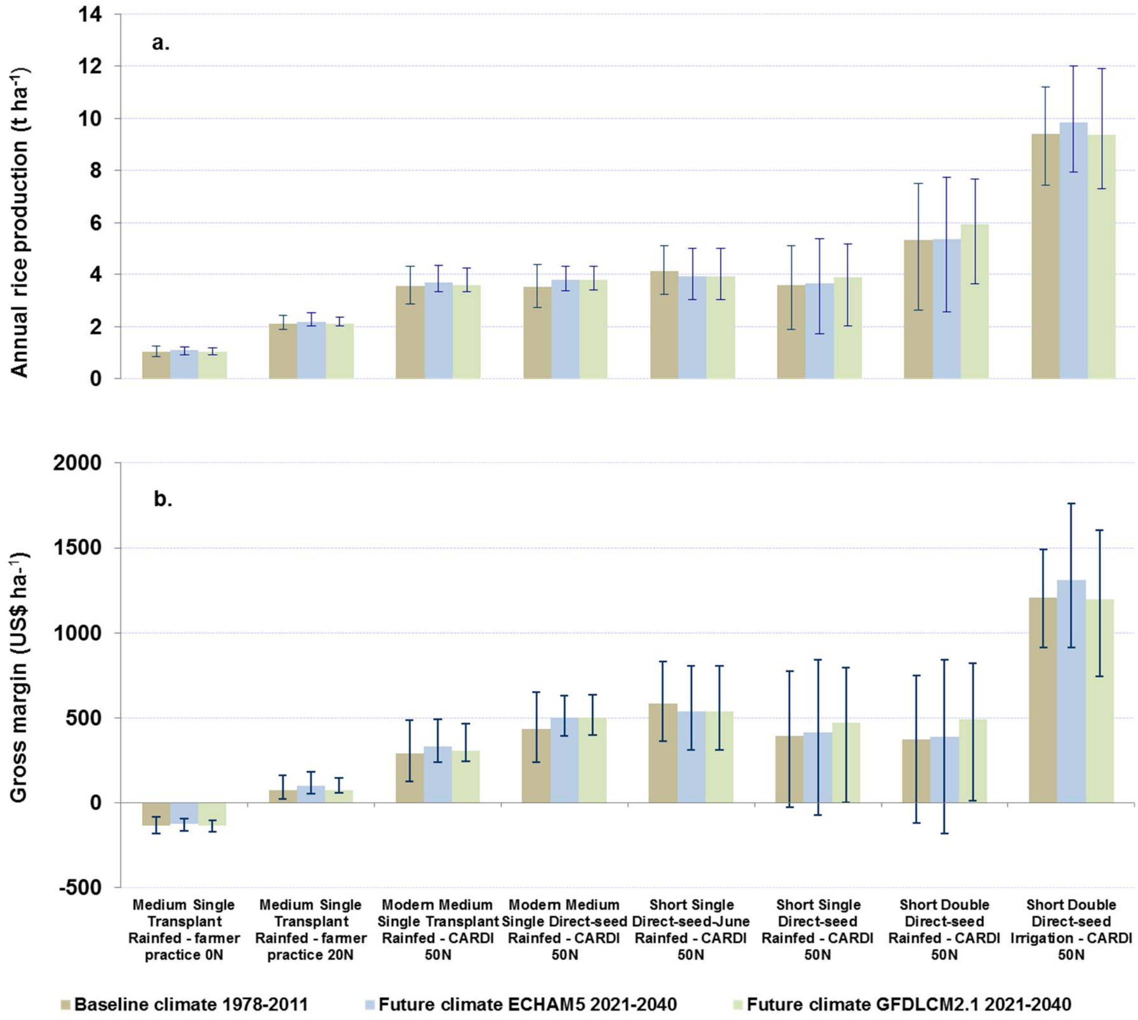


Figure 26. Simulated average annual rice production (a: t ha^{-1}) and average gross margins (b: USD ha^{-1}) for farmer practice and tested adaptation options grown under rainfed and irrigated conditions and fertiliser applications of 0, 20 and 50 kg ha^{-1} of applied nitrogen. Simulations compare yields grown under current baseline climate 1978-2011 and projected GCM (ECHAM5 and GFDLGM21) generated future climates (2021-2040). Error bars represent 20 and 80 percentiles.

Conversely, introduction of double cropped, direct seeded, short duration rice in combination with supplementary wet season irrigation would greatly reduce the impact of climate risk on annual yields under both current and future climates (right hand column in Figure 26a).

Leading collaborator farmers were able to demonstrate the technical and economic feasibility of this strategy in our on farm research. This constitutes transformational adaptation (Rickards and Howden, 2012). However, its widespread introduction will require a sustained policy response in many domains (eg provision of irrigation infrastructure).

Direct seeding shows greater potential for higher yields, when compared with transplanted modern varieties, given the opportunity to double crop as a result of earlier rice establishment. However, under rainfed conditions and in situations where the first crop is sown early, this comes with higher levels of production risk (error bars in Figure 26a).

Average gross margins show a slightly different picture (Figure 26b). Accounting for the additional labour requirement for transplanted rice, direct seeding increases the GM significantly over farmer practice. Adaptation options 3 and 5 (single short duration, early sown, either as a single crop or as crop 1 in a double crop situation) show a high degree of variability in GM, and in some instances lead to a negative GM. The single crop option that offers the highest yield, highest GM with moderate variability is adaptation option 4 (rainfed direct seeded, modern short maturation variety established in June with 50 kg/ha of applied nitrogen fertiliser).

These results for Cambodia are encouraging and similar findings from the other countries generally support our notion that helping farmers better manage current climate variability is likely to increase their adaptive capacity to respond to future climate. However, issues regarding sustainability of irrigation water use and potential increased greenhouse gas emissions need to be considered when evaluating whether the proposed adaptation options are climate smart.

Sustainability analyses

Sustainability polygons were generated as a graphic representation of multiple sustainability indicators. Each sustainability indicator is represented by a relative value from 1 to 0 where 1 is the most desirable outcome for that indicator.

For Cambodia, six criteria were used:

- Yield 1 = *highest production*
- Stability of yield 1 = lowest standard deviation from the mean
- Gross margin (GM) 1 = *highest gross margin*
- Stability of GM 1 = *lowest standard deviation from the mean*
- N_2O atm/ t yield 1 = low *N_20 N loss to atmosphere per tonne yield*
- C atm/ t yield 1 = low *carbon loss to atmosphere per tonne yield*

Polygons generated under LMESS baseline climate and an LMESS future climate (ECHAM5) are presented in Figure 27. Note that APSIM-ORYZA has not been validated for N_2O emissions in rice based systems. Relative differences between scenarios provide an indicator only of the potential effect on N_2O emissions.

Reviewing the sustainability polygons, the overall sustainability of the tested adaptation options for Cambodia is not as straightforward as for the Indian case study.

Most adaptation options have lower nitrogen emissions, but have higher carbon emissions. There is a trade-off, with the new practices generally performing better in terms of yield increases and higher GMs, while not necessarily leading to overall higher GHG emission intensities (C and N_2O emission / t yield). However, in the rainfed situation, this might come at the cost of greater variability of yields and GM compared to farmer practice. This lower variability of yields and GM for farmer practice is based on low absolute yields and negative or low absolute GMs. Under rainfed conditions, it could be argued that the best overall adaptations are options 2 and 3, both under current and future climates.

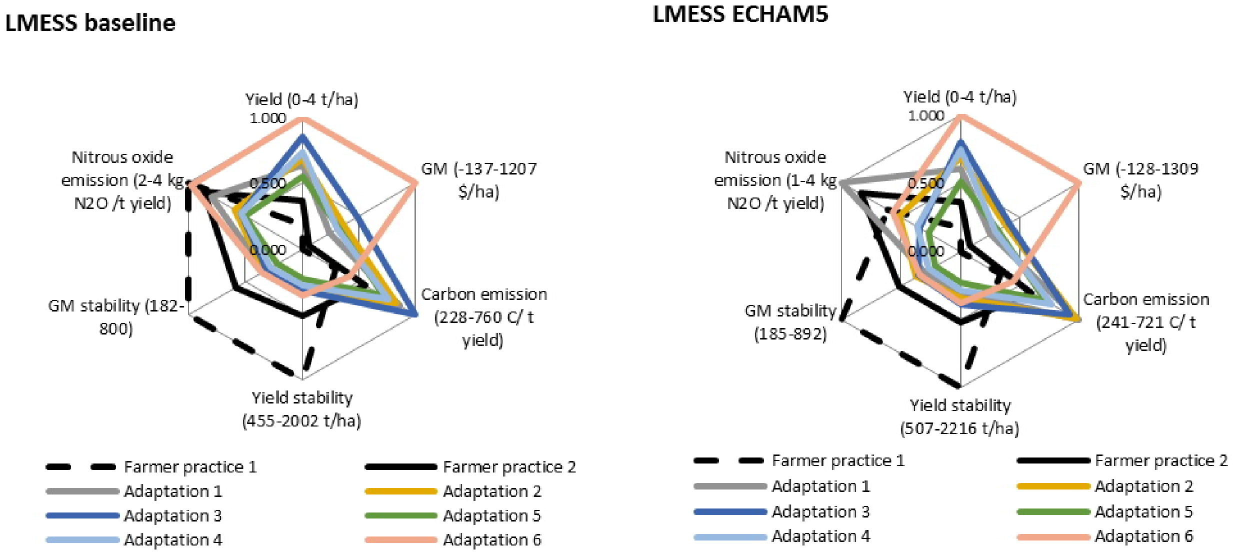


Figure 27. Comparison of two farmer practices with simulated adaptation options in terms of yield, stability of maintaining yield, GM, stability of maintaining GM ($/ha), N_2O atm/ t yield and C atm/ t yield. Management options compare baseline (LMESS) and one future climate scenario (ECHAM5; GFDLCM21 was very similar to ECHAM5 and thus not shown).

Results from the on farm work and the farmer focus group discussions indicate that the degree to which the risk eventuates relates strongly to the skill of the farmer, linking these results back to the household types. In addition, risk can be significantly reduced where farmers have access to supplementary irrigation. Amongst the farmers conducting on farm experiments, some consistently outperformed others, and consistently achieved yields at the higher end of those modelled (corroborating that the modelled yields are realistic and technically achievable). These farmers tended to be associated with household type D (Table 8). This suggests that there is merit in applying the Yield Gap Analysis concept to farmers in Cambodia, but expanding the concept to include socio-economic factors of yield gap analysis beyond just the biophysical crop growth limiting factors.

Farmer engagement

Focus group discussions (FGD) and key informant interviews (KII) were held in August and October 2013, respectively, to elicit farmer perceptions and feedback of adaptation practices. Participation was sought from across the different household types - those who had used the practices as well as those who hadn't - to get a balanced perspective. In the FGD we also selected control villages that had to date not been engaged by the project, to gauge to what extent practices from Koul and Kbal Damrey had already been adopted in neighbouring villages. Results of the KII (Dalgliesh et al, 2013) are provided in Appendix 9 of Volume 3.

The most commonly adopted practice was direct seeded, short duration rice varieties and double cropping with increased fertiliser use. This practice was seen as a good strategy to ensure food security and increase income (sale of surplus harvest). In introducing different cropping options, some households were exposed to crop damage by pests due to timing of maturation within the broader, traditional, medium duration system (ie first crop matures early, creating green island effect; second crop vulnerable to attack after harvest of medium duration varieties).

While the drum seeder sows neatly in rows and saves significant time and labour for crop establishment, some farmers still found it too expensive and laborious. As a consequence many opted to hand-broadcast their crops which continued to save labour, but to the detriment of weed control.

Uptake of vegetable production in the dry season was mixed in the focus groups, largely due to security concerns (risk of theft); lack of access to markets and social perceptions of vegetables as a subsistence activity.

Integration: Response farming package

Depending on whether households are focused on subsistence or commercial farming, land size, whether land is close to the homestead, considerations of risk are different and influenced responses to the adaptation options trialled. Households with water access and those with larger land areas, who had a heavier emphasis on commercial farming, were more likely to invest time and other resources in these practices. Those with less land (e.g. Type 1, 3), focused on subsistence farming and had less capacity to reallocate labour and other resources within agricultural activities, and higher relative risks of loss if changes are not successful. Where smaller household types implemented the practices, it was often with the intent of saving labour for reinvestment into non-farm activities.

Fragmentation and distribution of land holdings owned was not captured in the household types, but is important in terms of adaptation. Where land is closer to the homestead, there is generally greater ability to manage water (access to wells) and reduced risk of theft/damage to crops. The diversity of circumstances and motivations across household types mandates adaptation approaches that are flexible and meet multiple objectives.

Building on the results of the on farm experiments and the modelling we developed an integrated response farming package. Response farming assumes that there are a number of ways in which the monsoon period can be used to produce wet season rice, with particular options better suited to particular climatic conditions (eg an early, average or late start to the wet season; high, medium or low amounts of rainfall during the season). The ‘response’ made by the farmer will depend on these conditions and the strategy they perceive to be the most appropriate to meet their livelihood goals. This may result in a number of the proposed strategies being adopted as a season unfolds to best meet conditions and address climate risk.

The image of a ‘tool box’ that contains seasonal management options is a useful analogy, with appropriate tools used to meet production and livelihood demands as a season progresses (Figure 28). The type of tools that are stored in the box include: crop duration and variety, crop sequencing and timing of establishment, availability of supplementary irrigation, availability of labour and the potential for increased mechanisation, seeding technologies (direct seeding and transplant), fertiliser (both organic and inorganic) and pest management technologies; leading to aspirational seasonal production, crop return and gross margin goals.

It should be noted that the advocates of ‘response farming’ are not suggesting that all, or particular options are more important than others, or that they will be used by every farmer in every season or across an entire farm. Response farming is about having a range of options which are all likely to contribute to reduced climate risk and to improved yields, and in many cases, will also improve financial returns. The final choice of whether to use particular options is the decision of the individual.

The concept of response farming was presented to a Technical Reference Panel in Phnom Penh in July 2014. The Panel – rice and systems specialists from Cambodian Government agencies, locally based NGOs and Australian partners - peer reviewed the seasonal cropping calendars and associated response farming protocols (for timing and management actions) for ACCA recommended ‘response’ actions (refer to Appendix 3 in Volume 3 for details).

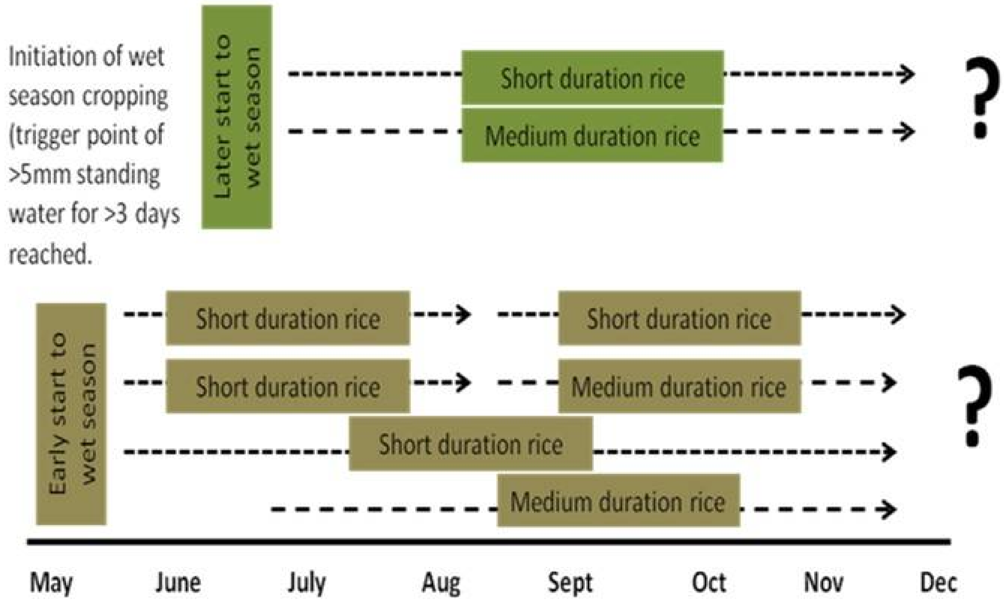


Figure 28. Range of management options and strategies farmers could use to respond to specific seasonal climate conditions.

The Panel recommended that the monsoon season rice production interventions be considered for promotion on medium and high lands, in provinces where the soils and environment were similar to those of Svay Rieng and Prey Veng. These included the other PADEE[8] focus provinces of Kampot, Kandal and Takeo (as well as Svay Rieng and Prey Vang), the proposed ASPIRE[9] focus provinces of Kampong Chhnang, Pursat, Preah Vihear, Kratie and Battambang, and the provinces of Preah Sihanouk and Kampong Speu.

The Panel's Technical Report on response farming was endorsed by GDA management and then used to support national climate policy initiatives (eg National Action Plan on Climate Adaptation (2013-2023), the sector document on Climate Adaptation for Agriculture, Forestry and Fisheries (2013-18) and the relevant sub-sector policy document for agriculture) by providing a framework for extension and training in response to climate variability and change.

The response farming approach and extension materials are now used in mainstream DAE and iDE extension activities, and are in widespread use in PADEE and ASPIRE initiatives around the country.

Engagement outcomes

Stakeholder plans for Cambodia were developed in 2011 to guide and prioritise engagement for a variety of reasons eg access to networks, policy influence, science exchange, capacity opportunities.

Investment in stakeholder engagement has been documented in trip reports, annual reports and in the stakeholder engagement report that appears as Appendix 1, Volume 3.

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[8] Project for Agriculture Development and Economic Empowerment; a six year IFAD funded program aimed at Improving livelihoods for poor people in targeted communes in the provinces of Kampot, Kandal, Prey Veng, Svay Rieng and Takeo

[9] Agriculture Services Programme for Innovation, Resilience and Extension; IFAD funded program

Table 12. Summary of stakeholder engagement in Cambodia

Stakeholder group	Engagement objective	Stakeholders
Project team	Cohesion; capacity	**CARDI; DAE; iDE; PDA Svay Rieng; CSIRO**
Farming community	Adoption; collaboration	**Participating farmers**; other farmers in Svay Rieng; farmers in other provinces
Research community	Science exchange; access to data; collaboration	**Royal Univ Agriculture**; CDRI; CIRAD; other ACIAR projects; **general researchers**
Provincial/local govt	Policy or planning influence; relevance; dissemination	**PDA Svay Rieng;** Heads of Village Communes
National govt	Policy or planning influence; relevance; support	**General Directorate Agric; Ministry Agric, Fisheries & Forestry**; Ministry Water Resources; Ministry Rural Devt
Regional agencies, donors, NGOs	Program influence; dissemination; collaboration	MRC; FAO; **IFAD**; **UNDP**; ADB; AusAID-DFAT; CAVAC; **SNV;** Oxfam

Note: Stakeholders with significant interaction listed only. Bold text indicates the stakeholders with whom ACCA had the most traction (towards the relevant engagement objective) at the end of the project.

Many engagement outcomes are described elsewhere in this report. For example, team cohesion and capacity building are described in capacity impacts (Section 6), while science exchange is covered in the publications list (Section 8). Two engagement outcomes are summarised here - adoption and dissemination of project practices and policy and program influence – as these will form the foundation of the project’s sustainability and impact in the region.

Adoption and dissemination of practices

There were four key (overlapping) mechanisms for dissemination of ACCA practices to Cambodian farmers. Estimates of current and potential dissemination are summarised in Table 13.

a) *Farm Business Advisor Network*

FBAs are a network of ‘micro-entrepreneurs who help farmers to initiate, intensify, or expand market-oriented agricultural production’. They are recruited and trained by iDE (and latterly, Lors Thmer) on good agricultural practice for main crops in their area, and in business skills. ACCA information – particularly the response farming ‘toolkit’ – is now embedded into their training.

Each FBA services 40-50 farmer clients. In 2013, iDE estimate that there were 50 FBAs in Svay Rieng and Prey Vang who had received training in ACCA research and were engaging with around 2000 farm enterprises. In 2015, there were over 240 FBAs across five provinces - Svay Rieng, Prey Veng, Takeo, Kandal and Kampot. The aim in the next three years is to have more than 400 FBAs established, providing some level of service to 16,000 to 20,000 farm enterprises. Most FBAs work in vegetable production; only around 40% work exclusively in rice.

b) DAE training and extension

DAE is responsible for training a network of provincial and commune extension workers and non-geographically aligned support teams in good agricultural practices and in new technologies, varieties and approaches developed or adopted by the various Departments of the General Directorate of Agriculture.

The mechanism is a Training of Trainer (TOT) approach, with trainers then conducting Farmer Field Schools (FFS) as a starting point for dissemination of information to farmers. The TOT training used the manual developed by DAE as part of ACCA, detailing the response farming decision support charts and associated text describing each action. FFS participants were provided with a less detailed manual describing the same response options, with a set of posters for display in each village or commune.

c) PADEE training and extension

This approach was piloted in 2013 in Svay Rieng and then rolled into the Project for Agricultural Development and Economic Empowerment (PADEE). Training and provision of climate adaptation tools (including ACCA outputs) to a network of Community Extension Workers (CEWs) across Svay Rieng, Prey Veng, Kampot, Kandal and Takeo raises potential exposure to up to 20,000 farmers.

d) ASPIRE training plans

A follow-on initiative to PADEE is the Agriculture Services Program for Innovation, Resilience and Extension (ASPIRE) which begins in 2015 in five pilot provinces: Battambang, Kampong, Kratie Chhnang, Preah Vihear, and Pursat.

For 2015-18, ASPIRE plans to train CEWs in 180 communes in these provinces. Each CEW will be responsible to establishing ‘small learning groups’ of 30 farmers; a total of 5,400 farmers. In its second phase (2018-21) it will be extended to the five current PADEE provinces of Kampot, Kandal, Prey Veng, Svay Rieng and Takeo, plus additional villages in the first five provinces.

Policy and program influence

a) Informing Cambodian climate policy

In final interviews, senior government officials in GDA (MAFF) confirmed that ACCA contributed to the clarification of climate change issues in Cambodia and provided a pathway for action on climate adaptation.

ACCA influence has been noted on the National Action Plan on Climate Adaptation (2013-2023), the sector document on Climate Adaptation for Agriculture, Forestry and Fisheries (2013-18) and the policy document for the agriculture sub-sector have all been influenced by the ACCA approach to climate change understanding and mitigation.

In particular, Dr Mak Soeun, the Deputy Director General of GDA was unequivocal when stating that ‘until ACCA involvement in Cambodian climate change research, it had been difficult to develop a clear understanding of the topic. The combination of ACCA training and communication, biophysical research, systems analysis and potential systems solutions had provided a way forward, allowing the government to develop appropriate responses.’

b) Mainstreaming research results into extension practice

As described, a technical report on response farming developed by the ACCA project team was peer reviewed and approved by a technical panel of Cambodian sector experts in July 2014. It was endorsed by GDA management and then used to support the climate policy initiatives previously described by providing a framework for extension and training in response to climate variability and change.

The response farming approach and extension materials are now used in mainstream DAE and iDE extension activities, and are in widespread use in PADEE and ASPIRE initiatives around the country.

Table 13. Summary of current and potential dissemination of ACCA practices in Cambodia.

Disseminating group	Current reach	Potential reach (3-5 years)
iDE/Lors Thmer	50 FBAs x 40 clients = 2000 farmers; Svay Rieng and Prey Vang	400 FBAs in 5 provinces x 40 clients = 16,000 farmers
	200 FBAs x 40 clients = 8000 farmers; 3 additional provinces	
PADEE	DAE pilot of 29 TOT x 6 FFS x 16 farmers = 96 farmers; Svay Ring	Stated target of 90,000 farmers by 2018 across 5 provinces
	64 CEWs x 3 FFS x 50 participants = 9600 farmers; Svay Rieng	
	432 CEWs in 4 provinces, with possible 4000-20,000 farmers	
ASPIRE	Program commenced in 2015	180 CEWs in 5 new provinces x 30 farmers = 5400 farmers by 2015 Proposed target of 120,000 farmers in 10 provinces by 2021

Note that these are estimates of possible exposure to ACCA components, not estimates of adoption. It is unclear the relative importance of ACCA information in training material being developed for ASPIRE and PADEE.

c) *Informing the design of the ASPIRE program*

An iDE-SNV consultancy used ACCA research and principles as a case study on climate resistant agriculture. This report was used in IFAD's annual strategic planning process as a Cambodia-specific opportunity, which culminated in the development of the ASPIRE program.

Synergies between ACCA research outputs and the proposed climate mitigation research and training outlined in the 2014 ASPIRE project document were highlighted in a commissioned report on the development of ICT tools using ACCA research outcomes (refer to Volume 3, Appendices 7-8).

MAFF officials indicate that Sections 2 (Improving Extension Quality and Knowledge Management), 4 (Infrastructure Supporting Climate Resilient Agriculture) and particularly 3.2 (Innovations for climate resilient agriculture) and 4 of the ASPIRE document had been explicitly influenced by ACCA research, while ASPIRE project consultants suggest that ACCA type research was influential in project design.

8.4 Lao PDR

Country focus

The emphasis in Lao PDR is managing risks associated with high variability of early-season rainfall and end-of-season drought, primarily by introducing dry direct seeding in conjunction with improved varieties and nitrogen management in rainfed lowland rice-based cropping systems of two districts in Savannakhet Province. Savannakhet Province was selected by the Lao PDR team as it has a highly variable wet season, yet is one of the largest producers of lowland rice, and hence is critical for national food security

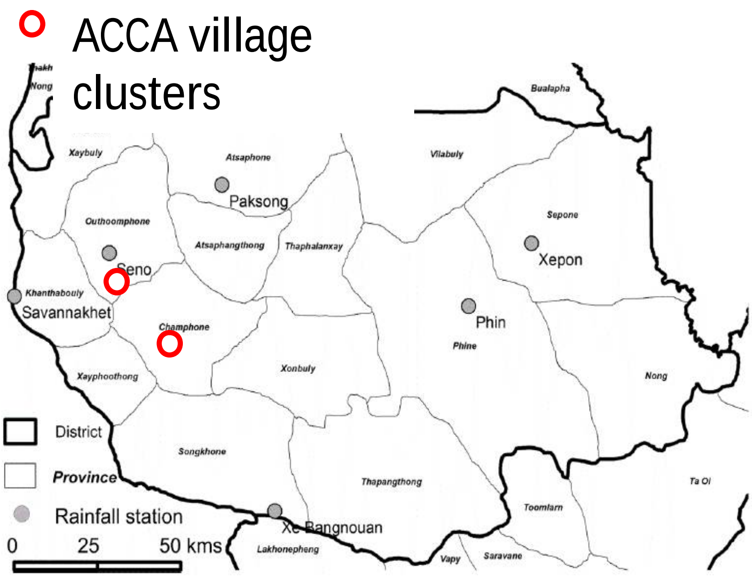
There are two focus districts: Outhoumphone, which is largely dependent on rainfall, with high incidence of drought; and Champhone, which has limited surface water resources for limited supplementary wet season and dry season irrigation in some villages, but is more flood prone.

An additional aspect of the work in Lao PDR was piloting agro advisories (building on the work in India).

In Lao PDR the formal collaborating institutions were the National Agriculture and Forestry Research Institute (NAFRI), the Department for Agricultural Extension and Cooperatives (DAEC, formerly National Agriculture and Forestry Extension Service, or NAFES), the National University of Laos (NUoL), the International Water Management Institute (IWMI), the Department of Meteorology and Hydrology (DMH) and the Provincial Agriculture and Forestry Office (PAFO) in Savannakhet.

Site information

Study villages are located in two clusters. The cluster in Outhoumphone (including the villages of Nonsavang, Phin Neua and Phin Thai) is located on higher toposequences with sandier soils and no supplementary irrigation The cluster in Champhone (including the villages of Toad, Nakham, Vangmao, Nanokkien, Sakheun) is located in an area in which some villages are serviced by a small, poorly serviced, canal irrigation scheme. Lower toposequence sites tend to have slightly heavier soils and some are located in flood affected areas.



Variable and unpredictable rainfall is the main production challenge in these rainfed areas.

Increasing migration of young people and resulting labour shortages brings an additional challenge for many farming households.

Cropping calendar

Nurseries for rainfed rice in lowland Lao PDR are traditionally established throughout June, following land preparation in late May on pre wet season rains (Figure 29 top). Rice seedlings are transplanted throughout July and harvested in late October and November, depending on variety duration, season and labour availability.

When rice is established by direct seeding land preparation begins earlier in the season; in late April and early May. Rice is sown in mid to late May, on early wet season rains and is harvested between late September and November (Figure 29 bottom). Detailed information from farmers about timing of cropping systems is recorded in 2010 and 2011 Trip Reports.

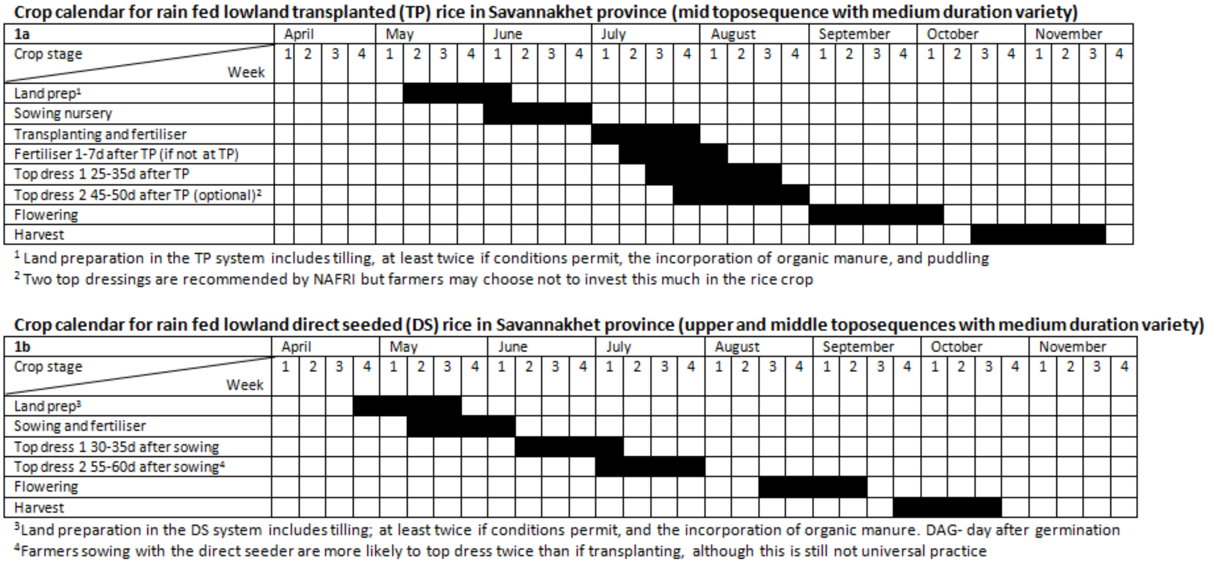


Figure 29. Crop calendars for transplanted (top) and direct seeded (bottom) rice in lowland rainfed Savannakhet

Household types

Household types were developed from household surveys and self assessment workshops across six villages in Outhoumphone and Champhone districts of Savannakhet Province. These types are summarised in Table 14 and explained in more detail in Williams et al. (2015).

Access to irrigation, topographic position (in general high-toposequence soils are poorer) and land size are defining factors of the household types in Lao PDR. Households in low-lying areas are flood prone in the wet season and while some have access to irrigation in the dry season, irrigation water is often expensive (due to high electricity costs) and the decision to pump water is often outside the household's control. Additionally irrigation water often dries up towards the end of the dry season and is often not available at critical times in the early wet season.

Table 14. Summary of household types, Lao PDR.

Type	Key characteristics	Key production constraints
1	Lower and upper lowland; small farms; no irrigation; family-only labour	Land size; soil quality; lack of capital; access to supplementary irrigation, training and equipment
2	Lower and upper lowland; medium farms; no irrigation; family-only labour	Lack of capital; access to supplementary irrigation and marketing information; soil quality
3	Lower and upper lowland; large farms; no irrigation; family and hired labour	High labour costs; soil quality; lack of sufficient water for irrigation and grazing land for livestock
4	Lowland; small and medium farms; irrigation available; family-only labour	Land size; lack of capital; high cost of dry season production
5	Flood affected lowland; small and medium farms; irrigation available; family-only labour	High risk of crop loss due to flooding; limited access to irrigation in dry season; lack of capital
6	Flood affected lowland; large farms; irrigation available; family and hired labour	High labour costs; high cost of dry season production; high risk of crop loss due to flooding

On farm research

The initial emphases of on farm testing were the promotion of improved varieties and the examination of yield response to different fertiliser rates. Ongoing engagement with farmers and extension agents indicated that potentially labour-saving options, such as the dry direct seeder, were of greatest interest to farmers and the seeder formed the focus of later on farm trials.

The success of the on farm testing, in terms of working with farmers to identify and test options of interest to them and in terms of promising results, is demonstrated by the increasing numbers of farmer participants year-on-year in project field trials (with the exception of 2014, where formal farmer participation was deliberately reduced). Additionally informal farmer uptake and use of the direct seeders increased in 2013 and 2014 (this is documented in trip reports from these years).

In 2015, 600ha of land in western Savannakhet, around Champhone and Outhoumphone districts, was sown using direct seeders. This initiative was independent of project activities and demonstrates farmers' developing interest in and enthusiasm for direct seeding arising from activities from ACCA and other projects.

On farm testing activities in the ACCA project concluded in 2012. However early direct seeding trials were sufficiently promising that ACIAR funded the SRA *Regional co-learning in simple mechanised tools for rice planting* (LWR/2012/110), under which on farm direct seeding trials continued in 2013 and 2014. Outcomes from the SRA (named here as the ACCA-SRA) have resulted from the ACCA project and are documented in the a discussion paper on direct seeding prepared by Laing et al. (Appendix 4, Volume 3) .

Adaptation options were tested on farm in the 2011-14 wet seasons across the case study villages (Table 15). Most farms were rainfed: some in Champhone were flood prone and had intermittent access to irrigation from nearby streams (this was haphazard: farmers could not rely on stream water for early-season irrigation and were at greater risk of flooding later in the season).

Table 15. Adaptation options examined in Lao PDR

Adaptation option	Tested on farm	Examined with APSIM
Improved varieties	Yes: 2011 (13 farms)	Yes
Type and rate of fertiliser application	Yes: 2011 (13 farms); 2012 (21 farms)	Yes
Drought and flood tolerant varieties	Yes: 2012 (21 farms)	No
Dry direct seeder	Yes: 2012 (21 farms); 2013[1] (27 farms); 2014[1] (9 farms)	Yes
Supplementary irrigation	No	Yes

[1] On farm testing of the dry direct seeder continued under the ACCA-SRA project in 2013 and 2014

Early on farm testing promoted the uptake of improved varieties (eg TDK8, TSN8) and highlighted the potential for increased yields with fertiliser applications (ie 'improved practice') targeted to measured soil deficiencies. Figure 30 illustrates the largely beneficial effects of these options across three farms in Nonsavang village, Outhoumphone.

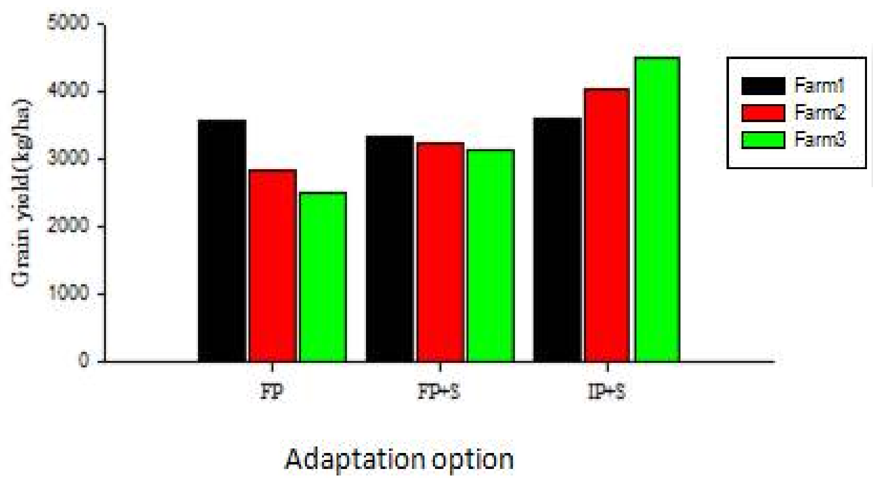


Figure 30. Yields from three farms in Nonsavang village, Outhoumphone, 2011, under farmer practice (FP); farmer practice with improved seed (FP+S) and improved practice with improved seed (IP+S).

The project supported the on farm testing of the drought (TDK11) and flood (TDK1-1) tolerant prototype varieties; these are traits farmers are keenly interested in, as they look to reduce their exposure to climate risks. Both TDK11 and TDK1-1 demonstrated significant weaknesses, including a high susceptibility to the common pest gall midge, and further on farm testing has been postponed until subsequent varieties with greater pest resistance are developed.

As a result of initial on farm testing and farmer interest, crop establishment using the dry direct seeder has become the main adaptation practice explored by the project. Direct seeders eliminate labour required for transplanting: a significant attraction for labour-constrained farmers. In terms of climate risk, use of a direct seeder allows farmers to plant earlier in the season without waiting for standing water – smaller rainfall events in the early wet season are able to trigger germination and crop development (a more detailed explanation of the rationale for direct seeding is contained in Laing et al., 2015, Volume 3, Appendix 4). Planting earlier in the wet season also enables farmers to grow a longer-duration improved variety, which has the potential to improve yields for few additional inputs.

On farm experience with the direct seeder highlighted to farmers and researchers the opportunities (in particular potential labour savings and reduced exposure to climate risks) and challenges (primarily non chemical weed control in the absence of ponded water) of this establishment method. Farmers who managed weeds well had thoroughly prepared land prior to sowing and removed weeds in a timely fashion. While there is interest in different methods of effective weed control to date herbicide use has been limited and is not of interest to most farmers, nor is its use supported by the Lao government.

Modelling scenarios

APSIM has been used to simulate wet season rice production for a present day climate (1971-2011) and future (2021-2040) climates, using the ECHAM5 climate model, representing a milder future climate, and the GFCLCM2.1 climate model, representing a more extreme future climate that is likely to be wetter in tropical regions and drier in temperate regions (Kokic et al., 2011). Key results of the modelling work are presented below.

Two sandy loam soils have been used in simulation modelling: a deeper soil, with greater plant available water capacity (PAWC), representing mid to low positions in the toposequence; and a shallower soil, with lower PAWC, representing the higher or top positions in the toposequence. These soils are representative of most of the low-lying, slightly undulating plains in which rice is grown in the Outhoumphone and Champhone districts of Savannakhet province (Sengxua, pers comm.). In both soils we simulate a puddled hard pan layer in transplanted (PTR) simulations which is less permeable than the comparable layer in direct seeded (DSR) simulations, in which the soil is no longer compacted each year with transplanting.

The standard rice phenology in APSIM-ORYZA was modified to represent a modern improved variety of Lao glutinous rice, TDK8. TDK8 is common across Savannakhet and is one of the most popular varieties chosen by farmers to use in ACCA project field trials.

APSIM was parameterised and calibrated using data from ACCA project field trials in 2011 and 2012, published soil data and expert knowledge from soil scientists, agronomists and cropping systems modellers. APSIM was validated using independent field trial data from 2013 and sensibility testing based on expert opinions.

Baseline simulations represent farmers' risk averse (low input) management practice: a single rainfed transplanted TDK8 crop established every wet season. The crop is transplanted the first time water ponds on the soil surface for three consecutive days; the nursery is sown 30 days before transplanting. Most farmers use small amounts of nitrogen fertiliser (7kgN/ha urea and 0.5t/ha farmyard manure) that are incorporated into the soil at sowing (scenario T1: farmer practice). Some farmers use higher nitrogen rates that are closer to the rates recommended by NAFRI (scenario T2).

For each combination of shallow (S) or deep (D) soil, low or high nitrogen fertiliser rates and climate (present day (PD) or future - GFCLCM2.1; ECHAM5), the following adaptation options have been examined relative to the baseline:

- Switching from transplanting to direct seeding;
- Sowing the direct seeded crop earlier in the wet season (ie into a drier soil) or slightly later (into a wetter soil);

- Applying supplementary irrigation in the first two months after sowing (ie in the nursery and for the first month after transplanting) in instances where no rainfall or irrigation water has been received in the previous seven consecutive days. This is a theoretical option examined in the simulation modelling as opportunities (particularly those around appropriate water storage and delivery) to access sufficient water in a timely manner to enable supplementary irrigation are limited in Outhoumphone and Champhone.

The eight management scenarios examined are summarised in Table 16.

Table 16. Scenarios modelled using APSIM in Lao PDR.

Scenario	Details
T1	PTR, rainfed, low N: this is the baseline scenario for most farmers (farmer practice)
T2	PTR, rainfed, high N
T3	PTR, supplementary irrigation, low N
T4	PTR, supplementary irrigation, high N
T5	DSR, sowing earlier (into a drier soil), low N
T6	DSR, sowing earlier (into a drier soil), high N
T7	DSR, sowing later (into a wetter soil), low N
T8	DSR, sowing earlier (into a wetter soil), high N

Simulation outputs were compared for each adaptation strategy in terms of:

- Yields
- Gross margin (GM), calculated using cost and income data collected from representative case study households
- Yield and GM stability: the standard deviation of yield and GM
- N_2O emission, calculated as kg N_2O per tonne of yield
- C emission, calculated as kg C per tonne of yield.

Note: N_2O and C emissions from failed crops (ie 0t/ha yield) were ignored in emission comparisons.

Yield results

Yield results are presented in the form of probability of exceedance graphs for PTR in Figure 31 and for DSR in Figure 32, for shallow and deep soils (left and right figures respectively). Current farmer practice (T1) shows a high risk of crop failure or poor yields (Figure 31). This is more pronounced on the shallow soils, with about 5% crop failure and 15% of instances with yields <1 t/ha, irrespective of nitrogen rate. On the deep soil this risk reduces to ~2% crop failure; here higher nitrogen rates in T2 are less risky.

Supplementary irrigation significantly reduces the risk of crop failure in both soil types, mainly by avoiding early season drought during rice establishment. The benefit of access to supplementary irrigation is more pronounced on the shallow soils. In terms of overall yield response, increasing the nitrogen rates (T2, T4) has a very significant impact on yields, with median yields increasing over T1 and T3 by about 1.5 – 2 t/ha. This aligns with results from the on farm experiments.

Yield responses for DSR differ from PTR (Figure 32), in that DSR effectively reduces risk of crop failure or low yields. Switching from PTR to DSR will confer a similar risk reduction benefit to that of supplementary irrigation and is a more realistic and attractive management option for farmers than creating the reliable water storage facility necessary for supplementary irrigation. Similarly to PTR, increased nitrogen fertiliser rates (T6, T8) lead to yield increases of about 1.5 - 2 t/ha, but with less risk than in PTR. Also, DSR tends to compensate for differences between soil types, presumably because under DSR, rice rooting systems can explore a larger volume of soil earlier in the growing season.

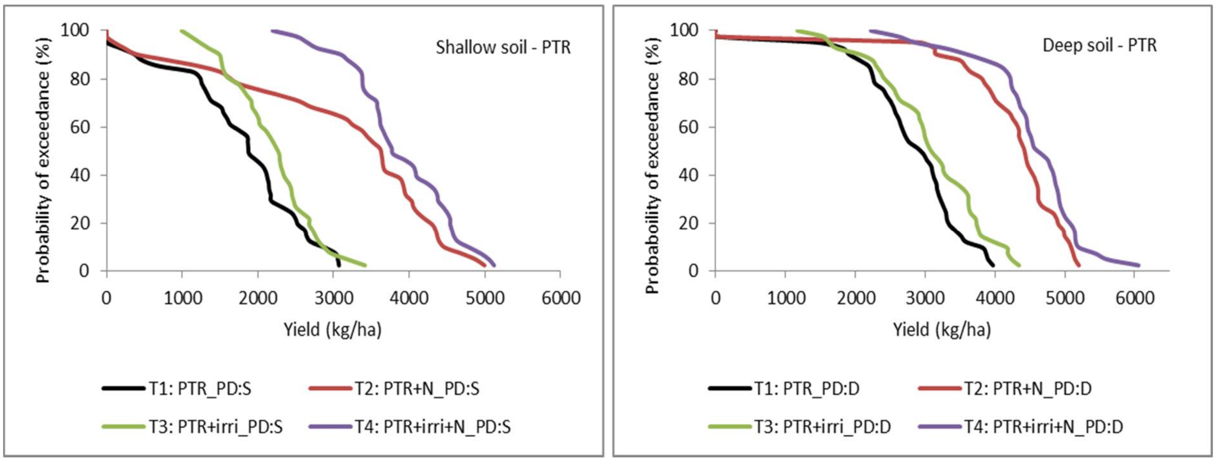


Figure 31. Probability of exceedance of rice yields (kg/ha) for puddle-transplanted rice (PTR), with low and high (+N) nitrogen fertiliser applications and without and with (+irri) supplementary irrigation, for the present day climate (PD; 1971-2011) for a shallow (left) and a deep (right) sandy soil

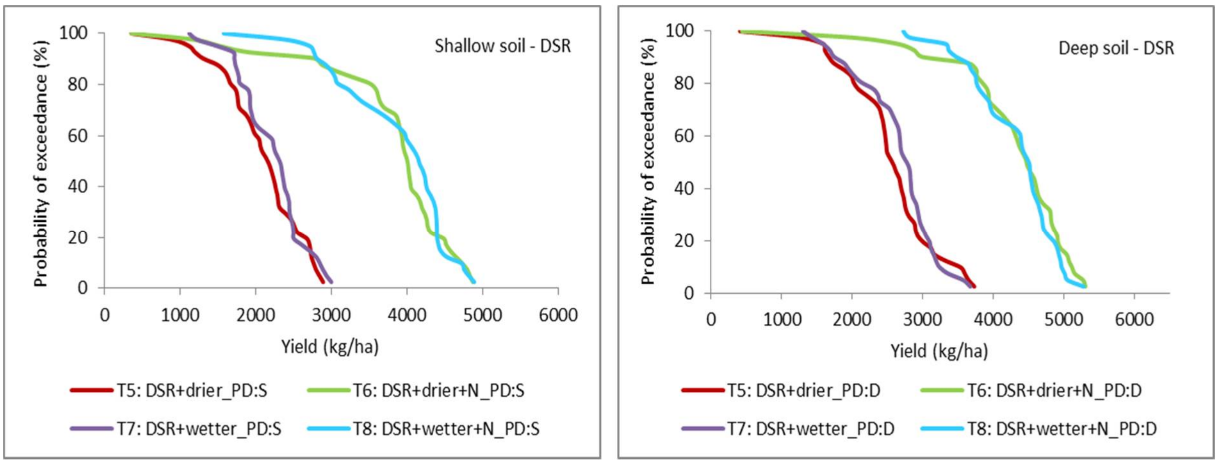


Figure 32. Probability of exceedance of rice yields (kg/ha) for direct seeded rice (DSR), with low and high (+N) nitrogen fertiliser applications and without and with (+irri) supplementary irrigation, for the present day climate (PD; 1971-2011) for a shallow (left) and a deep (right) sandy soil.

Probability of exceedance distributions of rice yield in PTR are compared against DSR for the low nitrogen and high nitrogen cases in Figure 33 and Figure 34, respectively. In both figures, we also compare present day performance with projected yield distributions under a future climate. For clarity, only GFDL results are shown; similar results have been achieved from ECHAM5 simulations.

DSR clearly outperforms PTR on shallow soils, under both current and future climates, irrespective of nitrogen management. In the case of deep soils, DSR reduces risk of crop failures compared to PTR, but otherwise PTR is as good as or better than DSR in wetter years (ie towards the higher yield end of the graphs). The performance differences of DSR relative to PTR under each soil type were observed in on farm testing and have been more generally confirmed by Lao scientists (Sengxua pers comm, Sipaseuth, pers comm).

DSR sown using the wetter sowing rule performs better than DSR using the drier sowing rule in the current climate, reducing the difference between PTR and DSR in wet years. Irrespective of rice establishment method and nitrogen management regime, both PTR and DSR are projected to perform better under a future climate than under today's climate, because of the projected increase in early wet season rainfall in future climates.

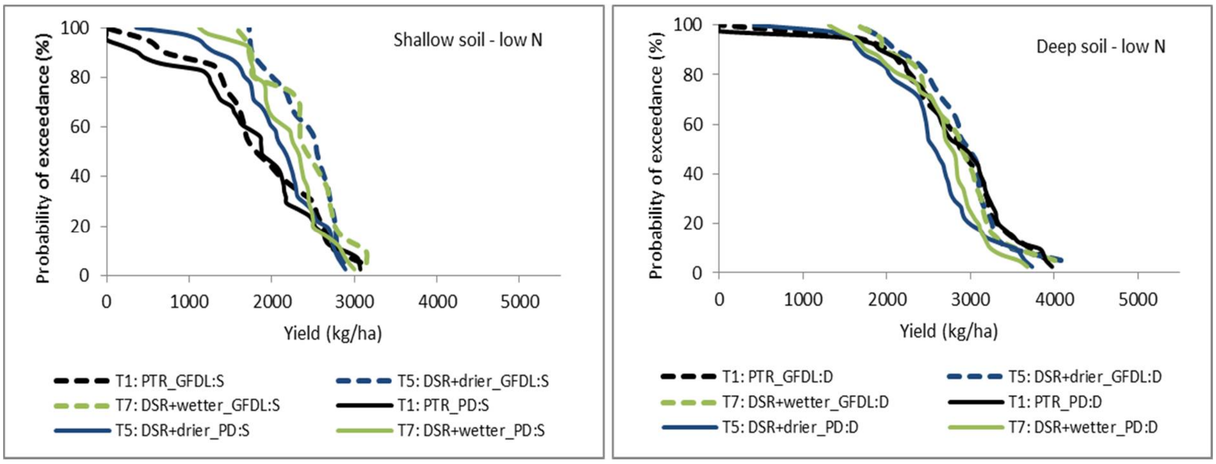


Figure 33. Probability of exceedance of rice yields (kg/ha) on shallow (left) and deep (right) soils for low N rates, comparing PTR (T1) with DSR sown into a drier soil (T5) or a wetter soil (T7), for the 1971-2011 (PD) and 2021-2040 (GFDL) climates

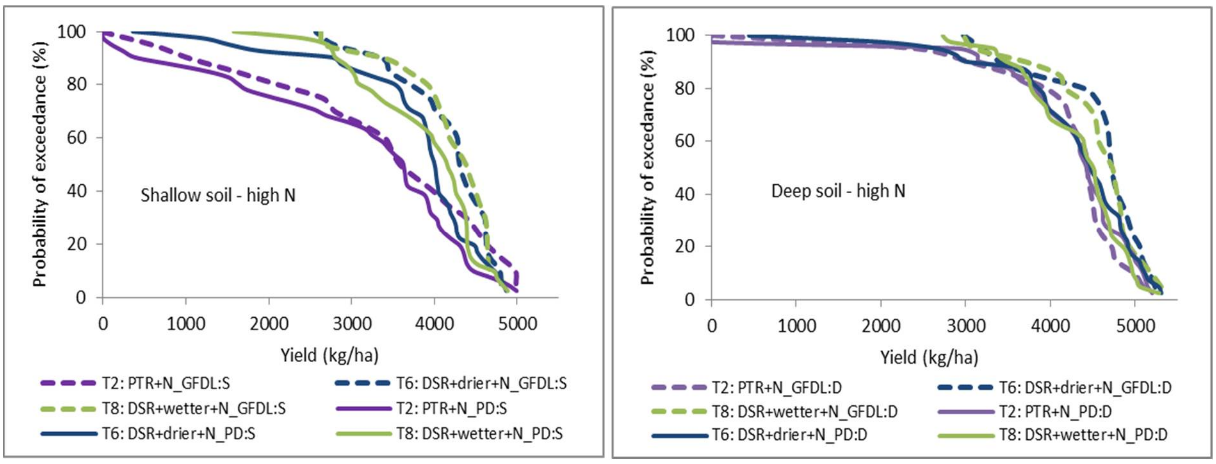


Figure 34. Probability of exceedance of rice yields (kg/ha) on shallow (left) and deep (right) soils for high N rates, comparing PTR (T2) with DSR sown into a drier soil (T6) or a wetter soil (T8), for the 1971-2011 (PD) and 2021-2040 (GFDL) climates.

Gross margin results

Gross margin (GM) results are presented in the form of probability of exceedance graphs for PTR and DSR for low nitrogen treatments in Figure 35 and for high nitrogen treatments in Figure 36, for shallow and deep soils (left and right figures respectively).

In all instances, DSR is projected to generate a higher GM than the comparable PTR treatment. This is mainly due to the reduction in required labour, and associated reduction in input costs under DSR. These differences can be expected to increase with increasing cost of labour.

PTR, as well as DSR sown using the dry sowing rule, will result in years with a negative gross margin: these are in the order of between 5 and 20% of years for PTR on deep and shallow soils respectively, and for about 2% of instances in DSR-dry, irrespective of soil type and nitrogen regime.

Comparing Figure 35 and Figure 36 also shows that the higher nitrogen treatments result in significantly higher GMs in the shallow soils, but less so in the case of the deep soil. However, these results are sensitive to assumed rice prices. As shown by sensitivity analyses conducted by Newby et al., (2013), depending on rice price and wage costs, the benefits of increased nitrogen fertiliser rates can fluctuate significantly.

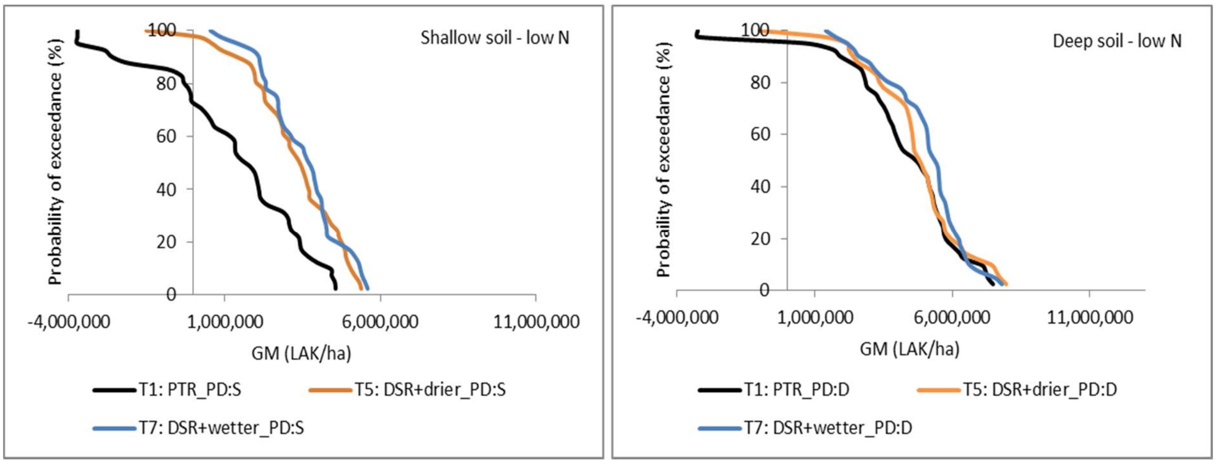


Figure 35. Probability of exceedance of rice gross margins (LAK/ha) on shallow (left) and deep (right) soils for low N rates, comparing PTR (T1) with DSR sown into a drier soil (T5) or a wetter soil (T7), for the present day climate.

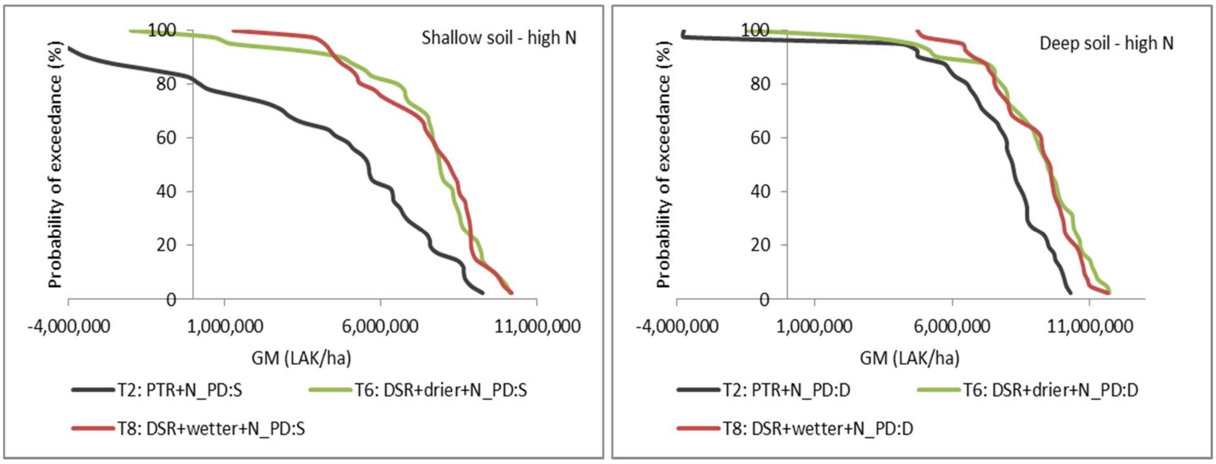


Figure 36. Probability of exceedance of rice gross margins (LAK/ha) on shallow (left) and deep (right) soils for high N rates, comparing PTR (T2) with DSR sown into a drier soil (T6) or a wetter soil (T8), for the present day climate

Sustainability analyses

Sustainability polygons were generated for each soil type and nitrogen treatment; results are presented in Figure 37. For each soil type the different treatments have been compared across a range of metrics, including yield and yield variability, gross margin and gross margin variability, water productivity and water productivity variability, carbon (C) emissions and nitrous oxide (N_2O) emissions.

In general terms, irrespective of soil type and nitrogen regime, the proposed DSR scenarios perform better on most indicators than the relative PTR benchmark. This is the case for both the present climate as well as the GFDL projected climate (simulations using the ECHAM future climate are very similar to those using the GFDL future climate and are not shown here). Hence we can conclude that the proposed adaptation options studied in Laos are unlikely to constitute maladaptive practices and can be considered climate smart.

DSR with high nitrogen and wet sowing (T8) has the highest scores for GM, yield, C emissions and water productivity. However, comparing between nitrogen regimes (ie Figure 37a and Figure 37c, and Figure 37b and Figure 37d, respectively), the low nitrogen DSR scenarios (T5, T7) tend to have better outcomes in terms of N_2O emissions, and the stability of yield, GM and water productivity measures. However, this is partly an artefact of the much larger range in absolute values of the T6 and T8 treatments. Perhaps a more robust measure of yield and GM stability would be to compare the variability between the 20^{th} and 80^{th} percentiles of each sustainability parameter. This will be revisited when we prepare journal papers reporting on these results.

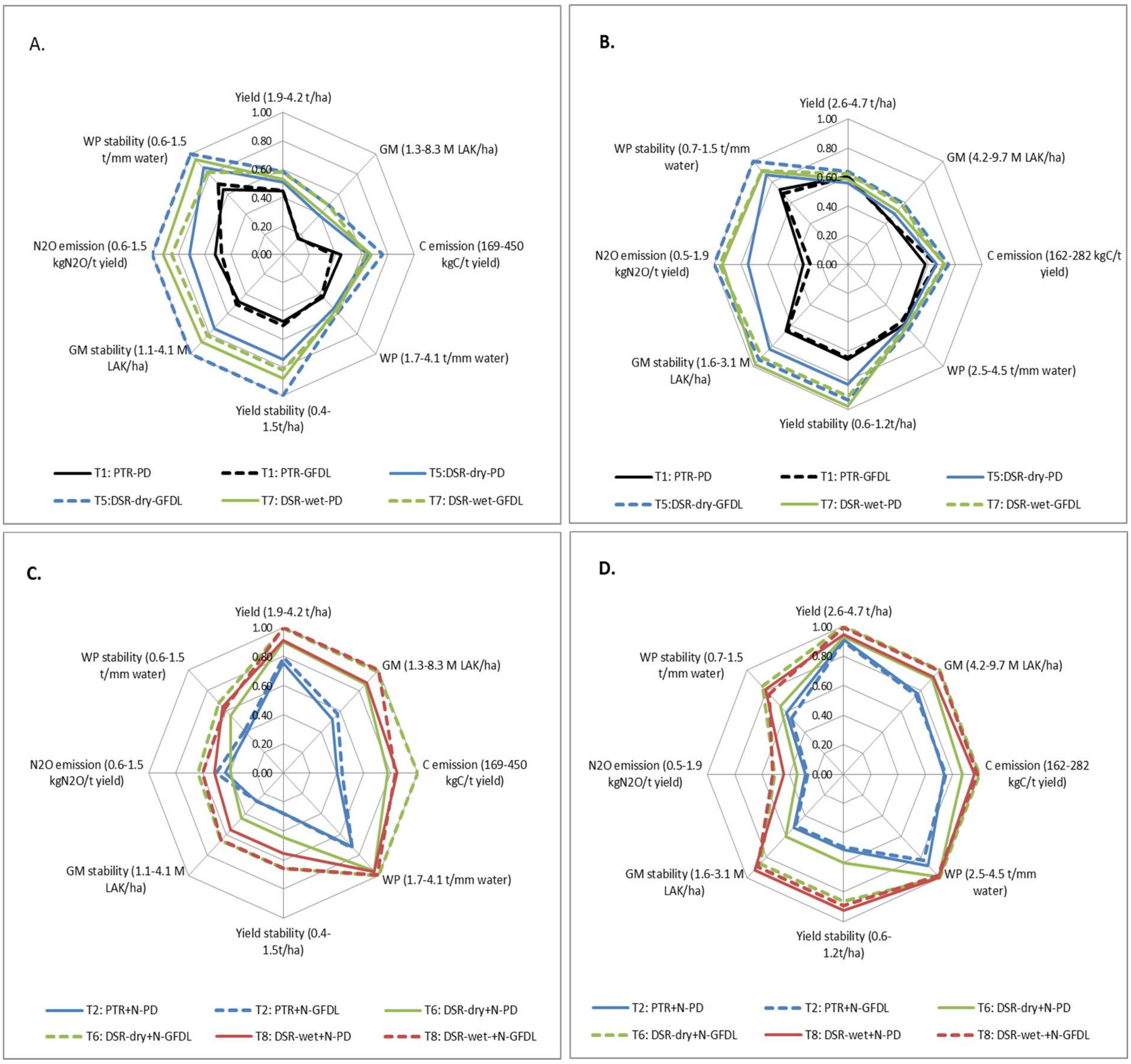


Figure 37. Comparison of yield, yield variability, gross margin (GM), gross margin variability, C emissions, water productivity (WP), water productivity variability, and N_2O emissions, for the 1971-2011 (PD) climate and the GFDL climate. A. shallow soil, low N; B. deep soil, low N; C. shallow soil, high N; D. deep soil, high N

Integration: Dry direct seeding

The initial focus of the project in Lao PDR was on understanding household livelihoods and adaptive capacity and the development of agricultural practices that would support improved rice production in a variable and changing climate.

Adaptation options for on farm testing and scenario analysis were selected after consultation between Lao and CSIRO researchers, extension agents and farmers and were chosen for their potential to reduce farmers' exposure to climate risks, while being mindful of the different capacities and resources available to farming households. Crop establishment using the dry direct seeder became the main adaptation practice explored by the project, as a result of on farm testing and farmer interest. On farm DSR testing which was established under the ACCA project in 2011-2012 was extended and continued in the ACCA-SRA project in 2013-2014.

Sowing with a direct seeder is much faster than traditional transplanting methods: one hectare can be planted in two hours with the DSR, while it takes 20 people one day to transplant an equivalent area. As well as saving time, farmers save the cost of hiring additional labour when planting with the direct seeder. For many farmers, the potential to reduce labour and input costs by using the direct seeder are its primary attractions (refer to Laing et al 2015 in Volume 3, Appendix 4 and for further details).

On farm demonstrations – to raise awareness of the opportunities provided by the seeders for rainfed lowland crops, as well as to highlight their strengths and weaknesses - were successful in the study region and beyond. In the 2013 wet season, in addition to the 51 farmers involved in on farm project demonstrations, PAFO Savannakhet facilitated the use of the seeders in other villages, such that an area of around 100 ha was direct seeded across Savannakhet province. A comparable area of land was direct seeded in 2014 and in 2015, around 600ha was sown in western Savannakhet using DSR. At the conclusion of the 2012 and 2013 wet seasons a series of interviews and structured focus group discussions were held with farmers from participating villages to gather feedback on the wet season overall and on their experience with implementing recommended practices (e.g. Volume 3, Appendix 2). Across all rainfed villages, households noted that their biggest challenge to rice production is adequate and timely water for crop production (this is most commonly adversely affected by poor rainfall distribution and prolonged dry periods), followed by the widespread pests gall midge and stem borer.

Key constraints to increased uptake and use of the dry direct seeder include access to equipment (the number of available seeders), adequate weed management in new cropping schedules, and adequate training and experience using the seeder. The high cost of fertiliser relative to the low rice price also prevents farmers from following recommended land preparation practices (Newby et al, 2013).

While farmers see potential to save labour costs by using the direct seeder they do not necessarily view it as a way to manage climate risk. Regardless of establishment method used, the vagaries of each season will always need to be managed, while well-managed direct seeded rice eliminates labour required for transplanting. Farmers are accustomed to managing climate variability in a transplanted system; with the newer technology they do not yet have the experience or knowledge to adapt to different conditions.

The biggest challenge in the use of the seeder related to weed management, which was exacerbated in 2013 by a relatively dry season and by farmers' inexperience in suppressing weeds without standing water. For some farmers, this negated the benefits of saved labour from transplanting. Despite this, many participants in the focus groups and involved in the field trials were interested to continue to experiment: the ongoing nature of this interest is demonstrated by the continued uptake and spread of DSR after the conclusion of the ACCA and ACCA-SRA projects.

Based on focus group discussions, and given current approaches to weed management, direct seeding was most compatible for households with irrigation (Types 4, 5 and 6) who were able to use standing water to suppress weeds. For those without supplementary irrigation, it was easier for households with smaller land areas to manually manage the weeds. Though this implies it might be more appropriate for smaller households (Type 1), this type was under-represented in focus group discussions, and it would be reasonable to suggest that these households may have more difficulty accessing seeders and training.

Engagement outcomes

A stakeholder plan for Lao PDR was developed in 2011 to guide and prioritise engagement. A summary is given in Table 17.

Investment in stakeholder engagement has been documented in trip reports, annual reports and in the stakeholder engagement report that appears as Appendix 1, Volume 3. Engagement activities in 2013 and 2014 were undertaken as part of both the ACCA and ACCA-SRA projects: outcomes are attributable to both

Table 17. Summary of stakeholder engagement in Laos.

Stakeholder group	Engagement objective	Stakeholders
Project team	Cohesion; capacity	**NAFRI; NUOL; PAFO; DAEC; DMH; CSIRO**
Farming community	Adoption; collaboration	**Participating farmers; other farmers in Outhoumphone and Champhone;** farmers in Savannakhet and other provinces
Research community	Science exchange; access to data; collaboration; synergy of approaches	ACIAR South Lao Project; IWMI; CIAT; IRRI; Savannakhet Univ; **Khon Kaen Univ**; World Vision Thailand; **general researchers**
Provincial/district govt	Planning influence; relevance; dissemination	**PAFO; DAFO;** provincial governors
National govt	Policy influence; relevance; support	Ministry Agric & Forestry; Ministry Natural Resources & Environ; **Dept Agriculture**
Regional agencies, donors, NGOs	Program influence, dissemination, collaboration	MRC; **IFAD;** UNDP; AusAID/DFAT; **LADLF; SNV**

Note: Stakeholders with significant interaction listed only. Bold text indicates the stakeholders with whom ACCA had the most traction (towards the relevant engagement objective) at the end of the project.

Many engagement outcomes are described elsewhere in this report. For example, team cohesion and capacity building are described in capacity impacts (Section 8), while science exchange is covered in the publications list (Section 10). Two engagement outcomes are summarised here - adoption and dissemination of project practices and policy and program influence – as these will form the foundation of the project's sustainability and impact in the region.

Adoption and dissemination of practices

There were four key mechanisms for dissemination of ACCA practices to Lao farmers and extension workers. Estimates of current and potential dissemination are summarised in Table 18.

a) *PAFO dissemination in Savannakhet*

PAFO Savannakhet are a strategy and implementation unit for rural production and development in Savannakhet. With NAFRI and DAFO, PAFO were integral to farmer field trials and demonstrations of the direct seeder in the two study districts.

PAFO also established further demonstration plots and Farmer Field Schools (with provincial and district extension centres), additional on farm testing, a range of communication material and facilitated access for farmers to direct seeding equipment.

In the 2013 and 2014 wet seasons, over 100ha (0.06% of the land available for paddy production) of rice was machine seeded in the province, using only three machines available to PAFO staff. In 2015, 600ha of rice was direct seeded in western Savannakhet, around project field trial sites in Champhone and Outhoumphone districts. The provincial administration is planning to purchase 1000 direct seeders over the next five years, with a potential reach of 5000-10,000ha (3-6% of available land) or 4000-8000 households.

b) NAFRI training

In addition to operational links with the national extension services (DAEC), NAFRI has a remit to provide training at national, provincial and district levels, to research and extension staff, who then provide extension services to farmers and rural communities.

Training focuses in Good Agricultural Practices, incorporating results of research and trials in which NAFRI has involvement. ACCA approaches to direct seeding and use of climate forecast information are now included in standard GAP training workshops and materials across southern Lao PDR. Production of a Lao language training video is now being funded by ACIAR.

c) SNV Climate Smart Agriculture initiative in Khammouane

ACCA's collaboration with SNV began in 2013 with an interest in incorporating direct seeded rice into SNV's Climate Smart Agriculture initiative in Khammouane Province. This evolved into a training package of direct seeding (PAFO and NAFRI), Good Agricultural Practices (NAFRI) and understanding climate (NAFRI and CSIRO), the latter comprising elements of climate monitoring and forecasting and agro-advisories that were successfully trialled by ACCA teams in India.

In the 2014/15 dry season, SNV tested three direct seeders on farms in Khammouane. Farmers were impressed with the seeders and they were then deployed in the 2015 wet season. Additionally, a climate advisory training workshop was piloted in Xaibangfai District in May 2015, with an aim to hold workshops in at least 10 villages by the end of the project in December 2015, resulting in around 500 farmer champions in SNV's focus districts.

d) IFAD training and extension material through SNRMPEP

Technical information from ACCA and ACCA-SRA direct seeder research in Savannakhet has been incorporated into an extensive training manual compiled by IFAD's Sustainable Natural Resource Management and Productivity Enhancement Project. One thousand copies will be distributed in late 2015 to research, extension and academic staff from PAFO, DAFO and universities in the five southern provinces.

SRMPEP have also produced an extension pamphlet that incorporates significant ACCA information. Three thousand pamphlets will be printed and distributed to farmers and extension officers in the 2015 wet season, and 2000 in the 2016 wet season.

Table 18. Summary of current and potential dissemination of ACCA and ACCA-SRA practices in the southern provinces of Laos.

Disseminating group	Current reach	Potential reach (3-5 years)
NAFRI	Six workshops in the course of the project, with 40 farmers in each = 240 farmer champions across 6 villages in study districts	Training plans largely dependent on external funding and government policy needs
PAFO	In 2013/14 over 100 ha in Savannakhet (0.06% of land available for paddy) were direct seeded as a result of ACCA activity. In 2015 600 ha were direct seeded (0.36% available land).	5000-10,000ha (4000-8000 households) over 5 years if Savannakhet administration purchases 1000 seeders (and equitable access can be achieved).

SNV	10 training workshops x 50 farmer champions = 500 farmer champions; Khammouane province	Project funding finishes end of 2015. Future scaling dependent on external funding and the ability of farmers to access seeders
IFAD - SNRMPEP	3000 DSR brochures distributed to farmers and extension in 5 provinces; 1000 training manuals distributed to research and extension officers in 5 provinces	2000 DSR brochures to be distributed in 2016

Note that these are estimates of possible exposure to ACCA components, not estimates of adoption. Engagement is supported by both ACCA and ACCA-SRA activities.

Policy and program influence

a) *Expanding NAFRI response strategy for climate adaptation*

Among NAFRI's strategic aims are the use of integrated research for development to improve efficiency in land use, including agricultural production, and provision of advice to policy makers on the impacts and opportunities for rapid rural change.

Recent changes to NAFRI's organisational structure support this expansion of focus from commodity based research to policy feedback, information provision and methodological development.

Because of the roles of key NAFRI staff, ACCA has supported NAFRI's strategic aims through: a) provision of tools and approaches to understand, monitor and predict climate events; b) provision of policy-specific information on changing circumstances of rural communities in rainfed southern provinces; and c) testing and disseminating promising labour-saving technologies and practices for climate smart rice production.

This knowledge has been used in a variety of fora, including national level climate change working groups, briefings for the Department of Agriculture and Provincial and District Governors and in new international projects on climate resilience.

b) *Changing content and delivery of climate-related extension*

Results from direct seeded rice research have been included in Good Agricultural Practice training activities undertaken by NAFRI, DAEC and PAFO. Importantly, this technological training has been delivered with overarching practical training in monitoring and understanding changes in climate.

Climate monitoring practices include recording daily rainfall, comparing current season to historical seasons using a rainfall visualiser tool and understanding and using agro-advisories and climate forecasting – a training package that has been successfully trialled in the ACCA project in India. This approach is currently used in two ACCA project villages in Savannakhet and in the ACCA collaboration with SNV's Climate Smart Agriculture initiative.

In addition, categorisation into household types undertaken by NUOL and CSIRO as part of the project has recently been used by DAEC and NAFRI to better match extension needs to extension content.

c) *Responding to policy interest in direct seeding*

The Laos-Australia Development Learning Facility (LADLF), funded by DFAT and administered by Adam Smith International, was intended as an innovative approach to link research and policy, by generating information to support decision making by key across a range of thematic areas, including climate change and agriculture.

In late 2014, a proposal for understanding the benefits and drivers for adopting dry direct seeding for rice production was drafted by NAFRI, as the lead Lao research agency. A major stakeholder meeting was convened in November 2014, generating significant interest in the initiative by policy makers and potential donors.

Although a reduction in Australian ODA closed this part of the Facility in early 2015, the exercise demonstrated interest at a policy level in ACCA's research outputs. Subsequently a NAFRI-initiated workshop is planned for late 2015 to garner support and funding for future expansion of the work.

8.5 Synergies and insights across countries

A benefit for the project has been the ability for the project teams to reflect on common themes and insights that have emerged and which have generated new knowledge and synergies between individuals, teams, disciplines and countries. Highlights are discussed in this section.

A key strength of ACCA is that it was preceded by a substantive scoping study that established a common understanding of the project across all countries, built relationships before the inception of the ACCA project, and enabled co-development of the integration framework. This framework was a critical foundation for the project's consistent methodological approach, with local modifications to accommodate partner priorities and capacities.

The common methodological framework meant that individual case study villages in each country (ranging from 3 to 6) could be pooled (n = 15) to allow credible generalisations from diverse socio-cultural environments. In other words, the application of a common integration framework across countries allowed us to generate deeper insights into local context, to develop locally relevant adaptation solutions and to extract higher order principles of greater relevance at the policy level.

From a science perspective, we were able to derive some common results and principles from across the case studies in each country. In some cases (eg HH typologies; applications of APSIM) the results will be easier to publish in high impact journals, as they can be more readily generalised. Common findings across the three ACCA research domains are summarised below and in Table 19.

Table 19. Key common findings across the four ACCA countries

Social research	On farm research	Modelling
Self assessments of adaptive capacity reveal recurring indicators across countries.	Adaptation practices need to address multiple objectives.	APSIM-ORYZA is comprehensively validated and is performing well in contrasting Asian rice environments
Household types and livelihoods analysis identified recurring drivers of change.	A toolkit of management options for response farming can help farmers and extensionists to better manage climate variability.	Range of yields resulting from seasonal climate variability is more significant than under projected climate changes to 2030.

A common framework (with a livelisystems approach) can be developed to explore adaptation options, allowing direct comparison between countries.	Developing underpinning community capacity (eg agro-advisories, weather interpretations) is important.	Adaptations options evaluated are likely to compensate for detrimental effects of average climate impacts by 2030.

Social research

The community self assessments of adaptive capacity were an effective method to explore local perspectives of the impacts and risks of climate variability, as well as the strategies and resources communities felt they needed to adapt. While the indicators for adaptive capacity to emerge from each of the focus group discussions varied, there were a number of common indicators, irrespective of household type and location. These include:

- Human capital: level of education/knowledge/experience; health
- Social capital: being part of a network or group (community or farmer groups)
- Natural capital: access to irrigation water
- Physical capital: livestock
- Financial capital: savings/cash/income/remittances

This synthesis of adaptive capacity results is currently being developed into a journal paper by Brown et al. (listed in section 11.3).

The set of household types was developed around resource access and livelihood strategies in all four countries, leading to four household typologies. Despite the diversity in socio-institutional settings, this analysis exposed major, common trends of agricultural change across all four countries, which point to broad considerations for policy in terms of how to support adaptive capacity.

Smallholder agriculture is sensitive to labour availability, market dynamics and access to inputs and finance. All four countries are undergoing major rural change, with the young generation leaving agriculture where possible. Temporal or permanent migration to take up urban or non-farm livelihood activities is a major factor, mainly driven by economic development, eclipsing any climate change related dynamics (see also Williams et al, 2015). We consistently found in our social research that the concept and timeframe of climate change does not resonate with farmers, and that the common entry point for a discourse with farmers on climate was climate variability, climate risk or climatic disasters.

A clear determinant for farmer uptake of adaptation practices that emerged from the household types is that the opportunity costs of labour are a key factor in the choices farmers make with respect to intensification. Other important factors are related to values and aspirations, not just economic benefits. In effect, we found across all countries that there is a growing dichotomy between those households that are engaged in rice growing primarily for food self-sufficiency (and earning income through other livelihood activities) and those becoming more market oriented and who see rice cropping as a means to derive an income.

Two key challenges for the social research team has been the limitation in the household types of capturing the temporal dynamics of household livelihoods from year to year, and finding a common framework to allow comparison of types across countries (rather than discussion of broad trends. To address these, the team has brought together two approaches: Dorward's (2014) livelisystems framework and Impredicative Loop Analysis (Giampietro 2004).

Dorward's livelisystem framework helps define 'meta-types' that can be considered common across the four case studies (Table 20). This meta-typology helps to understand the commonalities among rice farming smallholders in Asia based on a general tendency or trajectory. It also serves to narrow down the target population for development interventions (technology, practice change, infrastructure development, institutional reform) to those farmers likely to remain in farming, while identifying alternative mechanisms and interventions for those who are either struggling to remain in agriculture, or who are deliberately looking to exit.

Table 20. A meta-typology applying Dorward's (2009, 2014) framework to ACCA household types

	Hanging in (status quo)	**Stepping up** (increase of activities/assets)	**Stepping out** (new activities / assets)	**Falling down and out** (failure to maintain)
India	Resource poor, social capital low, subsistence oriented	Family labour, mixed resource base, diversified, willing to intensify production	Diversified, willint to specialise/ move out of ag, invest into education	Landless, competition with other industries draws households out of agriculture
Bangladesh	Low resource base, remote	Diversified, high social capital, market access	*Landless* → migrate to other areas *Wealthy* → non-farm business	Marginalised, social capital low, high salinity, landless or remote
Cambodia	Low resource base, no irrigation	Supplementary irrigation (at least potential), potential to diversify/intensify	Debt and small land size → migration	
Laos	Low resource base, limited family labour, no irrigation	Large land size or irrigation, non-farm or migration	Migration / non-farm can lead to giving up agriculture	Non-sufficient, agriculture is subsidised by migration
	→ "smallholders"	→ "farmers of the future"	→ "migrants or rural businesses"	→ "proletariat"

Analysing these meta-types via the lens of Impredicative Loop Analysis (ILA) allows us to compare the relationships and trade-offs between key resource variables. Land and labour are crucial to be able to conduct farming; water and income determine *how* land and labour can be used and applied.

A representation of the difference between a 'hanging in' type (orange shading) and 'stepping up' type (grey shading) is provided in Figure 38. A subsistence household (hanging in type) might have just enough farmland to feed the family, just enough labour to work the available land, income to cover agricultural inputs, and rely on rainfall. In contrast, a stepping up type may have the option to lease additional land, have surplus labour to pursue alternative income activities and income to invest in irrigation. This framework has been tested in two international forums (section 11.3, paper 55 and 56) and a paper is currently being prepared (section 11.3, paper 9).

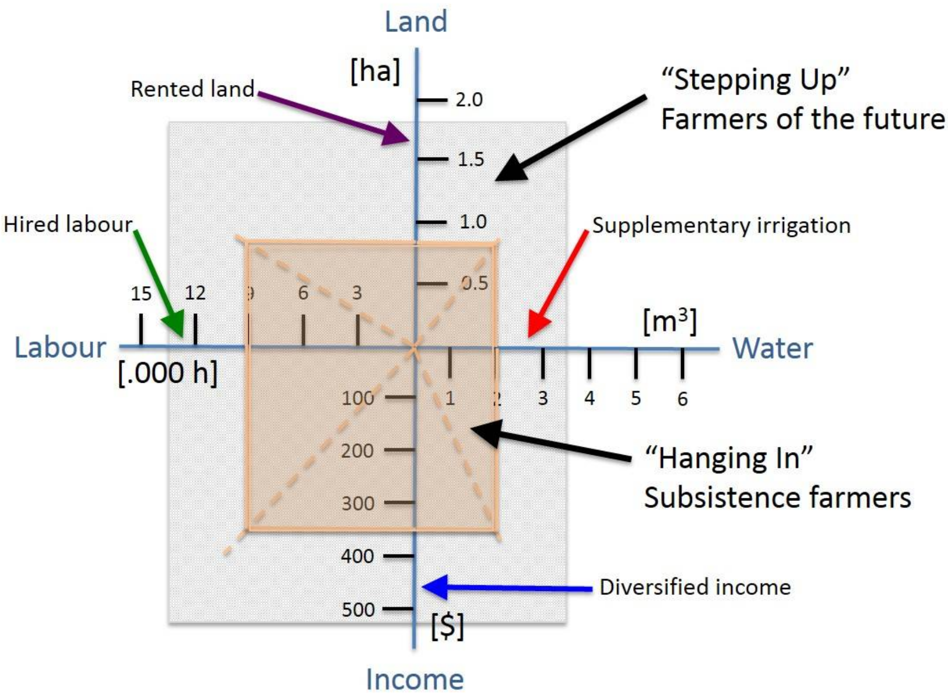


Figure 38. ILA of critical resources among rice-farming households. Two types of households (Hanging In and Stepping Up) are plotted against four resources (adapted from Giampietro 2004).

On farm research

A key learning from ACCA was that adaptation practices needed to address multiple objectives to be relevant and attractive to farmers. It was therefore important when designing strategies for future climate scenarios that current conditions and priorities are considered eg labour shortages; climate variability and risk.

The impact of current climate variability emerged across all countries in different ways, giving emphasis to the concept of response farming – having a toolkit of options to choose from in response to how a season progresses, rather than adhere to a strict set of management rules. For this to be effective, it was necessary to invest in developing the capacity of farmers to use the toolkit eg using agro-advisories, interpreting local and scientific measures of weather.

The response farming concept emerged initially from the work India and Cambodia. In India, it was catalysed by the agromet advisories and training farmers to collect and interpret their own weather data using rainfall visualiser tools. In Cambodia, the response farming concept evolved from the new flexibility in the cropping systems brought about by the combined use of direct seeding techniques and access to short duration rice varieties.

The concepts were explored and refined individually, but over time there was a productive cross-fertilisation between countries, reflecting a wide range of skills and experiences from across the ACCA teams. In Lao PDR the lessons in Cambodia are being adapted and trialled by NAFRI and PAFO colleagues in Savannakhet. Similarly, positive experiences with the dry direct seeding in Lao PDR have been incorporated into Cambodian initiatives that initially focused on wet direct seeding using drum seeders. The ability to initially pursue different routes and solutions to a similar problem, and then to merge these experiences allowed for a more varied exploration of the response farming concept, providing depth and richness of insights.

Initially the development and testing of agromet advisories was planned only for India, due to the already well developed seasonal weather forecasting system of the Indian

Meteorology Department. It became evident to the Lao PDR team that there were elements that could be readily adopted in Lao PDR, to support a pilot system to convey seasonal climate information to farmers. In theory the principles developed in India could also be used in Cambodia or Bangladesh, but in those countries generation of short range weather forecasts at high spatial resolution is not yet sufficiently reliable for similar approaches.

Participatory on farm research was new to many research partners. In some countries ongoing monitoring proved challenging, particularly where partners had long distances to travel to field sites or fields were unexpectedly affected by floods, and as a result, some of the datasets were incomplete. Nonetheless, a primary benefit in all countries was that on farm research provided an effective mechanism for researchers to connect and collaborate with farmers.

Modelling and scenario analysis

Application of APSIM-ORYZA across the four countries enabled a more rigorous testing and validation than would have been possible in single projects. APSIM-ORYZA was found to perform satisfactorily in contrasting ACCA environments eg the irrigated wet season rice grown on Indian vertisols; Cambodia's rainfed systems grown on low fertility duplex soils, with or without supplementary wet season irrigation; Bangladesh's rainfed (Khulna) or fully irrigated (Gazipur) systems on young, high fertility alluvials, with or without salinity.

Through the partnership with the SAARC-Australia project, this already wide range of site conditions was further broadened by a suite of additional sites across South Asia (Gaydon et al., in prep; Volume 2, Appendix 1), consolidating our confidence in APSIM-ORYZA's performance. In 2012, this created the opportunity for APSIM-ORYZA to be included in the Agricultural Model Intercomparison Program (AgMIP), where APSIM-ORYZA has consistently performed as well or outperformed most other rice crop models.

The modelling effort in ACCA required a large team of modellers, bringing a diversity of modelling skills to contribute to solving particular parameterisation or model application problems, as well as enabling a broad 'peer review' of model parameterisations prior to scenario analysis. An example is the development of sophisticated planting rules in APSIM's Manager module. This was a common problem to Cambodia, Lao PDR and India, and the pooling of coding approaches enabled the development of *what if then* logic that was efficient and versatile. Apart from greater efficiency, this enabled a substantial deepening of rice modelling skills within CSIRO, which is contributing to spill-over benefits to other ongoing (eg SRFSI) or potential future ACIAR projects (eg work in the coastal zone of Bangladesh).

The multi-country team approach also allowed the ACCA modelling team to develop shared methodologies that facilitate consistent comparison across the four countries. These included the use of crop calendars for depicting farmer adaptation options, and sustainability polygons for depicting the multi-faceted evaluation aspects that were used to compare adaptation options.

With respect to scenario analysis, an unexpected result across all four countries was that, at least until 2030, in many instances current cropping practices are not anticipated to show major climate change induced yield declines. Seasonal climate variability tends to be more significant than the projected changes in climate change. In other words, the range of current yields is significantly larger than the possible downwards or upwards shift in median yields under 2030 climates.

Most of the adaptation practices tested tended to perform as well as or better in a future climate. This suggests that finding ways to cope with today's climate variability gives farmers the best chance of protecting against future variability and our modelling indicates that there is scope to reduce climate-induced variability in yields, now and in the future.

The consistency of this result across the four countries (with some exceptions, eg *boro* rice in Bangladesh) is in contrast to many published results presenting a more pessimistic scenario, with a range of papers predicting yield reductions in rice of up to 40%, and losing sight of the opportunities offered in better managing current climate variability.

There are several possible explanations for this:

- Many past climate change impact modelling studies have used business as usual scenarios; in reality farmers adapt;
- Often models have not been parameterised to reflect specific locations or specific farmer crop and water management rules, and in even fewer instances have models been validated independently prior to use in scenario analysis;
- The CO_2 – temperature – evapotranspiration interactions are not captured well enough in some models (as shown by the AgMIP rice modelling results).

Other technical conclusions that can be drawn from across the four countries regarding adaptation to 2030 climate conditions include:

- Advantages of modern short-season varieties
- Advantages of early sowing
- Value of direct seeding in achieving labour imperatives and in minimising climatic risks associated with grain production.
- Gains from improved nitrogen use efficiency would be universal and further research into this aspect is recommended in individual regions.

Some adaptations we explored were ‘climate smart’ when comparing production increases and greenhouse gas emissions (eg alternate wetting-and-drying irrigation in rice), and others were not.

The adaptation simulations across the four countries illustrated that different (modelled) adaptations result in outcomes, that require trade-offs. Therefore adaptation options need to be assessed against all of these criteria before their promotion as good options for extension. In different situations, different indices could need to be weighted differently.

For example, in some environments increased recharge could be a major restricting factor for uptake of a given adaptation, regardless of its production benefits. In other environments, increased recharge could be of much less concern.

The summary message from our research is that the framework we have presented for comparative (‘climate smart’) assessment of adaptation options is a tool worthy of wider application, and that adaptations must be considered on a case-by-case basis.

The recognition that managing climate variability better in the present offers a more viable approach to dealing with climate change in the face of an uncertain future climate allows for a less alarmist framing of adaptation responses. However, we caution that the downscaling approach used does not fully take into account a change in frequency of extreme events; it is more a reflection of ‘average’ changes to climate parameters.

Finally, modelling scenarios were conducted for the near future (2030). Whilst the majority of our adaptation scenarios indicate that incremental change will compensate for potential yield declines as a result of climate change, it is likely that in some instances these incremental changes will not be sufficient to retain livelihoods and sustain productivity.

In these cases, transformational adaptation strategies will need to be developed that encompass step changes to farming (or livelihood) systems, requiring sustained policy support. An example is the value of providing access to irrigation in Cambodia, enabling a broad based system change from single cropping to double or more cropping.

8.6 Lessons learned

This section summarises reflections from the project teams on ACCA's design and operations, and aims to extract a set of considerations for similar future initiatives. Key elements are summarised in Table 21.

Co-developing an integrated framework

A key learning was the importance of creating an integrated, jointly owned research framework in the early stages of the project. This arose from recognition that recent advances in the field of adaptation science were based on an effective interdisciplinary approach to design and implementation that incorporates input from all relevant science domains.

ACCA's framework, incorporating social science, anthropology, climate science, agronomy and farming systems science became a cornerstone of the project. Key determinants of success include the *a priori* involvement of all disciplines in co-designing the project and adequate resourcing to support sufficient in-depth exchange and engagement.

In part, this was made possible by an initial investment by ACIAR in a significant scoping and design phase as a precursor to this project. To this was added the creation and maintenance of a working environment that embraces and promotes diverse disciplinary views and approaches. This was a significant investment of human resource, initially driven by project management and ultimately acknowledged and adopted by project teams.

Planning, reviewing and adapting

Regardless of how well a research project has been contextualised and conceptualised, without detailed planning and sound project management there is a significant risk that objectives will not be met. In the case of complex, multi-country, multi-partner and multi-stakeholder projects a project theory of change needs to be underpinned by detailed work planning. For ACCA, detailed planning and review of milestones and timelines also became a mechanism for team integration, by clarifying roles and responsibilities, confirming institutional and individual commitments and sharing and acknowledging progress and success.

Workplans were regularly reviewed and updated, which was considered time consuming and arduous early in the project. However the principle of adaptive management (planning-doing-observing-reflecting) was maintained and became more efficient and useful as the project progressed. The tension between formal planning and retaining flexibility became a key feature of the project and allowed us to both pursue opportunities and to embrace diverse perspectives.

Specific areas that were lacking in the ACCA design include data management, gender analysis and a systematic, quantitative monitoring and evaluation of impact.

Emphasising participation and engagement

The project combines crop modelling and field experiments with strong farmer participation. Possible adaptation practices are developed through on farm experimentation, the results of which are used to inform scenario analysis to test the long term viability of adaptation options against location specific climate change projections, which in turn inform a further selection of viable adaptation practices to include in the next round of modelling and farmer validation.

In practice it has proven challenging to fully implement such adaptive learning cycles between farmers and scientists. A key impediment is capacity limitations of collaborating extension agencies, which precludes effective community and farming household engagement. Partnerships with NGOs was felt to be a very positive aspect of the project, as NGOs tend to have stronger community level presence and complementary networks and skills to research agencies. Experience in India and Cambodia with WASSAN and iDE (compared with Bangladesh and Lao PDR, where we do not have NGO collaborators), supports this conclusion.

Similarly, explicit participation was sought from policy, research and development stakeholders, to ground the research in local context and need, to align project activities to existing or upcoming initiatives and to provide a springboard for future collaboration and sustainability. This participation was guided by a stakeholder engagement plan that maximised opportunities for impact, prioritised actions according to the research plan and progress and relied on feedback, review and adjustment.

The concept of scaling local-level insights (eg combining household typology development based on indicators, with self-assessments obtained from collaborating households) has been critical to connecting with policy development discourse, thereby ensuring research results can be applied at community and policy scales. In practice the development of typologies has also been a vehicle for interdisciplinary discourse. Typologies that are co-developed by social and biophysical researchers become the medium for interaction and more relevant and nuanced research results.

Investing in partnerships and people

It took some time for partnerships within and between project teams to develop. This is partly due to not having a history of working together, partly due to having different modes of operation, disciplines and institutional culture. While relationships between country teams strengthened (and in many cases continues outside the project), there was a recommendation that more cross-country discipline-based interactions would have been beneficial to both project outcomes and individual development.

The issue of partner institute expectations was raised. Bangladesh’s role in the project is a clear example of where contractual commitments (eg primary role of APSIM parameterisation and model development) did not necessarily align with partner expectations (eg iteration of modelling, generation of adaptation options and farmer engagement).

There is a sense across the project teams that investment in relationships and capacity (in addition to design elements already discussed) led to a strong commitment to project objectives and principles – this is evidenced by very little attrition of project staff from the start of the project, and ongoing inter-institute collaborations after the project. In addition, ongoing commitment of staff time meant that integration could grow, investment in capacity could be realised by the project and that specific activities could be tasked rather than shared (eg project coordination, stakeholder engagement).

Creating momentum for sustainability

Setting clear aspirations for scaling and sustainability of project outcomes was considered as important as creating the flexibility to seize opportunities as they arose. In this way, the dual drivers of dissemination of project practices and influence on policy and programs guided research outputs and stakeholder interactions.

In Bangladesh, there is a critical mass and of modelling capacity and institutional support that will continue after ACCA. In Cambodia, sufficient collaboration and momentum has been created by ACCA in policy, donor and community arenas that will sustain significant dissemination and adoption by farmers. In Laos, positive research results and motivated provincial and federal teams are the foundations of ACCA scaling outcomes. In India, the development and refinement of a beneficial, replicable and fundable mechanism for sharing results and information is the foundation of broadscale agricultural development.

Table 21. Influential elements of ACCA design and operations

Principles	Process and methods
Multiple disciplines/ perspectives essential to project	Time to foster and build relationships Strong project leadership
Adaptive learning / planning	Flexibility / ability to follow opportunities
Acceptance of cultural differences	Participatory action research
Mindful of capacity and competing demands	Informed by scoping study
Guided by common framework	Design of methods (eg modeling, household types) to encourage cross-disciplinary dialogue
Line of sight to pathways to impact	Clear expectations (shared understanding and ownership via work planning process)

9 Impacts

9.1 Scientific impacts – now and in 5 years

The development and application of the project's integration framework, linking social research with biophysical research, has fostered a number of initial science impacts. With a lag between publishing of scientific papers and subsequent use/impact, published papers, invited papers and presentations are listed as a proxy for scientific impact in Sections 11.2 and 11.3.

The approach and findings of ACCA has generated interest from other organisations and institutions, reflected in the invited participation in workshops and conferences listed below. In each case these have resulted in positive institutional reactions and discussions

- Invited to participate in design of umbrella program on Climate Change Adaptation and Mitigation in Southeast Asia for the South East Asian Regional Centre for Graduate Study and Research in Agriculture (SEARCA) in Hanoi, May 2015. Lessons and insights from ACCA were used to inform goal setting and program design in SEARCA as part of this process.
- Invited participant to workshop on Sustainable Intensification of rice based systems in the lower Mekong region, convened by the University of Sydney. Discussions are currently underway to design a new project incorporating some of ACCA's approaches with USyd as a result of this workshop.
- Presentations on ACCA methodology and results at the Indian Agronomy Congress 2012; at the Climate Change and Regional Response 2013 Conference in Germany in 2013; and at the East Asia Summit Climate Change Adaptation Workshop in Delhi in 2013;
- Presentation of adaptation research design principles at the First Global Conference on Research Integration and Implementation in Canberra in 2013.
- Invited presentations of the ACCA integration framework at an IRRI-FAO workshop in 2010 and to an IRRI Rice workshop in 2011; Invited presentation of broader adaptation research concepts at the Khon Kaen University community adaptation conference in 2010;

The project leader was invited to be part of an independent evaluation team charged with reviewing CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) in 2015. This provided a unique opportunity to benchmark ACCA against CCAFS research, identifying a number of domains in which ACCA is leading (eg taking a livelisystems approach to adaptation; linking HH typologies to on farm research; multiscale approaches to bridge local and policy levels; systematic application of modelling to evaluate adaptation options into the future), as well as identifying areas where CCAFS is leading (eg the Climate Smart Agriculture framing of adaptation; crop insurance and social safety nets; ICT based methods of dissemination of advisories to farmers). As a result of this interaction, there has been significant exchange of information between ACCA and CCAFS researchers in India, Lao PDR and Vietnam.

The ACCA project was also used as a case study for an internally funded review within CSIRO Agriculture which aimed to explore the principles and practices for impact in large, multi-scale agricultural research for development projects. This review is expected to inform CSIRO's approach to R4D projects into the future (Stone-Jovicich et al 2015).

Interactions with the Earth Observatory of Singapore, the Southeast Asia Disaster Prevention Research Institute, and the Asian University Network for Environment and

Disaster Management in 2011 led to ACCA's inclusion as a case study for regional climate change adaptation and an invitation to submit a paper to a Special Issue of the *Asian Journal for Environment and Disaster Management* (Roth and Grünbühel 2012). This special issue formed a key contribution to the regional assessment of adaptation activities in the Mekong region undertaken as part of the IPCC 5th Assessment Report.

The application of APSIM-ORYZA to rice, and rice in rotation with other crops has gained validation testing in wide range of South Asian environments, and now has a solid grounding. The above achievements placed APSIM-ORYZA on the South Asian map and have laid the foundation for a number of science impacts, listed below.

The modelling philosophy employed in this project (rigorous parameterisation of APSIM-ORYZA using location-specific data) and use of the model to systematically explore crop responses to a range of more complex management interventions has been recognised by the International Maize and Wheat Improvement Center (CIMMYT). As a result, researchers in CIMMYT involved in the design of ACIAR's new flagship program in the Eastern Gangetic Plains (SRFSI - Sustainable and Resilient Farming Systems Initiative) have worked with CSIRO to embed modelling as a major component in this new initiative, to underpin choices of technologies, and to conduct additional research to improve process representation in APSIM.

A series of APSIM-ORYZA publications has been produced by the CSIRO, Bangladeshi and IRRI teams. These and conference papers are listed in Sections 11.2 and 11.3. The earliest of these manuscripts are beginning to gather journal citations (eg Gaydon *et al.* (2012a) already has 12 citations and Gaydon *et al.* (2012b) has 14).

The strengthened capability of APSIM has had flow-on effects through ACIAR project LWR/2010/033, which built scientific capacity within SAARC agricultural research organisations to undertake more effective research using modelling-supported systems approaches. The SAARC-Australia project has been a significant multiplier of ACCA's model innovations and has established the foundations for a future functional network of cropping systems modellers in Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka.

In 2012, the increased visibility of APSIM-ORYZA through both ACCA and the SAARC-Australia project as a reliable rice cropping systems model created the opportunity for APSIM to be included in AgMIP, where APSIM has consistently performed as well or outperformed most other rice crop models. As a result, APSIM is now being used much more widely in South and Southeast Asia, which in turn increasing the number of APSIM users in the region. A recent impact is a request from ICRISAT for APSIM simulations for cotton, maize and rice to form part of a proposal for funding under the National Adaptation Fund for Climate Change to upscale ACCA results in India.

Field protocols developed by the ACCA project teams are now being adopted by other groups and perceived as practice standards. For example, in Cambodia, ACCA protocols are already being used by iDE in the five PADEE provinces and the USAID Harvest Program in Siem Riep province and by the private sector in Battambong province (through Asea Agri Group).

Whilst the definition of household types *per se* is not novel in social sciences, the application of household typologies undertaken by ACCA to underpin biophysical research and to contextualise farmer decision making and choices against the backdrop of rapid rural change is new. This approach is now being replicated in a number of other ACIAR projects, e.g SRFSI (CSE/2011/077), the Vietnam climate change project (CLUES project - SMCN/2009/021) and the Myanmar livelihoods project (ASEM/2011/043).

A series of methods papers have already been published or are being finalised to articulate the project approach, including reflections on the social science framework (Williams et al 2013; Grünbühel et al *in prep*), the integration framework (Roth et al. 2010; Roth and Grünbühel 2012; Hochman et al. *in prep*), design principles for adaptation science (Roth et al. *in prep*; Clarke et al. *in prep*), case studies of the household types approach (Williams et al *in prep*) and constraints to household adaptive capacity (Brown et al. *in prep*).

Continued academic exposure through publications and conferences is expected to yield changes in the approach and practices of other research groups. A recent example of this is the degree to which integration learnings and approaches from ACCA have provided a strong foundation for the design of a new ACIAR project on social inclusivity of agricultural intensification (LWR-2014-072).

9.2 Capacity impacts – now and in 5 years

During the first two years of the project, considerable effort was invested in training activities to achieve project milestones. A summary of significant training activities appears as Appendix 9.2 in this volume. These include training in: soil and crop monitoring methods, systems modelling, seasonal climate forecasting, social methods, agricultural extension and use of project equipment such as dry seeders and climate equipment.

Beyond project milestones, the project has initiated three intensive training courses in APSIM, farming systems, and extension methods with support from the Crawford Fund. Using the Australian broadacre cropping and rice industries as case studies, workshop participants (from all project countries) were exposed to production drivers, infrastructure, research approach and techniques and advanced modelling.

Enhanced capacity and experience gained from involvement in ACCA are now being widely used outside the scope of the project. Details of how these are being embedded into new country initiatives are summarised in the engagement sections of the country chapters in Section 5. Additional examples include:

- *Laos*: Training of technical personnel in the Lao PDR Department of Meteorology and Hydrology (DMH) in the use of a range of forecasting tools has improved the way in which DMH prepares its seasonal climate projections provided to the Ministry of Agriculture and Forestry and other national government institutions in Lao PDR.
- *Bangladesh*: Training in the use of the Sustainable Rural Livelihoods framework to assess household adaptive capacity enabled the SERDI team in Bangladesh to bid for and conduct a similar World Bank funded study in other parts of Bangladesh.
- *Laos*: Ideas generated in the ACCA project (eg better ways to establish and monitor demonstration sites) have been used in training to district agricultural officers and in other climate resilience projects such as the UNDP's Improving the Resilience of the Agriculture Sector project.
- *India, Bangladesh*: Enhanced crop modelling skills have resulted in invitations for the project teams to participate in AgMIP projects.
- *Cambodia*: World Vision became aware of CARDI's modelling capability from recently published scientific literature and approached the team to collaborate in a proposal for USAID funding.
- *Bangladesh (IRRI)*: Experience *on* integrated and iterative research approaches led IRRI staff request to review a major new climate initiative in Madagascar.
- *Bangladesh*: Through key personnel, ACCA practices have influenced CSISA trials (eg double cropping, BR23 variety) in medium salinity cropping systems, impacting more than 1000 farmers in southwest Bangladesh.

A significant and growing impact of the ACCA project has arisen from the increased modelling capacity in agricultural institutes of Bangladesh. The ACCA experimental trials at Dacope, Satkhira and Gazipur were the first shared experiments between BRRI (responsible for rice research) and BARI (responsible for other crops). Because ACCA was defined as a cropping systems research initiative, it required research on rice and other crops (eg maize, mungbean, cowpea, mustard) as part of a system. For the first time, BRRI and BARI staff shared experimental duties and facilities to conduct ACCA trials, resulting in greater shared understanding of systems issues and the value of working across institutional boundaries.

With the SAARC-Australia project, ACCA initiated the 'Bangladeshi Modelling Group' (BMG) – a network of BRRI, BARI, and IRRI Bangladesh scientists keen to develop their skills in crop systems modelling. The original five members of this group attended APSIM training in Australia, and there have been several subsequent groups travel to Australia for training.

In August 2013, the group achieved a major milestone by conducting their first own in-country APSIM training session for other BRRI and BARI staff, completely unsupported by the Australian team. In April 2015, the BMG had grown to 28 members and a training workshop and Modelling Symposium held in Dhaka illustrated the progress of the group to high level managers in BRRI, BARI and BARC.

There are strong indications that the group will continue to grow as a self-sustaining entity, including:

- Steady growth in the number of scientists using APSIM and attending monthly BMG meetings, and growth in the range of projects in which APSIM is being used independent of ACCA, SARC and other ACIAR investments.
- Group members providing training to new members through three independent training sessions over the last three years
- Group members running NARS-funded field trials for calibration and validation based on guidelines and principles learned during ACCA/SARC projects.
- Members taking part in international modelling initiatives, including AgMIP and Global Yield Gap Atlas. Their invitations to participate in these initiatives came as a direct result of the ACCA project, and the demonstrated achievements which the respective staff members had made during the modelling activities of the project.
- Several members undertaking advanced modelling studies at PhD and Master levels at reputable international institutions (Apurbo Chaki, BARI – planned PhD at University of Queensland 2016; Mamunur Sarker, BARI – MSc studies at Wageningen University (2012-2014). This in-country modelling experts will form the basis of the growing modelling group into the future.
- Integration of farming systems modelling with detailed farm economic budgets in the PhD of Jahangir Kabir, a former ACCA team member from Bangladesh and now a John Allwright Fellow associated with ACCA

Feedback and reflection were a regular feature of planning and review meetings. In particular, the systematic project planning processes, adaptive project management approach and focus on integration of science were viewed by project teams as supportive of managing competing demands, streamlining operations and fostering inter-disciplinary and inter-institutional collaborations.

In terms of operational capacity, aspects of ACCA that project teams have or will take into a new project or initiative include:

- *India*: 'We now use research results as examples when talking to policy makers – this was not done before ACCA.'
- *Cambodia*: 'One change is in our thinking about climate change. Now we listen to farmers about how they change according to their experience of climate – we don't assume they keep traditional practices.'
- *Laos*: 'SLP, IRAS and ADB projects all promote direct seeding, but ACCA was the only project to organise training for PAFO, DAFO and farmers from the Thai manufacturers and researchers'.
- *Australia*: 'Many projects claim to cross disciplines – inter, multi, trans etc. ACCA has had the most traction in this regard because integration was in itself an objective and there was a lot of investment in finding connection and creating opportunities to learn from each other. It's not easy but it's very rewarding.'
- *Cambodia*: 'There has been very good planning, but also flexibility – we have the capacity to change according to progress and what needs to be achieved.'
- *India*: 'We do things differently now. ACCA processes have helped us improve our management.'
- *Laos*: 'The workplan is time consuming, but it helps us understand what we need to do.'
- *Bangladesh*: 'The level of planning is good – we know what to do ahead of time and are able to incorporate changes to the workplan.'

In terms of research approach and capacity, feedback includes:

- *Cambodia*: 'ACCA concepts of farming are novel, especially in Svay Rieng. How to set up crops in relation to available water, looking at farmer type and risk and adjusting the practice – this is new and relevant to the time and location.'
- *Bangladesh*: 'In the past, social activities have been done by social departments and biophysical activities have been done by biophysical departments. The ACCA typologies were done together, and this has made both departments stronger.'
- *India*: 'Integration across disciplines is a great strength of this project – it is more effective than linear approaches of single disciplines.'
- *Australia*: 'Rice modelling capacity in CSIRO has increased and is being used throughout the region.'
- *Cambodia*: 'There is new experience and knowledge from ACCA, like APSIM – we've never seen it before. We've learned how farmers can use the findings from modelling.'
- *Australia*: 'Importantly, I've learned more about the integration of social science and biophysical science. In particular, I've built skills in communicating social science to non-social scientists as well as improving my own understanding of agricultural science.'
- *Cambodia*: 'The information is not inherently new, but the combination of drum seeder, short duration variety, rainfall information all together is new. It creates flexible options for the farmer and this is new.'
- *Laos*: 'APSIM will be very useful to us in the future. Also the cropping calendar will be useful for farmers. Direct seeding alone won't improve farmer livelihoods – we need to improve soil fertility, understand risks, look at watershed management – we need to put all the research together."

9.3 Community impacts – now and in 5 years

In accordance with the multi-scale research strategy envisaged by this project (Figure 2), we were pursuing two primary pathways to impact, one through immediate outscaling of adaptation practices and the other through policy outcomes that facilitate extension of project principles to other contexts.

9.3.1 Economic impacts

While there is evidence that ACCA is generating impact through both pathways, this section focuses on economic impact resulting from household and community uptake of project-recommended practices.

There have been significant outcomes at the policy interface and through influence on the development or implementation of broadscale adaptation programs and initiatives. These are detailed in the stakeholder engagement report (Volume 3, Appendix 1) and summarised in the country chapters. At this stage, the economic impact of these connections is difficult to quantify. For donor programs, the key impacts are likely to be an improved return on investment or an elevated efficiency gain. For policy areas, the impacts are likely to be a more targeted, nuanced or informed approach to an existing challenge.

India

In India, efforts have focused on supporting farmers to understand and act on climate information, with a focus on on farm practices to increase water use efficiency in both rice and rainfed crops such as cotton and maize. The full range of practices is discussed in Section 5.1. Here, we focus on the potential benefit of applying the sowing rule and strategic irrigation. In both cases we consider the impacts for cotton, as the dominant cash crop in the study area.

In Bairanpally,[10] economic analysis suggests a rainfed cotton crop sown following two consecutive days of rain has a gross margin (GM) of USD 560/ha or USD 566/HH (average holding in Warangal District is 1.01ha; Indian Agricultural Census, 2010-11). If this same crop had been sown following the soil moisture rule (see Section 5.1) the GM would be estimated at USD 686/ha, with a gross margin gain of USD 127/ha or USD 128/HH.

If a household were to also strategically irrigate the cotton crop, the gross margin gain (compared to a rainfed cotton crop, planted using the soil moisture rule to determine sowing time) is estimated at USD 389/HH.

The primary strategy to support dissemination and adoption by households is the establishment of CLICs. The network of CLICs currently sits at 33 across Telangana, with project partners estimating a total of 8,000 farmers exposed to information on practices through these centres. In Table 22 and Table 23, this estimate has been used as the basis of potential economic impact for conservative adoption rates of between 1% and 5% over 5 years.

Table 22. Estimated gross margin gains (USD) from adoption of soil moisture sowing rule for cotton.

Adoption	Year 1	Year 2	Year 3	Year 4	Year 5	Cumulative impact
Optimistic 5% after 5 years	10,241	20,483	30,724	40,966	51,207	153,621 (400 HHs)

[10] Bairanpally is used as the basis of impact calculations due to the village having a longer history of working with this/related projects; and a higher confidence in the accuracy of economic data. The longer exposure of Bairanpally to project practices suggests a more accurate representation of what may be possible over time compared to other villages.

Moderate 2.5% after 5 years	5121	10,241	15,362	20,483	25,604	76,811 (200 HHs)
Conservative 1% after 5 years	2048	4097	6145	8193	10,241	30,724 (80 HHs)

Note: Assumes linear adoption rate over five years; average agricultural holding of 1.01 ha in Warangal district (Census of Agriculture in India 2010-11); and gross margin gain of USD 128/HH. Cumulative impact assumes that adoption results in the same economic benefit for each year of adoption.

Table 23. Estimated gross margin gains (USD) from adoption of strategic irrigation of cotton for crop grown based on soil moisture sowing rule.

Adoption	Year 1	Year 2	Year 3	Year 4	Year 5	Cumulative impact
Optimistic 5% after 5 years	31,120	62,240	93,360	124,480	155,600	466,800 (400 HHs)
Moderate 2.5% after 5years	15,560	31,120	46,680	62,240	77,800	233,400 (200 HHs)
Conservative 1% after 5 years	6224	12,448	18,672	24,896	31,120	93,360 (80 HHs)

Note: Assumes linear adoption rate over five years; average agricultural holding of 1.01 ha in Warangal district (Census of Agriculture in India 2010-11); and gross margin gain of USD 389/HH. Cumulative impact assumes that adoption results in the same economic benefit for each year of adoption.

Estimated cumulative economic impact, based on the reach of current CLICs for application of the sowing rule and strategic irrigation of cotton is estimated to be between USD 93,360 (adoption by 80 households) and USD 466,800 (adoption by 400 households). Estimated economic impact from the sowing rule ranges from USD 30,724 to USD 153,621.

Note this is quite a conservative estimate of the population of farmers exposed, which is likely to be far greater through media and community engagement and training of farmers and agricultural officers through other programs, and potential expansion of CLICs into the future (Table 5, section 8.1).

Bangladesh

On farm research and ongoing farmer engagement, with the intent of developing, evaluating and promoting adaptation practices was not part of the project plan for Bangladesh.

However, some scaling of ACCA practices has occurred (or is projected to occur) by connections with other projects and initiatives working in the same or similar districts. These include:

- Co-investment with IRRI's SARCCAB project for on farm trials near Khulna using ACCA adaptation practice options, allowing credible and location specific scenario analyses to explore feasible adaptation options that can flow into other projects.
- The Bangladesh component of CSISA, through connections with IRRI and key staff who were formerly in the ACCA project. The contribution from ACCA will be the future–proofing with APSIM of a wider range of practices that have been tested and are being promoted by the CSISA project. For example, on farm field testing of salinity tolerant rice varieties has demonstrated the ability of these varieties to significantly out-yield traditional rice varieties grown in the project target areas in Dacope.
- The farm scale components of the CPWF in southwest Bangladesh, through IRRI researchers and the CGIAR Water, Land and Ecosystems program
- The new ACIAR project on cropping systems intensification in salt-affected areas of coastal southern Bangladesh (LWR-2014-073)

Cambodia

In Cambodia, the 'response farming' approach to addressing seasonal variability is the foundation of ACCA's dissemination to farmers and extension agents. This approach assumes that there are a number of options that a farming enterprise can use to make best use of a monsoon period to produce wet season rice, accounting for variability in start, duration and amount of rainfall. These include crop duration and variety, crop sequencing, time of establishment, use of supplementary irrigation, potential for mechanisation or alternative seeding technologies, and pest and fertiliser application times and rates.

Focus groups discussions with farmers (refer to the Cambodia country chapter in Section 5) suggest that the most commonly adopted practices were direct seeding, use of short duration rice and double cropping.

Economic analysis suggests that the median gross margin (GM) over three years, including labour input costs for transplanted, local variety rice in the study region is negative USD 101/ha or negative USD 117/HH[11] (average holding in Svay Rieng and Prey Veng is 1.16 ha/HH; National Institute of Statistics 2014).

If, in response to changed seasonal conditions, a farmer direct seeded a single crop of a short duration variety, the GM is estimated to be USD 213/ha, with a subsequent GM gain over farmer practice of USD 314/ha (or USD 364/HH). A single medium duration, modern variety direct seeded crop yields a GM of USD 289/ha, for a GM gain over farmer practice of USD 390/ha (or USD 452/HH). If seasonal conditions were appropriate to direct seed two crops of the short duration variety, the GM is estimated to be USD 227/ha, for a GM gain of USD 328/ha (or USD 380/HH).

As discussed in the Cambodia country chapter (Section 5), the key mechanisms for dissemination to farmers are: Farm Business Advisor network of iDE/Lors Thmer that exists and is growing in Svay Rieng and four other provinces; DAE's Training of Trainers and Farmer Field School initiatives in Svay Rieng and four other provinces; and PADEE's training and extension initiatives through SNV, iDE and DAE in five focus provinces, including Svay Rieng. Note that there is some overlap between these activities.

In considering adoption and potential economic impact, we have assumed as a starting point farmers already exposed to ACCA approaches through iDE networks (300 FBAs

[11] This means that if labour costs are incorporated into analyses, farmers lose money growing rice by conventional means. FGDs suggest that as many farmers grow rice for food security rather than economic gain, labour as an input for rice growing is often discounted as it does not impact on capacity to increase household income through work in other enterprises. We include labour in analyses for consistency.

with 40 clients each, half of whom have a rice focus = 6000 farmers) and PADEE initiatives (pilot training of community extension workers in Svay Rieng plus roll-out to four other provinces = 14,000 farmers as a very conservative estimate), and then calculated adoption rates of between 5% and 15% over five years.

For one direct seeded, short duration, modern variety crop (Table 24**Error! Reference source not found.**), cumulative economic impact of adoption after five years is estimated to be between USD 218,400 (adoption by 200 households) and USD 1,092,000 (adoption by 1000 households).

For two direct seeded, short duration, modern variety crops (Table 25), cumulative economic impact of adoption after five years is estimated to be between USD 228,000 and USD 1,140,000.

Table 24. Estimated gross margin gains (USD) from adoption of direct seeding one short duration modern variety crop over one transplanted local variety crop in five focus provinces in Cambodia.

Adoption	Year 1	Year 2	Year 3	Year 4	Year 5	Cumulative impact
Optimistic 5% after 5 years	72,800	145,600	218,400	291,200	364,000	1,092,000 (1000 HHs)
Moderate 2.5% after 5years	36,400	72,800	109,200	145,600	182,000	546,000 (500 HHs)
Conservative 1% after 5 years	14,500	29,120	43,680	58,240	72,800	218,400 (200 HHs)

Note: Assumes linear adoption rate over five years; average agricultural holding of 1.16 ha (Census of Agriculture in Cambodia 2013); and gross margin gain of USD 364/HH. Cumulative impact assumes that adoption results in the same economic benefit for each year of adoption.

Table 25. Estimated gross margin gains (USD) from adoption of direct seeding two short duration modern variety crops over one transplanted local variety crop in five focus provinces in Cambodia.

Adoption	Year 1	Year 2	Year 3	Year 4	Year 5	Cumulative impact
Optimistic 5% after 5 years	76,000	152,000	228,000	304,000	380,000	1,140,000 (1000 HHs)
Moderate 2.5% after 5years	38,000	76,000	114,000	152,000	190,000	570,000 (500 HHs)
Conservative 1% after 5 years	15,200	30,400	45,600	60,800	76,000	228,000 (200 HHs)

Note: Assumes linear adoption rate over five years; average agricultural holding of 1.16 ha (Census of Agriculture in Cambodia 2013); and gross margin gain of USD 380/HH. Cumulative impact assumes that adoption results in the same economic benefit for each year of adoption.

However, these two agencies have additional targets for farmer reach (refer to the Cambodia country chapter in Section 5 for details). In five years, iDE plans to reach 16,000 farmers (50% engaged in rice production) with a network of 400 FBAs, while PADEE has a stated target of 90,000 farmers by 2018. Theoretically, there is scope for ACCA approaches to spread to between 4500 (5%) and 13,500 (15%) additional farmers, with a potential economic impact of USD 2 - 6 million.

Lao PDR

The key adaptation practice being promoted in Laos by ACCA and the ACCA-SRA projects is the use of dry direct seeding. Apart from reduced exposure to early season drought and terminal drought stress and higher yields in poor years, farmers are attracted mainly by the prospect for reduced costs of production. Planting with the direct seeder is much faster than traditional transplanting methods: with traditional methods 20 people can transplant 1ha/day and with the seeder, one farmer can plant 1ha/day.

Economic analysis suggests that the gross margin (GM) for transplanted rice in the study region is USD 208/ha and the GM for direct seeded rice that is well managed for weeds is USD 358/ha, with a subsequent gross margin gain of USD 150/ha.

As discussed in the Lao country chapter (Section 5), the key mechanisms for dissemination of project practices to farmers in the southern provinces of Laos are: PAFO dissemination in Savannakhet; NAFRI (and DAEC) training initiatives that now incorporate ACCA approaches and practices; the SNV Climate Smart Agriculture initiative in Khammouane province (estimate of 500 farmer champions by the end of 2015); and distribution of IFAD training and extension material in five southern provinces (estimate of 5000 pamphlets distributed by the end of 2016).

In response to these mechanisms, in the two study districts of Outhoumphone and Champhone only, we conservatively predict between 1% and 5% of farmers will adopt project practices after five years.

In Outhoumphone (Table 27), cumulative economic impact of adoption after five years is estimated to be between around USD 61,179 (adoption by 127 households) and USD 305,897 (adoption by 635 households).

In Champhone (Table 27), cumulative economic impact of adoption after five years is estimated to be between around USD 83,682 (adoption by 160 households) and USD 418,409 (adoption by 802 households).

Table 26. Estimated gross margin gains (USD) from adoption of direct seeder over transplanted rice in Outhoumphone district.

Adoption	Year 1	Year 2	Year 3	Year 4	Year 5	Cumulative impact
Optimistic 5% after 5 years	20,393	40,786	61,179	81,573	101,966	305,897 (635 HHs)
Moderate 2.5% after 5years	40,786	81, 573	122,359	163, 145	152,948	152,948 (318 HHs)
Conservative 1% after 5 years	20,393	40,786	61,179	81, 573	61,179	61,179 (127 HHs)

Note: Assumes linear adoption rate over five years; 12,706 households (HH) in district, with average paddy area of 1.07 ha/HH and gross margin gain of USD 150/ha. Cumulative impact assumes that adoption results in the same economic benefit for each year of adoption.

Table 27. Estimated gross margin gains (USD) from adoption of direct seeder over transplanted rice in Champhone district.

Adoption	Year 1	Year 2	Year 3	Year 4	Year 5	Cumulative impact
Optimistic 5% after 5 years	27,894	55,788	83,682	111,576	139,470	418,409 (802 HHs)
Moderate 2.5% after 5years	13,947	27,894	41,841	55,788	69,735	209,205 (401 HHs)
Conservative 1% after 5 years	5579	11,158	16,736	22,315	27,894	83,682 (160 HHs)

Note: Assumes linear adoption rate over five years; 16,031 households (HH) in district, with average paddy area of 1.16 ha/HH and gross margin gain of USD 150/ha. Cumulative impact assumes that adoption results in the same economic benefit for each year of adoption.

9.3.2 Social impacts

A central aim of this project is to build capacity for farming households to adapt to future climate change. This not only entails commonly used and more narrowly defined economic gains (e.g. employment, income per capita), but also a suite of broader livelihood values surrounding personal and community capacity, security and wellbeing. A key livelihood outcome is the potential to increase social capital for smallholder farm households and communities. There are several avenues for a project to increase and enhance social capital, including (for example) the fostering of a greater level of shared new knowledge, personal and community empowerment, self learning experiences and establishment of effective social networks. Shared learning of positive experiences will increase the social capital of the targeted communities. Enhanced social capital and improved human capital through better access to knowledge emerged clearly as determinants of adaptive capacity in the focus groups discussions we conducted.

An example of an approach to foster greater community based learning are the Farmer Climate Clubs (FCCs) established in India in each case study village. Membership varied, but was about 30 to 40 farming households in each village. These FCCs fostered debate amongst farmers about a range of crop management issues, triggered by the recommendations in the agromet advisories. In the case of Bairanpally, the original FCC expanded in scope, evolving into a farmer cooperative that achieved additional benefits for its members by bulk sourcing and buying inputs. In that case, we catalysed a self-sustaining entity that is benefiting many more farmers than the project engaged with directly through it on farm research. In Gorita, the effectiveness is uncertain; however, at the beginning of the project there was a lot of scepticism and even hostility about the FCC. Currently, FCC and village meetings are well attended.

Whilst the above would indicate there has been social impact, we are aware through our surveys that there remain challenges of inclusiveness and equitable access to village institutions such as the FCC or the CLICs, due to India's complex social structures and issues such as literacy and numeracy.

Enabling farming communities to achieve or at least maintain food security in the future as climatic conditions become more adverse has the potential to become a significant social impact. Without support, smallholder livelihood strategies will inevitably become even more constrained than at present, leading to both personal and communally-shared hardship and potential social dislocation as communities stagnate or lose members to migration.

Protecting against this source of adverse social impact is being positively achieved by increasing productivity through project generated crop and water management options currently not being utilised. Flow-on benefits associated with greater food security include better health, education and income generation options. These in turn lead to savings for future growth and the ability to recover quickly from flood or drought events. On farm trial and modelling results indicate that the cropping practices promoted by ACCA are likely to increase yields through reduction of climatic risks and better use of inputs, resulting in potential beneficial food security impacts.

At the time of project design (2009-10), there was not a significant or explicit requirement for gender-based approaches to ACIAR projects, as such, specific gender approaches were not part of ACCA's original design. Although it was not a specific part of the ACCA design, consideration of women's roles and impacts did occur, particularly as they pertain to the domains of economic empowerment and manageable workload. Specifically in Cambodia and Lao PDR, the potential for direct seeding of rice to reduce the need for transplanting has significant potential benefits for women. Direct seeding offers the potential for significant reduction of women's work in transplanting, reducing peak workloads and the drudgery and physical exertion associated with transplanting. This may allow the pursuit of other more remunerative livelihood activities. These benefits are positive, provided mechanisation does not displace wage opportunities (for which there was little evidence in our case studies).

In India, feminisation of agriculture was highlighted through the research of postdoctoral fellow Tanya Jakimow. Tanya's work highlighted the challenges for female household members who are left to manage farmlands while their male family members migrate for paid labour opportunities. Women can struggle to access the necessary markets for inputs and sale of produce compared to male household members. The team has been aware of challenges in terms of ensuring equitable access to climate clubs and CLICS, both for women and also lower caste households. However the prospects for a project to shift and adapt to counteract such social norms and dynamics within such short timeframes are limited.

9.3.3 Environmental impacts

This project had the potential to result in both positive and negative environmental outcomes. Better matching of cropping to seasonal rainfall variations is likely to increase water and nutrient use efficiencies and to reduce the environmental footprint of crop production, while also increasing farmers' return on investment in inputs.

Conversely, intensifying crop production by using supplementary irrigation and intensive nitrogen fertiliser regimes also has the potential to increase greenhouse gas emissions and reduce water resources, leading to maladapted farming systems. Dry direct seeding and broadcasting of rice most likely will also require an ongoing and higher use of herbicides, which if used inappropriately, can harm the environment and negatively affect co-benefits from rice fields (e.g. fish, frogs are an important source of protein in Cambodia and Lao PDR).

APSIM modelling was used to evaluate crop performance (grain and biomass productivity), against a number of parameters to assess how the proposed practices may either positively or negatively affect the environment. Of the many possible parameters, we have opted to extract four key measures of environmental performance:

- Water productivity – gross margin/irrigation
- Water use efficiency - net irrigation water use
- C lost to atmosphere per tonne yield produced
- N_2O produced per tonne yield produced

By intensifying a cropping system, food production (tonnes grain per hectare) may increase but with increased gross emissions (global warming emissions per hectare) due to greater use of fertilisers or increased cycling and decomposition of organic materials. Such a positive correlation would often be inevitable, hence a more appropriate index upon which to judge the emissions performance of a particular cropping system could be the ‘emissions intensity’ rather than the total emissions, where ‘intensity’ is measured in global warming emissions per tonne of grain produced, or per unit currency of profit the farmer makes.

In this project we have compared traditional (control) systems with a range of adaptation options in each country, in both historical and future climates, from a range of perspectives. We have used ‘sustainability polygons’ for this purpose, as detailed in the main body of the report, to provide an all-encompassing visual means of comparing both the production and emissions performance of the systems. We have considered the emissions intensity of each adaptation, due to both nitrous oxide and carbon as separate variables. Examples of these comparisons can be found in each country chapter, or full details in Appendix 5, Volume 3. Future effort could be dedicated to converting these to a ‘Carbon Dioxide Equivalent’ (CDE) measure, which could provide a single index on which to base comparisons for global warming potential.

Our research indicated that there is not always a win-win situation when comparing production increases, greenhouse gas emissions, and other environmental outcomes, however there can be (alternate wetting-and-drying irrigation in rice is a good example of a win-win). The adaptation simulations across the four countries illustrated the fact that different potential adaptations present different outcomes, and must always be assessed on these criteria before promotion as good options for extension.

In different situations, different indices could need to be weighted differently. For example, in some environments increased recharge could be a major restricting factor to suitability of a given adaptation, regardless of its production benefits, whereas environments this aspect could be of much less concern. The summary message from our research is that the framework we have presented for holistic assessment of adaptation options should be widely utilised, and adaptations must be considered on a case-by-case basis.

10 Conclusions and recommendations

10.1 Conclusions

The ACCA network of project teams achieved significant research, community and institutional advances throughout the project, with a range of indicators outlined for impact and sustainability. In terms of key learnings, we focus here on three: reflections from the team on design and operations of a complex project, highlights of new research knowledge arising from the project, and a summary of how ACCA addressed key development drivers in each country.

Key operational learnings

Aspects of ACCA's design and implementation are discussed in section 8.6. Highlights include:

Co-developing an integrated framework

A key operational learning was the importance of creating an integrated, jointly owned research framework in the early stages of the project. This arose from recognition that recent advances in the field of adaptation science were based on an effective interdisciplinary approach to design and implementation that incorporates input from all relevant science domains.

Planning, reviewing and adapting

Regardless of how well a research project has been contextualised and conceptualised, without detailed planning and sound project management there is a significant risk that objectives will not be met. In the case of complex, multi-country, multi-partner and multi-stakeholder projects a project theory of change needs to be underpinned by detailed work planning. For ACCA, detailed planning and review of milestones and timelines also became a mechanism for team integration, by clarifying roles and responsibilities, confirming institutional and individual commitments and sharing and acknowledging progress and success.

Emphasising participation and engagement

The project combines crop modelling and field experiments with strong farmer participation. Possible adaptation practices were developed through on farm experimentation, which informed scenario analyses to test the long term viability against location specific climate projections, which informed a further selection of viable adaptation practices to be considered by modellers and validated by farmers.

Similarly, explicit participation was sought from policy, research and development stakeholders, to ground the research in local context and need, to align project activities to existing or upcoming initiatives and to provide a springboard for future collaboration and sustainability. This participation was guided by a stakeholder engagement plan that maximised opportunities for impact, prioritised actions according to the research plan and progress and relied on feedback, review and adjustment.

Investing in partnerships and people

It took some time for partnerships within and between project teams to develop. This is partly due to not having a history of working together, partly due to having different modes of operation, disciplines and institutional culture. While relationships between country teams strengthened (and in many cases continues outside the project), there was a recommendation that more cross-country discipline-based interactions would have been beneficial to both project outcomes and individual development.

Creating momentum for sustainability

Setting clear aspirations for scaling and sustainability of project outcomes was considered as important as creating the flexibility to seize opportunities as they arose. In this way, the dual drivers of dissemination of project practices and influence on policy and programs guided research outputs and stakeholder interactions.

Key research learnings

Research results are featured in the country chapters of section 8, while section 8.5 summarises cross-country learnings. Highlights include:

Social research

- Self assessments of adaptive capacity reveal recurring indicators across countries, including health, level of education or knowledge, access to irrigation and livestock ownership.
- Household types and livelihoods analysis identified recurring drivers of change, including feminisation of agriculture, labour shortages and rapid rural change.
- A common framework (with a livelisystems approach) can be developed to explore adaptation options, allowing direct comparison between countries.

Modelling and scenario analysis

- APSIM-ORYZA has been comprehensively validated and is performing well in contrasting Asian rice environments, including the ability to dynamically model salinity impacts on rice.
- The range of yields resulting from seasonal climate variability is more significant than under projected climate changes to 2030.
- Adaptation options evaluated in the project are likely to compensate for the detrimental effects of average climate impacts by 2030. Note that ACCA considered incremental climate change, and not extreme events and did not consider impacts beyond 2030.

On farm research

- For greater relevance and uptake, adaptation practices need to address multiple objectives eg yield, labour and risk reduction.
- A toolkit of management options can help farmers and extensionists better manage climate variability by allowing them to respond flexibly to the progress of a particular season.
- Developing community capacity to relate weather observations to farming decisions (eg with rainfall visualisers and agro-advisories) is important and relatively easy to implement.

Integration tools

- Impredicative Loop Analysis, with a livelisystems foundation is a promising policy and planning tool that integrates social and biophysical aspects of climate adaptation.
- Sustainability polygons are useful visual representations for a range of purposes, including relative environmental effect, potential for maladaptation, the degree to which a practice is ‘Climate Smart’ and a measure of adoption risk.

Key development learnings

The outcomes and anticipated development impacts of ACCA research activities are summarised in the country chapters of section 8 and in section 9. A snapshot for each country appears below.

Lao PDR

In Lao PDR, the key adaptation practice promoted by the project was the use of direct dry seeding. In addition to reduced exposure to early season drought and terminal drought stress farmers were attracted mainly by the prospect for reduced costs and labour for production. Planting with the direct seeder is much faster than traditional transplanting methods (one farmer can transplant one hectare in the same time it takes 20 people to transplant using traditional methods).

From an economic perspective, analysis suggests that the gross margin gain of direct seeded rice (that is well managed for weeds) over transplanted rice is USD 150/ha. Using the dissemination mechanisms established by the project (PAFO Savannakhet extension, NAFRI and DAEC training and SNV and IFAD training initiatives), over 1200 households could share this economic benefit after 5 years (assuming linear adoption to 5% after five years) in the two study districts of Outhoumphone and Champhone. Weeds (from low herbicide use) and access and cost of seeders are outstanding challenges.

Cambodia

The ‘response farming’ approach to addressing seasonal variability was the foundation of ACCA’s adaptation work in Cambodia. This approach assumes that there are a number of options that a farming enterprise can use to make best use of a monsoon period to produce wet season rice, accounting for variability in rainfall (start, duration and amount of rain). These include crop duration and variety, crop sequencing (including double cropping), time of establishment, use of supplementary irrigation, potential for mechanisation or alternative seeding technologies, and pest and fertiliser application times and rates.

Focus groups discussions with farmers suggested that preferred practices were direct seeding, use of short duration rice and double cropping – in response to specific seasonal conditions. Economic analysis suggests the gross margin gain of a single medium duration, modern variety direct seeded crop is USD 390/ha over farmer practice; and USD 328/ha for direct seeded double cropping of the short duration variety.

Using the dissemination mechanisms established by the project (iDE’s Farm Business Advisor network, DAE’s training and demonstration initiatives and PADEE’s training and extension activities through SNV, over 1000 households could share this economic benefit after 5 years (assuming linear adoption to 5% after five years) in the focus provinces. Unequal access to irrigation, access to appropriate machinery and extension services remain challenges.

India

In India, the project aimed to address issues of drought risk, lack of climate information to guide decisions on type and management of crops, rapid rural change with significant social complexity and perceived agricultural labour constraints. The rainfall visualiser, agro-advisories, farmer climate clubs and CLICs merged traditional and scientific knowledge of weather, supporting farmers to make decisions as a season unfolds, while recommendations such as the sowing rule and strategic irrigation between crops increased efficiency of inputs and reduced perceived risk.

From an economic perspective, adoption of the project’s recommended soil moisture rule for a rainfed cotton crop would result in a gross margin gain of USD 127/ha over existing sowing practices. If a farmer also strategically irrigated the cotton crop, the gross margin gain (compared to a rainfed cotton crop, planted using the soil moisture rule to determine sowing time) is estimated at USD 389/ha.

Using the CLICs as our primary dissemination mechanism, we would expect the benefits to be shared by at least 400 households after five years (assuming linear adoption to 5% after five years). Groundwater resources and the viability of the CLICs remain as challenges to sustainability.

Bangladesh

Encroaching salinity and lack of irrigation are major constraints to agricultural intensification and adaptation in southwest Bangladesh, while social tensions exist around community decision making and adoption of some livelihood options (eg shrimp farming) in the study region in Bangladesh.

While ongoing farmer engagement, with the intent of developing, evaluating and promoting adaptation practices was not part of the project plan for Bangladesh, systems modelling suggests opportunities to manage salinity at farmer and polder level. These opportunities and their social and economic influence are being explored in two new ACIAR-funded projects.

10.2 Recommendations

Recommendations for research activities

- Across countries, a key factor for household decision making and planning was found to be rapid social change in rural communities. Further study is recommended to understand the dynamics of this change eg identifying the farmers of the future, understanding the implications for the trend towards larger, consolidated units of production.
- Through on farm collaborations, it became apparent that some farmers were or were approaching the yield potential of their enterprise, while others with a similar level of inputs were still falling short of the yield potential. In addition to understanding the biophysical yield gap, further study is suggested to understand the social and economic basis of yield gaps in the study region.
- It is proposed that ACCA findings and insights be shared with existing or planned ACIAR projects with similar aims. These might include: CSE/2012/077 – mechanisation and value addition in Laos and Cambodia; LWR-2014-073 - cropping systems intensification in coastal Bangladesh; CSE/2011/077 – modelling to manage climate risk in Eastern Gangetic Plains farming systems.
- The ACCA project emphasised the importance of addressing the climate variability issues facing farmers through a livelihoods or livelisystems lens, rather than with a focus on individual enterprise components. Such a systems approach provides more grounded and nuanced insights into rural challenges, and also reduces the likelihood of unintended research outcomes. Further, greater emphasis, resourcing of capacity strengthening of systems science and thinking is advised.

Recommendations for project implementation

- The significant transaction costs associated managing large integrated complex projects can be outweighed by the opportunity to maintain a critical mass and momentum in the project team. Critical features include a well designed scoping study, a theory of change that incorporates a shared integration framework, a strategic engagement plan and MEL framework and a detailed but adaptable workplan.

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11.3 Other publications and reports produced by the project

Papers in preparation

Manuscripts with an asterisk are provided in Final Report Volume 2.

1. Brown, Afroz, Chialue, Chiranjeevi, Grunbuhel, Khan, Pitkin, Reddy, Roth, Sacklokham and Williams. Constraints to capacity of small scale farmers to adapt for climate change in South Asia and Southeast Asia and implications for adaptation. For submission to *Agriculture and Human Values* in December 2015.

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4. * Dalgliesh NP, P Charlesworth, L LeNon and PL Poulton. Cultivating resilience in Cambodian lowland rice ecosystems. Part 1: Farming system research to support flexible climate response strategies for smallholder farmers. For submission to *Experimental Agriculture* . Currently in CSIRO internal review
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12. Laing, A, DS Gaydon, T Inthavong, V Phengvichith, PL Poulton, CH Roth, K Thiravong, G Lacombe, Sipaseuth. Direct seeding of rain fed rice in lowland Lao PDR reduces farmers‟ exposure to climate risks and ameliorates gross margins in poor years. For submission to *Experimental Agriculture* or *Climate and Development* in Jan 2016.
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76. Tallapragada, C (2011). Climate Variability and Adaptive Capacity of Farmers. National Conference, 5th Round Table Meet on *Sustainable Agriculture and Climate*

Change organized by National Council for Climate Change and Sustainable Development, Hyderabad, India

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ACIAR reports

ACIAR Annual Report 2010-2011; Roth, van Wensveen and Grünbühel; June 2011.

ACIAR Annual Report 2011-2012; Roth and van Wensveen; June 2012.

Midterm Progress Report; Roth and Laing; January 2013 (prepared for ACIAR Midterm Review).

ACIAR Annual Report 2012-2013; Roth and Laing; June 2013.

ACIAR Semi-annual Report 2013; Roth; November 2013.

Final Review Notes; Roth and van Wensveen; July 2014 (prepared for ACIAR Final Review)

Trip reports

2010		
1. February	Bangladesh, India	Roth, Hochman, Gaydon, van Wensveen
2. April	Cambodia, Laos	Roth
3. May	Bangladesh, India	Brown, Williams, Grunbuhel
4. May	Cambodia	Roth, Dalgliesh, van Wensveen
5. June	Bangladesh	Gaydon
6. June	Laos	Abawi (contract)
7. June	Laos	Roth, Crimp, Laing
8. June	Philippines, Laos, Nepal, Bangladesh	Roth
9. July	Cambodia	Dalgliesh
10. August	Cambodia	Brown, Pitkin
11. August	Cambodia, Laos	Williams, Grunbuhel
12. October	Cambodia	Dalgliesh
13. November	Bangladesh	Gaydon
14. November	Cambodia	Pitkin
15. November	India	Hochman
16. November	India	Nidumolu
17. November	Laos, Philippines	Roth
2011		
18. February	Bangladesh	Roth, van Wensveen
19. February	India	Roth, van Wensveen, Hochman
20. March	Cambodia	van Wensveen, Dalgliesh, Grunbuhel
21. March	Laos	van Wensveen, Laing, Brown, Roth
22. May	Cambodia	Dalgliesh, Poulton
23. May	Laos	Laing
24. June	India	Hochman

25. July	Cambodia, Vietnam	Grunbuhel
26. July	India, Bangladesh	Roth
27. August	Bangladesh	Roth
28. August	India	Williams, Grunbuhel, Brown
29. August	Laos	Roth
30. September	Cambodia	Dalgliesh
31. October	Laos	Roth
32. November	Bangladesh	Gaydon
33. November	Bangladesh	Roth, Gaydon Poulton
34. November	Cambodia	Williams, Grunbuhel, Brown
35. November	Cambodia	Poulton
36. November	Laos	van Wensveen, Laing, McDonald
37. December	India	Hochman
2012		
38. January	Cambodia	Dalgliesh
39. February	Bangladesh	van Wensveen, Roth
40. February	India	van Wensveen, Roth
41. February	Laos	van Wensveen, Roth
42. April	India, Bangladesh	Williams
43. April	India	Hochman
44. April	Cambodia	Roth, Dalgliesh, Grunbuhel
45. April	Laos	Laing
46. June	Bangladesh	Gaydon
47. June	Laos	Roth
48. July	Laos	Schiller
49. October	Laos, Thailand	Laing
50. October	Cambodia	Dalgliesh
51. October	India	Hochman
52. November	Philippines	Gaydon
53. December	Bangladesh, India	Roth, Hochman
2013		
54. February	Cambodia	Roth, Laing, Hochman, Williams, Gaydon
55. February	Laos	Laing
56. April	India	Hochman
57. March	Bangladesh, Cambodia	Roth
58. May	Cambodia	Dalgliesh
59. May	Germany	Roth
60. July	Laos, Thailand	Laing, Roth
61. August	India	Hochman, Nidumolu
62. October	Laos	Schiller
63. October	Cambodia	Dalgliesh, Poulton
64. November	Bangladesh, India	Roth
65. November	Cambodia	Roth
66. November	Australia	Khounphonh, Doungmala
67. December	Laos	Laing, Williams, Grunbuhel
2014		
68. February	India	Hochman, Nidumolu
69. April	Laos	Laing
70. April	Australia	Radanielson
71. May	Cambodia, Laos	Roth

72. June	Cambodia	van Wensveen, Dalgliesh
73. July	Laos, Cambodia	van Wensveen, Roth, Williams, Laing, Gaydon, Hochman
74. September	India	Roth, Nidumolu
75. October	Cambodia	Roth
76. December	Laos	Laing
2015		
77. February	Cambodia	Roth, Williams
78. April	Bangladesh, Philippines	Gaydon
79. April	India	Roth, Nidumolu, Hochman
80. May	Laos	Laing
81. August	Cambodia	Dalgliesh
82. August	India	Nidumolu

11.4 List of ACCA team members and institutions

Australia

CSIRO

Dr Christian Roth (ACCA Project Leader)

Dr Peter Brown

Mr Steve Crimp

Mr Neal Dalgliesh (Cambodia coordinator)

Dr Don Gaydon (Bangladesh coordinator)

Dr Clemens Grünbühel (CSIRO until July 2011; then through AIT Bangkok)

Dr Zvi Hochman (India coordinator)

Ms Heidi Horan

Dr Tanya Jakimow (until July 2012)

Dr Warren Jin

Dr Phil Kokic

Ms Alison Laing (Lao PDR coordinator)

Mr Neil Macleod (until July 2011)

Mr Cam McDonald (CSIRO until July 2012; then through Petani Systems)

Dr Uday Nidumolu

Ms Cathy Pitkin (until April 2011)

Mr Perry Poulton

Ms Monica van Wensveen

Ms Liana Williams

University of Queensland

Dr John Schiller

India

PJTSAU

Dr Danda Raji Reddy (India Team Leader)

Mr Narender Babu Darla

Dr Mahadevappa Sajjana Gandla (from November 2012)

Dr Dakshina Murthy Kadiyala (from November 2012)

Mr Rajender Kulla

Dr Prabhu Prasadini

Mr Kamalakar Reddy Abboori

Dr G Sreenivas

LNRMI

Dr Ratna Reddy

Dr Chiranjeevi Tallapragada

WASSAN

Mr Ravindra Adusumilli

Mr Suresh Kosaraju (until July 2013)

Mr Janaki Rama Rao (from April 2012)

Dr G Venkat Raman (from July 2013)

Ms Bhagya Laxmi (from July 2012)

Local NGO Representatives

Ms Govardhani (Gorita)

Mr M Janardhan (Nemmani)

Mr Sudakhar Reddy (Bairanpally)

IMD

Dr LS Rathore

Dr KK Singh

Dr Satya Kumar (until February 2012)

NCMRWF

Dr SC Kar

Bangladesh

IRRI Bangladesh

Dr Zainul Abedin (Bangladesh Team Leader; retired in February 2013)

Dr Paul Fox (Bangladesh Team Leader from August 2013)

Dr Manoranjan Mondal

Dr Sheikh Md Abdus Sattar

Mr Barkat Ullah (from July 2011)

BARI

Dr Akkas Ali (until April 2011)

Mr Apurbo Kumar Chaki (from November 2011)

Dr Mahbubur Rahman Khan (from April 2011)

Dr AKM Habibur Rahman (until September 2012)

Mr Mamunur Rashid Sarker (from April 2012 until September 2013)

BRRI

Dr Md Mahbubur Alam (from September 2012)

Dr Hazrat Ali (from April 2011)

Mr Md Nazul Islam (from September 2012)

Dr Abdul Muttaleb (from April 2011)

Dr Md Harunur Rashid (until April 2011; May 2011 – June 2014 collaborating through IRRI Bangladesh; from June 2014 through BRRI)

Dr Sanjida Parveen Ritu (until September 2012)

Dr Pranesh Kumar Saha (from April 2011)

Dr Md Abu Saleque (until April 2011)

IRRI Philippines

Dr Tao Li

Dr Ando Radanielson (from December 2011)

SERDI

Dr Iqbal Alam Khan

Ms Sharmin Afroz (until 2013; then through PhD studies)

Ms Himu Bain (until August 2011)

Ms Khodeza (until March 2012)

BARC

Dr Ghulam Hussain (until Dec 2012; now retired)

Cambodia

DAE

Dr MAK Soeun (Cambodian Team Leader)

Dr MAO Minea

Mr SAY Tom

CARDI

Dr EL Sotheary (until June 2012)

Dr SENG Vang

Mr SVAY Sinarong

Mr TOUCH Veasna

iDE Cambodia

Dr Philip Charlesworth (until 2014)

Mr LONH Le Non (from June 2011 until 2014)

Mr SIENG Kan (until June 2011)

Mr LAM Boramy (2013-2014)

Mr LIM Naluch (from 2013)

Svay Rieng PDA

Mr TOUCH Ratana

Lao PDR

NAFRI

Dr Vanthong Phengvichith (Lao PDR Team Leader)

Dr Thavone Inthavong

Dr Pheng Sengxua

Mr Sipaseuth

Mr Xaysathid Souliyavongsa

Mr Somsamay Vongthilath

Ms Sysavanh Vonglorkham

NUoL

Dr Silinthone Sacklokham

Mr Lytoua Chialue

Mr Fue Yang

PAFO

Mr Khammone Thiravong

Mr Sysavanh Vorlasan

DAFO

Mr Mixay Thavong

Mr Phouthone Xum Phonphardy

DAEC

Ms Thongsavath Boupha (until February 2011)

Mr Khamphouvieng Phouisombath

DMH

Mr Khanmany Khounphonh

IWMI

Dr Guillaume Lacombe

11.5 Summary of significant training and capacity activities

1. Training to meet project milestones

Training in soil and crop monitoring methods: from June 2010

Establishment of experimental protocols and necessary training in soil and crop monitoring methods applicable to the project were conducted with local teams in each country. Neal Dalgliesh (CSIRO) coordinated training with PDA, iDE and CARDI staff in Cambodia in July 2010; Don Gaydon (CSIRO) coordinated training with BARI and BRRI staff in Bangladesh in June 2010; Dr Zvi Hochman and Dr Christian Roth (CSIRO) led training with ANGRAU staff in India in July and November 2010; Dr Pheng Sengxua and Dr Thavone Inthavong led training of NAFRI staff and Outhoumphone district extension officers throughout the 2010-11 wet season. This training is ongoing.

In July 2011, Dr Christian Roth conducted field-based training with ANGRAU technical staff (India) in soil sampling techniques, and revision of the project's monitoring protocols.

Training in farming systems and systems modelling: June 2010, April 2011, October 2012

Exposure workshop sessions in APSIM and sampling of minimum datasets were conducted in all inception workshops. In Bangladesh, a more comprehensive APSIM training workshop was conducted by Don Gaydon (CSIRO) in Dhaka in June 2010. The workshop was attended by twelve staff from BRRI, BARI, BRAC and IRRI and comprised an introduction to the model, familiarisation with data requirements and model capabilities and practical modelling work.

An in-depth farming systems training course was held in Australia in April 2011. Workshop participants were Sanjida Parveen Ritu (BRRI), Dr Hazrat Ali (BRRI), Dr Pranesh Kumar Saha (BRRI), Dr Harunur Rashid (BRRI and CSISA), Touch Veasna (CARDI) and Dr Thavone Inthavong (NAFRI). The course was designed and led by Don Gaydon, Perry Poulton, Alison Laing and Neal Dalgliesh (CSIRO) and was supported by the project and the Queensland Branch of the Crawford Fund. The first week (in Toowoomba) focused on field techniques, experimental design and sampling procedures; the second and third weeks (in Brisbane) focused on advanced APSIM training including simulation of actual field experiments using local project data. A more detailed report on this activity is provided in Appendix 9 of the Annual Report 2010-11.

A Crawford Fund training visit to Australia was held in October 2012 to increase skills in farming systems research for Lao and Cambodian colleagues. Using the Australian rice industry and broad acre cropping industries as case studies, participants were exposed to the diversity and drivers for production, as well as the latest infrastructure and how various organisations approach research. The visit was administered jointly by ACIAR projects CSE-2009-037 (host for rice establishment was Geoff Beecher) and LWR-2008-019 (ACCA host was Neal Dalgliesh). Participants for rice establishment were Mr Ngin Chhay and Mr Lim Vandy (Cambodia) and from ACCA were Mr Lon le Non (iDE) and Mr Xaysathip and Mr Somsamay (NAFRI).

Training in seasonal climate forecasting: May 2010, June 2010 and November 2013

A training workshop on seasonal climate forecasting using FLOWCAST and SCOPIC was held for key DMH staff in Lao PDR in May 2010 (Mr Khanmany Khounponh, Nikhom Keosavang and Vanhdy Doungmala). This workshop was conducted by Dr Yahya Abawi (Queensland Centre for Climate Applications) and funded by the project. This was followed up in June 2010 by CSIRO staff (Crimp). A one day workshop was held for DMH staff in Vientiane on use of RainMan and other techniques.

Mr Khanmany and Mr Vanhdy completed an exposure visit to Australia in November 2013. The visit covered Australian methods of observing and forecasting weather and climate (with the Bureau of Meteorology), and communicating information to a variety of audiences. Introductions were made to Australian forecasting groups who may be able to invest time in increasing the knowledge and skill base of DMH staff over a longer term.

Training in use of Sustainable Rural Livelihoods framework techniques: May 2010 to March 2011

Exposure workshop sessions on assessment of adaptive capacity using the Sustainable Rural Livelihoods (SRL) framework were given to partners in Cambodia and Lao PDR during the inception workshops in May and June 2010. Refresher sessions were conducted in India and Bangladesh in May 2010, as these partners had previous experience in adaptive capacity assessment from LWR/2008/015.

Teams of local enumerators were trained in the use of the SRL framework and methods of facilitating adaptive capacity self assessment workshops with farmers. In Cambodia, training was led by Cathy Pitkin, Dr Peter Brown (CSIRO) and Dr El Sotheary (CARDI) in August and November 2010; in Lao PDR, the training was led by Dr Peter Brown (CSIRO) and Dr Silinthone Sacklokham (NUOL) in March 2011; in Bangladesh, the training was led by Dr Iqbal Alam Khan and Sharmin Afroz (SERDI) in August 2010; in India, training was led by Dr Chiranjeevi and Dr Ratna Reddy (LNRMI) in October 2010.

Training in other project-specific techniques

In December 2011, two World Vision Thailand officers travelled to Savannakhet to demonstrate use and benefits of a Thai dry seeder to PAFO and DAFO officers and farmers. A reciprocal visit was made in early 2012 by project partners from PAFO (Khammone Thiravong and Sysavanh Vorlasan) to northeast Thailand to learn more about the seeder from the farmers who use it. An additional visit was made in April 2012 by a World Vision Thailand officer and a Thai farmer to Savannakhet to tutor local farmers and extension staff in the use of the seeder.

In February 2011, Neal Dalgliesh ran two training courses – one for CARDI staff in Phnom Penh and one for iDE staff in Svay Rieng – on establishment and monitoring of Tiny Tag climate loggers, as well as capture, analysis and quality control of climate data.

Training in agricultural extension

Significant training needs assessments were undertaken by DAE in Cambodia and DAEC in Lao PDR. The assessments targeted training needs of provincial and district level extension officers in Svay Rieng province and Savannakhet province, respectively (see Appendix 12 from Annual Report 2011-12 as an example from Cambodia) This assessment formed the foundation of training 25 district and community extension officers in integrated farming and climate change adaptation in Svay Rieng in March 2014, led by DAE. In Lao PDR, a train-the-trainer course in Good Agricultural Practice was held in mid April and was led by DEAC and NAFRI. Subsequently, provincial level training courses for PAFO and DAFO officers from Savannakhet and the two study districts were implemented in May 2014.

A Crawford Fund extension training visit was held in Australia in September 2013, to introduce participants to Australian extension practices (government, private and non-profit services), to broaden awareness of simple crop management tools used by farmers and extension practitioners in Australia and to demonstrate to them successful farming in marginal environments in an Australian context. Participants were Mr Say Tom and Dr Mao Minea (DAE, Cambodia), Mr Sipaseuth and Mr Pasalath Khounsy (NAFRI, Lao PDR), Mr Khammone Thiravong (PAFO, Lao PDR) and Ms Bhagya Laxmi (WASSAN, India). Participants were exposed to three private extension agencies in the Burdekin and on the Darling Downs, to government extension and support for emerging primary industries (rice industry in the Burdekin) and to state government and non-profit (BCG and MSF) extension agencies in southern Australia. They engaged with farmers in dryland

Mallee in South Australia and Victoria and trialled the ADOPT extension tool and climate risk management tools at the Waite campus in Adelaide.

2. Formal capacity initiatives for which ACCA was a catalyst

SRA project for redevelopment and associated training of NAFRI soil analysis laboratory: May 2011

In May 2011, Dr Christian Roth (CSIRO) and Dr Pheng Sengxua (NAFRI, Lao PDR) completed a scoping study to assess the needs and options to redevelop NAFRI's soil analysis laboratory. Funds were granted for an SRA (SMCN/2010/084) and in December 2011, Dr Gavin Gillman (consultant) completed equipment upgrades and undertook development of analytical protocols and training of NAFRI staff.

ACIAR project on developing capacity in cropping systems modelling: August 2011 to June 2013

The first APSIM-ORYZA capacity workshop of project LWR-2010-033 (*Developing capacity in cropping systems modelling to promote food security and the sustainable use of water resources in South Asia*) was held in Dhaka in August 2011 and this has been followed by workshops in November 2011 and May 2012 and concurrent compilation of datasets. Two of the three trainers are from the ACCA project (Don Gaydon and Perry Poulton, CSIRO).

SRA project on dry direct seeding in Lao PDR and drum seeding in Cambodia: April 2013 to December 2014

Additional funds were made available by ACIAR to extend testing of the mechanised establishment tools, as a result of high farmer and extension interest in the seeders and on farm demonstrations during the 2012 wet season in Savannakhet (Lao PDR) and Svay Rieng (Cambodia). Additional objectives for the SRA are to develop and disseminate local language information materials and to support Masters students in Lao PDR and Thailand. Alison Laing (CSIRO) leads this LWR/2012/110 project.

CARDI soil laboratory redevelopment: June 2011

Funding and design was provided by the ACCA project to upgrade the CARDI soil laboratory's water supply so clean water is available for testing, particularly nitrate and ammonium testing.

3. Students and Fellowships

The project supported seven post graduate students:

Liana Williams (CSIRO)

Scale effects: Multi-scale research for resource management and livelihood security. PhD thesis; University of Queensland; expected completion December 2017.

Elizabeth Clarke (ANU)

The synergies of difference: Moving beyond transdisciplinarity. PhD thesis; Australian National University; expected completion July 2017.

Sharmin Afroz (SERDI) - John Allwright Fellowship

Institutions and adaptation to climate change: A livelihoods study in rural south-western coastal Bangladesh. PhD thesis; University of Queensland; Expected completion July 2016.

Souphaphanh Amphonedouangdeth (NUOL)

Study on farmer's adaptation capacity to climate change in Savannakhet Province. MSc thesis; National University of Laos; completed 2011.

Jahangir Kabir (BARI) - John Allwright Fellowship

The sustainability of rice-based farming systems in coastal Bangladesh: A whole-farm economic analysis. PhD thesis; University of Queensland; expected completion December 2015.

Jacob Thomson (UTS) – CSIRO Climate Adaptation Flagship top up funding

Disaster risk reduction within subsistence socio-ecological systems in Lao PDR. PhD thesis; University of Technology Sydney; expected completion December 2015.

Barkat Ullah (IRRI Bangladesh)

Cropping practices in response to climate variability and change: Farmers' adaptation in southwestern coastal Bangladesh; PhD thesis; completed April 2015.

Project personnel were involved in additional significant training activities.

Crawford Fund Master Class on communicating research to stakeholders: December 2011

In December 2011, Dr Chiranjeevi Tallapragada (LNRMI, India) attended a Crawford Fund Master Class on communicating research to stakeholders, with joint funding from the Crawford Fund and the project. The Master Class was held in Chiang Mai and focussed on stakeholder identification and engagement, including use of media and other communication tools.

Australian Government

Australian Centre for International Agricultural Research

Final Report – Volume 2 Appendices – Papers

project	**Developing multi-scale adaptation strategies for farming communities in Cambodia, Laos, Bangladesh, India**
project number	LWR-2008-019
date published	04/04/2016
prepared by	Monica van Wensveen, Liana Williams and Christian Roth (CSIRO)
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Contents

1 Appendices

This is Volume 2 of final report of the ACCA project (LWR/2008/019). The appendices included in this report are referred to in Volume 1 of the Final Report, and are included here to provide a record for ACIAR of key publications that have that have undergone some level of internal peer review prior to future submission to scientific journals.

Appendix 1 – Gaydon et al: Evaluation of APSIM paper

Evaluation of the APSIM model in cropping systems of Asia

Gaydon, DS., Balwinder-Singh., Poulton, PL., Horan, H., Ahmad, B., Ahmed, F., Akther, S., Ali, I., Amarasingha, R., Chaki, AK., Choudhury, BU., Darai, R., Hochman, Z., Hosang, EY., Li, T., Kumar, VP., Khan, ASMMR,. Malaviachichi, W., Rai, GS., Rashid, Md.H., Rathanayake, U., Sarker, MM., Sena, DK., Shammim, M., Subash, N., Suriyagoda, LP., Suriadi, A., Veasna, T., Yadav, RK., and Roth, CH>

Full Draft

Submitted to Environmental Modelling and Software.

Evaluation of the APSIM model in cropping systems of Asia

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[18] Balai Pengkajian Technology Pertanian Nusa Tengarra Barat (BPTPNTB), Indonesia
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ABSTRACT

Resource shortages, driven by climatic, institutional and social changes in many rice-growing regions of Asia, combined with growing imperatives to increase food production whilst ensuring environmental sustainability, are driving research into modified agricultural practices. Well-tested cropping systems models that capture interactions between soil water and nutrient dynamics, crop growth, climate and farmer management can assist in the evaluation of such new agricultural practices. One such cropping systems model is the Agricultural Production Simulator (APSIM). We evaluated APSIM's ability to simulate the performance of cropping systems in Asia from several perspectives: crop phenology, production, water use, soil dynamics (water, nitrogen, and organic carbon) and crop CO_2 response. The evaluation was conducted over a diverse range of environments (11 countries, numerous soils), crops and management practices throughout the region. APSIM's performance was statistically assessed against assembled replicated experimental datasets. For rice, wheat, maize, and cotton the revealed error between simulated and observed production data was within the bounds of the experimental uncertainty, indicating robustness in model performance (eg. for simulated rice crop performance, n = 361, R^2 = 0.83 with low bias (slope, α = 1.1, intercept, β = -246 kg/ha), RMSE = 1084 kg ha^{-1} (cf. SD of measured data = 2038 kg ha^{-1})). The rice dataset (n=361) was disaggregated to separately evaluate APSIM performance for key establishment and cultivation practices in the region (puddled transplanting vs direct-seeding, rainfed vs irrigated, continuously flooded vs alternate wet-and-dry). Robust differentiation and simulation performance was demonstrated, with RMSE's less than observed experimental standard deviations (indicating robust model performance) for all practices. Once properly parameterised and calibrated locally, the model performed well in simulating the diversity of cropping systems to which it was applied, with particular strengths in simulation of multi-crop sequences and specification of realistic dynamics in farmer management practices. APSIM was shown to be a useful tool to investigate production and sustainability issues associated with management change in the cropping systems of Asia, however to keep the model relevant for emerging practices in the region, some areas for future improvement were identified.

266 words

Keywords: APSIM, simulation models, rice, wheat, maize, legumes, Asia, cropping systems, soil water dynamics, soil nutrient dynamics

1. INTRODUCTION

Increasing scarcity of resources (labour, water, and energy), costs of production, and climate variability are the major challenges for sustainability of cereal-based cropping systems in Southern Asia (Gathala et al., 2013), Eastern Asia and for agriculture in general globally (Godfray et al., 2010; Rijsberman 2006). Ensuring sustainability of vulnerable agricultural environments and their support systems (soil and water health) can be added to the list. Rice-based cropping systems, both irrigated and rainfed, represent the most important cropping system in South Asia (Devendra and Thomas, 2002), and an important system throughout Southeast and East Asia. The forthcoming global challenge of producing more food and fibre with limited or reduced resources has been identified by numerous authors (Keating et al., 2010, Ali and Talukder, 2008; Bouman, 2007; Tuong et al., 2005).

Recent studies suggest that the world will need 70 to 100% more food by 2050 (World Bank 2008, Royal Society of London, 2009), and that current trends in population and consumption growth will mean that the global demand for food will increase for at least another 35-40 years (Godfray et al, 2010). Projections indicate that the production of cereals must increase by roughly 2% per annum over the next four decades to ensure food security in South Asia (Ray et al., 2013), or alternately, from a sectoral perspective, the production of rice, wheat, and maize must increase by about 1.1%, 1.7%, and 2.9% per annum, respectively (Gathala et al 2013). To meet this demand sustainably, crop intensification while increasing resource-use efficiency and reducing the environmental footprint, or 'ecological intensification' (Cassman, 1999; Cassman et al., 2003; Ladha et al., 2009; Hochman et al 2013) or 'sustainable intensification' (Royal Society of London, 2009) will be obligatory. For example, the Indian Punjab has been heralded for its technical achievements in past decades but increasingly criticized for leveraging its success on the environment (Jalota et al., 2007). Achieving such gains in productivity whilst reducing degradation of environmental resources will require a holistic systems approach, potentially incorporating the principles of conservation agriculture (CA), and judicious crop rotations (Balasubramanian et al., 2012), amongst other potential adaptations. To complicate matters, any system advancements must be achieved under the overbearing shadow and uncertainty of a changing climate (Godfray et al., 2010)

There is a desire to investigate new practices in Asia with the aim of enhancing water productivity (WP) (Bouman, 2007), and cropping intensity (Dobermann and Witt, 2000) whilst maintaining environmental sustainability (Humphreys et al., 2010). Suggested pathways include the incorporation of non-flooded crops and pastures into traditional rice rotations (Zeng et al., 2007; Singh et al., 2005; Cho et al., 2003), changed agronomic and/or irrigation practices (Gathala et al., 2014; Sudhir-Yadav et al., 2011a; Belder et al., 2007; Bouman and Tuong, 2001), reduction of non-productive water losses (Humphreys et al., 2010), and genetic improvement (Bennett, 2003; Sheehy et al., 2000; Peng et al., 1999). Well-tested simulation models are useful tools to explore opportunities within the context of a holistic systems approach - for increasing system productivity, assessing environmental trade-offs, and the evaluating the effects of a changing climate.

The APSIM cropping systems model (Holzworth et al., 2014; Keating et al., 2003) is such a model, with a proven track record in modelling the performance of diverse cropping systems, rotations, fallowing, crop and environmental dynamics (Whitbread et al., 2010; Carberry et al., 2002; Robertson et al., 2002; Verburg and Bond., 2003; Turpin et al., 1998). APSIM has recently been enhanced to simulate rice-based cropping systems and environmental dynamics of ponded systems (Gaydon et al., 2012a, 2012b). Model evaluation in Australia and Africa is established and well-documented, however limited in Asia due to the only recently developed capability to model rice-based systems predominant in this region. With particular focus on research into adaptation strategies, a notable strength of the APSIM model is it's unique capacity to capture intricate detail and subtleties of farmer management practices through a highly flexible 'Manager' Module allowing the user to specify detailed farmer decision-trees in simple 'if-then-else' logic (Holzworth et al., 2014). The first step in evaluating a model's credentials is to define model capacities required for addressing research questions around some of the aforementioned issues. We suggest that a model for simulation of cropping system performance for Asia should be capable of several key functions: (i) robust yield and phenology simulation for a wide variety of crops; (ii) the ability to examine cropping sequences and the effect of different fallow management and tillage strategies on system performance; (iii) robust simulation of soil water and nutrient dynamics in conjunction with crop performance; (iv) flexibility to capture detailed farmer-imposed management, including subtle changes to farmer decision-trees and strategies, and evaluate their impact on system performance; and (v) robust simulation of crop response to CO_2 and temperature variation (Rötter et al., 2011). Before a researcher should be confident in employing such a model, it should be rigorously tested in a wide variety of environments and management practices.

Several large agricultural research initiatives in the South Asian region of recent years have facilitated a broad assessment of the APSIM model, its strengths, weaknesses and priorities for future development. These include the ACCA project (Roth and Grünbühel, 2012) and the SAARC-Australia Project (Gaydon et al., 2014),the National Science and Technology Support Program of China, the National Basic Research Program of China, and the CSIRO-Chinese Ministry of Education (MOE) PhD Research Fellowship Program (Liu et al., 2013; Wang et al., 2014). Data collected as part of these projects has formed the basis of the evaluation presented here, in addition to several associated datasets.

In this paper, we present details of APSIM evaluation across cropping systems of Asia and critically evaluate its performance, identifying strengths and weaknesses using 42 diverse experimental datasets from 11 countries, covering a broad spectrum of management practices, crop species/varieties, and environments. As part of this process, we document indicated needs for further model improvements.

2. METHODS

2.1. *Overview of the APSIM model*

Detailed descriptions of APSIM are provided by Holzworth et al. (2014) and Keating et al. (2003). Here we merely provide a brief outline. APSIM is a dynamic daily time-step model that combines biophysical and management modules within a central engine to simulate cropping systems. The model is capable of simulating soil water, C, N and P dynamics and their interaction within crop/management systems, driven by daily climate data (solar radiation, maximum and minimum temperatures, rainfall). Daily potential production for a range of crop species is calculated using stage-related *resource use efficiency* (RUE) constrained by climate and available leaf area. The potential production is then limited to actual production on a daily basis by soil water, nitrogen and (for some crop modules) phosphorus availability (Keating et al., 2003). The SOILWAT module uses a multi-layer, cascading approach for the soil water balance following CERES (Jones and Kiniry, 1986). The SURFACEOM module simulates the fate of the above-ground crop residues that can be removed from the system, incorporated into the soil or left to decompose on the soil surface. The SOILN2 module simulates the transformations of C and N in the soil. These include fresh organic matter decomposition, N immobilization, urea hydrolysis, ammonification, nitrification and denitrification. Crop residues tilled into the soil, together with roots from the previous crop, constitute the soil fresh organic matter (FOM) pool. This pool can decompose to form the BIOM (microbial biomass), HUM (humus), and mineral N (NO_3 and NH_4) pools. The BIOM pool notionally represents the more labile soil microbial biomass and microbial products, whilst the more resistant HUM pool represents the rest of the SOM (Probert et al., 1998). APSIM crop modules seek information regarding water and N availability directly from SOILWAT and SOILN modules, for limitation of crop growth on a daily basis. Biological and chemical processes occurring in rice ponds are simulated using the POND module within APSIM (APSIM-Pond, Gaydon et al., 2012b), while crop modules specifically relevant to the evaluation presented in this paper are APSIM-Oryza (Gaydon et al., 2012a), APSIM-Wheat (Wang et al., 2003), APSIM-Maize (Carberry and Abrecht,1991), APSIM-Ozcot (Hearn 1994); APSIM-Soybean (Robertson et al., 2001; Robertson and Carberry, 1998) and APSIM-Canola (used for mustard; Robertson et al., 1999).

2.1 *Description of datasets*

Datasets were assembled from across twelve (11) countries in Asia; Pakistan, India, Bangladesh, Sri Lanka, Nepal, Bhutan, Indonesia, Cambodia, Philippines, China and Japan. Essential criteria included the availability of detailed information on experimental soils, climate, imposed management, and observed crop phenology, final biomass and grain yield. Many datasets possessed additional measurements such as intra-crop biomass measurements, soil water and or nitrogen dynamics, and/or system water balance terms (measured transpiration, evaporation, runoff, drainage etc.). Only datasets with replicated experimental data were used. Experiments covering at least two seasons were essential, for the purposes of both model calibration and subsequent validation. A broad spectrum of cropping environments and crop species/varieties across the region were represented (42 datasets; 959 crops – resulting in a model validation dataset composed of 361 rice crops, 326 wheat, 236 maize, and smaller numbers of cotton, soybean, mustard and canola crops; Table 1). The experiments encapsulated a diverse range of imposed treatments capturing a wide breadth of management practices in Asian agriculture. Several of these were multi-year, multi-crop sequences which included rice in rotations with other non-flooded crops. Table 1 gives a description of each dataset used – geographical location, timeframe, treatments imposed and links to published references for further details.

Insert Table 1 here

2.1.1 *Parameterisation and calibration protocol*

APSIM was *parameterized* for each experiment using reported values for the datasets. Specifically, parameterization refers to the process of supplying the model with input parameters which have been independently measured. The model requires daily values of rainfall, maximum and minimum temperature and solar radiation. Also required were measurable soil physical parameters including layer-based bulk density, saturated water content, field capacity and wilting point. Two parameters, U and CONA, which determine first and second stage soil evaporation (Ritchie, 1972) are also required. The latter parameters were set at 6 mm and 3.5 mm day^{-1}, respectively, values accepted for tropical conditions such as those described here (Probert et al., 1998; Keating et al., 2003). The proportion of water in excess of field capacity that drains to the next layer within a day was specified via a coefficient, SWCON, which varies depending on soil texture. Poorly draining clay soils will characteristically have values <0.5 whilst sandy soils that have high water conductivity can have values >0.8 (Probert et al., 1998). The values for saturated percolation rate (K_s in APSIM, mm day^{-1}) were extracted from published experimental papers and observation. Soil chemical parameters required by APSIM included soil pH, organic C and initial mineral N. The maximum daily algal growth rate was estimated and assumed to be constant between sites (Gaydon et al., 2012b). Other parameters, not directly measured, required iterative *calibration* and are described in the following sections.

2.1.1.1. *Soil organic matter* (*SOM) mineralization*. Because SOM mineralization capacity varies between locations as a function of soil biota ecology and the proportion of SOM in the resistant or lignin pool (inert fraction), the values of the APSIM parameters *Fbiom* and *Finert* (Probert et al., 1998) were calibrated for each experiment using data from zero-N treatments, when available. A certain amount of plant-available mineral N was assumed to come from rainfall and/or irrigation water, and the remainder from mineralization of organic matter for the simulation of these treatments. In the absence of zero-N treatments, estimations were made using values from similar sites. The values of Fbiom and Finert were incrementally varied within physically plausible bounds (Probert et al., 1998) until the simulated indigenous N supply in the zero-N treatments allowed close simulation of the measured crop yields.

2.1.1.2. *Crop phenology*. In simulation of each experiment, crop varieties were calibrated by varying the APSIM crop phenology parameters until the modelled phenology dates matched the observed dates. Usually, the first crop in each dataset was used for this calibration procedure, and subsequent crops were used for model validation. The primary dates of focus were those associated with sowing, transplanting, maximum tillering, panicle initiation, flowering, and physiological maturity.

2.1.1.3 *Crop biomass partitioning.* Observed ratios between grain, straw, and straw components (stems, leaves etc.) were used to calibrate parameters governing allocation of assimilated biomass amongst plant components.

2.1.2 *Validation protocols*

The parameterised and calibrated model was then used to simulate independent years/seasons/crops in each experimental dataset, as a means of checking the veracity of the calibrations. These validation data-pairs (simulated vs observed) were used to evaluate the model's performance from a range of perspectives discussed in the following section.

2.2 *Aspects evaluated*

The model's capacity to simulate crop production (grain yields and above-ground biomass) for different crops (rice, wheat, maize, others), in different environments and under different management practices was the primary aspect evaluated. The combined dataset for rice crops was broken into subsets of rice establishment method (PTR- puddled transplanted rice; or DSR – direct-seeded rice) overlayed with water management (irrigated with (i) continuous flooding (CF); (ii) alternate wetting and drying (AWD); or rainfed (RF) lowland). The large size of the dataset allowed this (361 paired data points), and provided an opportunity for model evaluation for these key rice management options. At this stage in APSIM's application history in Asia, this breakdown process has not been possible for other crops due to smaller dataset size. Other aspects of model performance evaluated were:

- The ability to robustly simulate crop phenology for sowing date trials.
- Simulation of crop sequences – by examining residual error as a function of crop progression (continuous simulation of multiple crops and fallows without resetting soil water and nitrogen variables between crops).
- Soil water and soil carbon dynamics – in conjunction with crop production
- System water balance terms (crop transpiration, soil and pond evaporation, runoff, drainage etc.) and irrigation water use.
- CO_2 response - using free-atmosphere carbon enrichment (FACE) experiments

2.3 *Statistical evaluation methods used*

Linear regression was used to compare paired data-points for measured and simulated grain yield, for both rice and other crops. We determined the slope (α), intercept (β), and coefficient of correlation (R^2) of the linear regression between simulated and measured values. We also evaluated model performance using the Student's t test of means assuming unequal variance P(t), and the absolute square root of the mean squared error, RMSE (equation 1).

$$RMSE = \frac{\sqrt{\sum_{i=1,n}(S_i - O_i)^2}}{n} \quad (1)$$

Where S_i and O_i are simulated and observed values, respectively, and N is the number of pairs. A model reproduces experimental data best when α is 1, β is 0, R^2 is 1, P(t) is larger than 0.05 (indicating observed and simulated data are the same at the 95% confidence level), and the absolute RMSE between simulated and measured values is similar to (and ideally less than) the standard deviation of experimental measurements (representing the error between treatment replicates, or the 'uncertainty' of the measured data). When this criterion is met, it essentially demonstrates the model is predicting the variable of interest within the bounds of observed experimental uncertainty (which is all that a model can ever be expected to do). Statistical comparisons were conducted for subsets of the overall rice dataset, to explore the performance of the model in simulating different establishment practices (PTR and DSR) as well as different water management practices (irrigated, both fully ponded and AWD) and rainfed).

We also calculated the modelling efficiency, *EF* (Willmott, 1981; Krause et al., 2005) as another recognized measure of fit. The modelling efficiency is defined as:

$$EF = 1 - \frac{\sum_{i=1,n} (O_i - S_i)^2}{\sum_{i=1,n} (O_i - \overline{O}_i)^2} \qquad (2)$$

Where ō is the mean of the observed values. A value of *EF* = 1 indicates a perfect model (MSE = 0) and a value of 0 indicates a model for which MSE is equal to the original variability in the measured data. Negative values suggest that the average of the measured values is a better predictor than the model in all cases.

The method outlined by Kobayashi and Salam (2000) was used for a deeper examination of revealed error in the rice grain yield dataset, via decomposition of the mean squared deviation (MSD) components. This method breaks the MSD (= $RMSE^2$) into the numeric sum of three parts (Equation 3); the squared bias (SB), the squared difference between standard deviations (SDSD), and the lack of correlation weighted by the standard deviations (LCS:

$$\text{MSD} = \text{SB} + \text{SDSD} + \text{LCS} \qquad (3)$$

The relative sizes of these three components allow attribution of the relative sources of error. A small value for the SDSD indicates that simulated data exhibits a similar sensitivity to changes in conditions as the observed data – a large value indicates differing sensitivities play a large role in observed error; the LCS reflects the contribution of general correlation to the error; and the relative size of SB is a measure of the bias in the simulated data compared with the observed.

3. RESULTS

3.1 *Crop production*

3.1.1 *Rice*

The major crop represented in our assembled datasets was rice, due to its dominance in Asian cropping systems. A large number of paired data-points (361 crops) allowed segregation into a range of managements, and subsequent evaluation of APSIM model performance in simulating each of those across a range of geographical locations and environments. Considering the combined rice dataset as a whole, the model performed well in simulating above-ground biomass and grain yield (Figure 1 and Table 2).

Insert Fig. 1 here

Insert Table 2 here

The RMSE of 1084 kg ha^{-1} for the combined rice grain yield dataset compares favourably with the standard deviation amongst the observed data and replicates (2038 kg ha^{-1}). This is supported by a strong correlation between simulated and observed data (r^2 = 0.83) with low bias (α = 1.1, β = -246 kg ha^{-1}). The Student's paired T-test (assuming non-equal variances) gave a significance of P(t) = 0.09, indicating that there is no statistical difference between measured and simulated data at the 95% confidence level, while the high overall modelling efficiency, *EF*, of 0.72 indicates the model is performing acceptably. A value of *EF* = 1 indicates a perfect model (MSE = 0) and a value of 0 indicates a model for which MSE is equal to the original variability in the measured data. Hence there is convincing evidence here that APSIM is simulating rice yields well within the bounds of experimental error across a range of varieties, environments and imposed management practices, and its performance must be considered adequate over the range of this diverse Asian dataset.

The analysis of the rice management subsets (Table 3) reveals no particular aspect in which APSIM has performed inadequately (all low RMSE with high modelling efficiencies), however the performance of the model in simulation of PTR is better than DSR (P(t) of 0.69 cf 0.38, combined with EF of 0.85 cf 0.76). Across the water treatments, the simulation of continuously-ponded irrigation performs the best – not surprisingly due to APSIM-Oryza's derivation from ORYZA2000 and CERES-Rice (ponded bio-chemistry and saturated soil environment algorithms) both of which were originally derived for PTR lowland irrigated rice production. This analysis indicates future model improvement efforts are best targeted at process simulation in PTR AWD and DSR RF (and probably DSR AWD, no data available).

3.1.2 *Wheat, maize and other crops*

Wheat, maize and cotton production were similarly simulated well, with RMSE values well within the range of observed experimental variability, P(t) indicating no significant difference between observed and simulated yields at the 95% level, and high modelling efficiencies (EF > 0.7 in all cases) (Figs. 2 and 3; Table 3).

Insert Fig 2 here

Insert Fig 3 here

Insert Table 3 here

Insert Fig. 4 here

Mustard and soybean performance were less robust (Fig 4; Table 3) with significantly lower confidence levels (P(t) and RMSE figures very close to, or greater than, the observed experimental standard deviations. EF values were also negative, suggesting that the average of the measured values is a better predictor than the model in all cases. Given the strong validation of APSIM in simulating these crop species in more data-rich environments outside Asia (Robertson et al., 1999; Robertson and Carberry, 1998) these low figures are almost certainly due to the limited amount of validation data available (number of paired data points for Mustard (8) and Soybean (6)) combined with uncertainties on data quality. More validation work is indicated for these crops in Asia.

3.2 *Crop phenology*

3.2.1 *Rice*

Simulation of rice crop phenology for the two sowing date trials (datasets 13 and 31, Bangladesh and India respectively) indicated strong performance of APSIM in simulation of phenology (and associated yield responses) for both photoperiod-sensitive (Fig. 5) and non-photoperiod sensitive (Fig. 6) rice varieties. However the importance of good calibration for photoperiod sensitivity parameters was clearly indicated (Figs.7 and 8).

Insert Figs. 5 – 8 here

It is important to note that crops in these sowing date trials were fully irrigated, and neither water or nutrient-stressed. Water-stressed conditions (AWD and RF) are handled acceptably (high r^2, low RMSE; data not shown), however, deficiencies are noted in the simulation of N-stressed crops with significant bias indicating poor simulation of rice crop phenological responses to N stress (Table 4a and 4b). This situation arises from a phenological model within APSIM-Oryza and ORYZA2000 (Bouman and van Laar, 2006) developed on non-N-stressed crops and without the current capacity to capture effects of N stress on phenology. Improvement in simulation of this aspect is indicated, however importantly observed simulation errors for both rice grain yield and biomass were within the bounds of experimental uncertainty (standard deviation of observed data) indicating model performance is still acceptable.

Insert Table 4 here

3.2.2 *Wheat and Maize*

Simulation of wheat and maize phenology for validation datasets indicated good correlation ($r^2 > 0.99$) and low error (Figure 5)

3.3 *Ability to simulate crop sequences (without resets)*

The APSIM model was originally conceptualised and developed to simulate cropping sequences and allow research into the impacts on crop production of different fallow management practices and climate variability (Holzworth et al., 2014; Keating et al., 2003). To the best of our knowledge, however, there has been no specific metric used in the scientific literature (relating to crop systems modelling) which allows evaluation of a model's ability to the simulate *system processes* leading to successful modelling of cropping sequences. We have chosen to evaluate the variation in residual error between simulated and observed grain yields as function of progressive crop number in the sequence, to serve this purpose. In other words, the hypothesis is that residual error will not increase with successive crops if system processes are being correctly or adequately simulated. As cropping sequence datasets with appropriate data and the required degree of experimental rigour for all relevant variables are rare in Asia, we focussed on evaluation of three (3) most complete modelled datasets from our assembled selection (datasets # 2 (Suriadi), #4 (Bucher), and #7 (Gazipur)). Figure 9 gives a graphical example of simulated vs observed crop production from one treatment in each of these experiments.

Insert Fig 9. Here

All the simulated versus final observed grain yield measurements for treatments across each of these three experiments were combined in an analysis of residual error and the results illustrated in Fig. 10 as a function of advancing crop number in the sequence.

Insert Fig 10. Here

For each of these crop sequence datasets there is no evidence of a trend in residual error, with the error between simulated and observed yield within the bounds of experimental variability (section 3.1.1). According to our hypothesis, this indicates robust simulation of system processes leading to confidence of acceptable simulation of cropping sequence performance by APSIM in these rice-based systems.

3.4 *Soil water dynamics and system water balance terms*

Experimental datasets in Asia with observed soil water dynamics and measurements of system water balance terms (evaporation, runoff, drainage) in conjunction with crop performance are also rare, however growing in frequency with increasing accessibility and affordability of instruments and data-logging equipment. We used the two most complete datasets from the Indian Punjab to evaluate APSIM performance in simulating soil water dynamics under CF and AWD irrigated rice (dataset #5, Sudhir-Yadav, 2008-09) and under irrigated and rainfed wheat (dataset #28; Balwinder-Singh, 2006-08).

Figs. 11-14 illustrate the performance of APSIM in simulating dataset #5, across four (4) water management treatments in PTR rice. The dynamics of soil water (Fig 11), water-balance terms (Fig 12.) and associated crop production (biomass (Fig.13) and grain yields (Fig.14)) were all simulated well. Accuracy of simulated biomass production decreased with increasing water stress level (Fig. 13), with over-prediction of crop performance indicating the model may be under-estimating the crop stress associated with AWD. Further investigation into specific causes is suggested using more datasets – the bias could be driven by inadequacies in the simulated crop response to the stress, or by the degree of simulated environmental stress imposed on the crop.

Insert Figs 11-14 here

The performance of APSIM in simulating soil water dynamics in non-flooded systems, under crops like wheat, is well established (for example, Verburg and Bond, 2003) and has been subject to greater testing and development over a much longer period, and in a greater spread of environments, than flooded system dynamics. The robust performance of APSIM in simulating soil water dynamics and water balance terms for dataset #28 was therefore not surprising (Fig. 15)

Insert Figs 15-16 here

3.5 *Soil Carbon dynamics*

Soil carbon dynamics were measured and simulated in several Asian dryland cropping datasets, with acceptable performance for maize and wheat systems over 20+ years with a range of fertiliser and stubble treatments (dataset #27, figure 16). Acceptable APSIM simulation of soil carbon levels in a long-term rice cropping system (IRRI long-term cropping experiment) has also been demonstrated (Gaydon et al., 2012b)

3.6 *Response to increases in atmospheric CO_2*

Simulated crop response to increased CO_2 levels is clearly an important criterion in model evaluation for future research needs in Asia relating to climate change. Only a small number of FACE experiments have been conducted with datasets amenable to our analysis. These were rice FACE datasets from Japan and China (datasets #24 and 25). Both rice biomass and grain yield predictions under ambient and increased atmospheric CO_2 concentrations compared well with the experimental data (Fig. 17), and although no replicate variability data was available, we conclude that the model has simulated the observed crop responses within the bounds of experimental error (assumption based on standard error reported in similar trials from the research organisations concerned).

There is no published validation of APSIM's performance to simulate non-rice crop CO_2 response in the Asian context, however evidence of adequate performance simulating wheat for FACE datasets in Australia (O'Leary et al., 2015) and the United States (Asseng et al., 2004).

Insert Fig 17 here

4. DISCUSSION

4.1 *Model performance*

4.1.1 *Grain Yields*

Model evaluation has taken place over a broad spectrum of Asian locations, environments, and crop management practices, with a focus on APSIM's ability to simulate individual crops as well as wider cropping system performance. The model performed comparably well for grain yield with other previous model evaluation studies in the region – for example, rice grain yield was predicted by APSIM with an RMSE of 1084 kg ha^{-1} (variability of observed yields in the assembled dataset (*n*=361) was 2038 kg ha^{-1} (standard deviation) indicating model prediction acceptably within the bounds of experimental uncertainty at a 95% confidence level. This compares very closely with a large-scale evaluation of CERES-Rice (*n* = 250; Timsina and Humphreys, 2006) who reported a RMSE of 1140 kg ha^{-1} with an experimental variability of 1800 kg ha^{-1} in simulating rice grain yield in rice-wheat systems, most of which were in South Asia. In simulating regional experimental wheat yields, APSIM achieved a RMSE of 845 kg ha^{-1} in a dataset with experimental standard deviation of 1794 kg ha^{-1} (*n*=83),once again comparable with CERES-Wheat (n= 137) which reported an RMSE of 480 kg $ha^{-1}$for a dataset (*n*=137) with SD of 1400 kg ha^{-1} (for South Asian only). In conclusion, it appears the models are remarkably similar in their ability to provide acceptable simulation of individual rice and wheat crop performance in the region.

For rice the data indicates that APSIM performs better in simulating PTR than DSR, and better in simulating CF water management than either AWD irrigation or rainfed systems. However simulation of all of these systems indicated no significant difference between simulated and observed rice grain yields at 95% confidence level, hence APSIM's performance across the systems must be categorized as acceptable. Nonetheless, we suggest ongoing improvement effort in simulation of DSR technologies and water management practices likely to produce crop water stress. The reduced performance in these situations likely demonstrates the need to enhance rooting simulation in APSIM-Oryza – an issue already identified and improved in the original ORYZA2000 model (Sudhir-Yadav et al., 2011b)

The evaluation of APSIM for simulation of maize, cotton, soybean and mustard crops in the region indicated reasonable performance within the bounds of limited numbers of datasets (*n* = 28, 8, 10, and 6 respectively), but it should be noted that maize and cotton simulations produced high modelling efficiencies (EF = 0.97 and 0.72 respectively) with low RMSE and high P(t). Given strong validation of these APSIM modules internationally, we suggest that thorough parameterisation and calibration will yield continued good (and improving statistics for) results in Asia. Soybean and mustard crops gave negative modelling efficiencies (EF), which suggests that the average of the measured values is a better predictor than the model for any particular case. This is almost certainly due to the low number of data points (10 and 6 respectively) and further validation and evaluation efforts in Asia is indicated.

4.1.2 *Crop phenology*

APSIM-Oryza demonstrated reliable simulation of rice crop phenology providing care is taken in parameterising and calibrating photoperiod sensitivity. Data from sowing date trials makes this a relatively straightforward task, however the biggest issue for APSIM users in the region will be adequately parameterising photoperiod-sensitive varieties when such data is not available (see Figs. 6 and 7). In our experience from the ACCA and SAARC-Australia projects, the optimum photoperiod parameter (MOPP, hrs) is readily known and available for different rice crop varieties - the greater challenge is selecting a sensible value for photoperiod sensitivity (PSSE). Our suggestion is to use PSSE = 0.1-0.2 for a mildly photoperiod sensitive variety, 0.3 for a medium, and 0.4-0.5 for a strongly photoperiod sensitive rice variety. Of course this is only relevant if different crop sowing dates are a focus of the research question under investigation. If sowing dates are unchanging, then the cultivar phenology can be calibrated under the assumption that PSSE = 0 (non-photoperiod sensitive).

Simulation of crop phenological development is closely tied to success in simulating grain yields. Across the entire rice dataset, APSIM performed acceptably well with no difference between simulated and observed phenology dates at the 95% confidence level – not unrelated to the strong yield prediction performance. In the few (n=5) datasets in which crop N-stress was extreme, the story was different, with clear indication that further improvement of the APSIM-Oryza phenological model is required. In dataset # 1, there was an 11 day (6.4%) error in "time to maturity" under extreme N-stress conditions, cf a 4-day error under mid-range N-stress conditions, cf simulation of an unstressed crop. This translated to a 12% error in total biomass production (extreme to no stress). Although random extreme N-stress conditions are unlikely in commercial rice production, our data indicates improvements would be desirable to APSIM-Oryza's capacity to model N-stress effects on phenology. Unlike other APSIM crops, there is currently no N-stress feedback to phenology in APSIM-Oryza (or the parent model ORYZA2000), unlike the effect of water stress and temperature stress which are described.

4.1.3 *Cropping sequences*

Simulations of diverse cropping sequences up to seven consecutive crops showed no trend of increasing residual error between simulated and observed yields, despite no re-setting of soil parameters (water, nutrients) between crops. This demonstrates reliable simulation of system processes for these rice-based systems, and the reliability of using the APSIM model in research on cropping patterns and their impact on crop productivity and soil and environmental dynamics.

4.1.4 *Soil water dynamics and water balance terms*

Good quality datasets for soil water dynamics and water-balance terms are rare in Southern Asia. For ponded rice (dataset #5, CS and AWD, Sudhir-Yadav et al, 2012a,b) non-flooded maize and wheat crops (dataset #38, rainfed and irrigated wheat , Balwinder-Singh et al, 2011; dataset #28, rainfed and irrigated wheat and maize, Chen et al, 2010a) high correlation was demonstrated by APSIM in simulating soil water balance in individual soil layers and system water-balance terms (input requirement (irrigation), transpiration, evaporation, runoff and drainage). These were achieved in conjunction with sensible simulation of crop production (Figs.12-16), often considered to be a key criterion of "getting the right results for the right reasons" (Gaydon et al., 2012a; both above and below-ground processes correct). Simulation of soil moisture and system water balance using APSIM has been more thoroughly evaluated outside of Southern Asia (for example, Verburg and Bond, 2003), greater rigour possible due to a larger availability of quality datasets in

Australia. Given the added confidence from studies such as these, and the lack of any major differences between soils of southern Asia and the diversity of soils in Australia, we propose confidence in APSIM's capacity to simulate the system water balance terms and soil moisture dynamics. Having a model which is 'capable' is clearly essential, however correct soil parameterisation, calibration and validation procedures will always be important for APSIM users in obtaining robust model performance at a local scale.

4.1.5 *Soil carbon dynamics*

Simulation of sensible soil carbon dynamics in several experiments of 20^+ years in diverse environments and cropping practices (dataset #27, figure 16, wheat-maize in China with a range of fertiliser and stubble treatments; and continuous flooded rice in the IRRI long-term cropping experiment, Gaydon et al 2012b) indicates confidence in APSIM's ability to represent the sustainability of the diversity of cropping practices to be encountered in Asia.

4.1.6 *Response to CO_2*

Confidence in a model's capacity to respond sensibly to changes in CO2 is a pre-requisite to its successful employment in climate change studies, either on impacts or adaptations. We used FACE datasets for rice from Japan and China for this evaluation. On the basis of this limited available data, we conclude that APSIM is capable of sensibly simulating CO_2 response of rice crops in the region under non-stressed water conditions (Fig. 17) and across a range of N-stress conditions imposed in these FACE experiments. Further data evaluating potential interaction between water stress, nitrogen, and CO_2 would provide enhanced confidence in model performance, particularly for simulation of rainfed rice systems in future climates.

4.2 *General comments on model applicability and limitations*

Many of the looming research questions for the south Asian region relate to development of best management practices for cropping systems within their local environmental and socio-economic constraints - aiming to maximising land and/or water productivity whilst minimising negative environmental outcomes (Godfray et al, 2010). In this regard we have demonstrated APSIM's capacity to reliably simulate sequences of crops and system dynamics over a broad expanse of Asian agriculture, in addition to gaining some confidence in the model's response to increasing CO_2. The APSIM model is particularly strong in its capacity to simulate detailed farmer management practices and decision-trees (Holzworth et al., 2014; Keating et al, 2003), allowing simulations to reflect how farmers will actually respond in different seasons and conditions. This makes APSIM a robust choice for a cropping systems model when the research questions centre around development of adaptation strategies to external forces of change. This analysis has highlighted numerous strengths, however has also identified some aspects which limit APSIM's applicability. These include (i) a current inability to simulate GHG emissions associated with different adaption options; (ii) an inability to quantify the limitations placed by shortages in micro-nutrients (and consequently how to manage them within local resource constraints – an issue relevant to poorer parts of Southern Asia), and also (iii) an ability to simulate rice crop responses to salinity and submergence which are of growing relevance to the major rice-growing deltas of South and Southeast Asia (Ganges-Brahmaputra, Irrawaddy, Chao Prahya, Mekong) threatened by rising seas levels and a changing climate.

4.3 *Future improvements indicated*

Needs for future improvements to APSIM for application in Asian rice –based cropping systems can be derived from our model evaluation against experimental data. In brief terms, the improvements suggested are listed below under categorical headings:

General rice crop issues:

- better description of rice rooting (to improve simulation of crop response to drought stress in irrigated AWD and RF managements)
- improved phenology modelling for extremes of N-stress
- response to submergence
- response to salinity
- response to limitations in micro-nutrients.

Climate change issues:

- sensible GHG emissions quantification for rice-based systems (further development work to segregate emissions into specific pools (N_2, NO_2, N_2O, CO_2, CH_4))
- high temperature response (all crops)
- low temperature injury (all crops)

Conservation agriculture related issues:

- water and nutrient dynamics in raised bed systems
- improved description of wheat and maize phenology under mulch
- more realistic dynamics of soil parameters after tillage
- water-use considerations and soil cracking in AWD irrigation
- better simulation of emergence in direct-seeded crops (all crops)

5. CONCLUSIONS

APSIM has been shown to perform in a statistically acceptable manner in simulating rice-based cropping system performance over a wide variety of environments and management practices in southern and south eastern Asia Aspects evaluated include individual crop production and phenology (rice, wheat, others); cropping sequences, soil water and nutrient dynamics, and crop response to CO_2. Our analysis indicates that APSIM performs better in simulating PTR than DSR, and better in simulating continuously-flooded water management than either AWD irrigation or rainfed systems in rice production. However simulation of each of these important systems indicated no significant difference between simulated and observed rice grain yields at 95% confidence level, hence APSIM's performance across the systems can still be categorized as , and within the range of experimental data uncertainty. Similarly, performance in simulating the other major crops of the region, maize and wheat, were shown to be well within the bounds of experimental error. Desirable improvements and features for future model implementation have been identified to better position APSIM as a useful tool for adaptation research into the future. These include aspects related to conservation agriculture and responses to extremes of temperature, as well as aspects more specific to Southern Asia such as shortages of micro-nutrients.

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Table 1

Details of field experiments used in the calibration and validation of the APSIM model (PTR-puddled transplanted rice; DSR-direct-seeded rice; DS-direct-seeded; B-broadcast; R-rice; S-soybean; W-wheat; B-barley; M-maize; Mus-mustard; CF-continually ponded/submerged; AWD-alternate wet and dry; I-irrigated; RF-rainfed; das – days after sowing; NCP – North China Plain; UP-Uttar Pradesh)

Dataset No.	Reference	Location	Years	Crops	Estab	Treatments
1	Buresh et al (1988)	Pila, Philippines	1985	**Rice** (IR58	PTR	Five (5) N treatments (0,30,60,90,120 kgN/ha)
2	Suriadi et al (2009)	Lombok, Indonesia	2007-09	**Rice** (cigeulis) **Soybean** (wilis)	PTR DS	R-R-S-R-R rotation; two (2) water treatments (CS,AWD); three (3) N treatments:- 0,69,138 kg N/ha/crop
3	Boling et al (2004)	Java, Indonesia	1997-2000	**Rice** (IR64)	DSR PTR	Six (6) consecutive rice crops (wet (DSR) and dry (PTR) seasons); three (3) N treatments: 0,120,144 kg N ha^{-1} $crop^{-1}$; two (2) water treatments (I,RF)
4	Bucher et al (2001)	Los Baños, Philippines	1996-2000	**Rice** (IR72)	PTR	Seven (7) consecutive rice crops; +/- straw, early/late straw incorporation
5	Sudhir-Yadav et al (2011a,b)	Punjab, India	2008-09	**Rice** (PAU-201)	PTR DSR	Two (2) establishment methods (PTR,DSR); four (4) irrigation treatments (daily (CF), and AWD at soil water tensions (20cm depth) of 20, 40 and 70 kPa.
6	Yadvinder-Singh et al (2009)	Punjab, India	2003-05	**Rice** (PR115)	PTR	CF – one crop per year
7	Gaydon et al (2013)	Gazipur, Bangladesh	2010-13	**Rice** (BRRI Dhan 28,29, 48, 49); **Maize** (BARI Hybrid 7); **Mustard** (BARI	PTR DS DS	Four (4) cropping sequences; (i) boro rice – fallow – T.Aman rice; (ii) boro rice – T.Aus rice – T.Aman rice; (iii) Mustard – T.Aus rice – T.Aman rice; and (iv) maize – mungbean – T.Aman rice.

				Sarisha-15); **Mungbean** (BARI Mung-6)	DS DS	
8	Gaydon et al (2013)	Dacope, Bangladesh	2010-13	**Rice** (Nonakachi – local variety; BR23; BRRI Dhan 47);	PTR	Four (4) cropping sequences; (i) fallow - fallow - T. Aman rice (Nonakachi); (ii) fallow - Fallow - T. Aman rice (modern variety-BR23); (iii) cowpea - fallow - T. Aman rice (BR23); and (iv) Boro rice (BRRI dhan47) - Fallow - T.Aman rice (BR23)
				Cowpea (BARI Felon-1)	DS	
9	Gaydon et al (2013)	Satkhira, Bangladesh	2010-13	**Rice** (Nonakachi – local variety; BR23; BRRI Dhan 47);	PTR	Four (4) cropping sequences; (i) fallow - fallow - T. Aman rice (Nonakachi); (ii) fallow - Fallow - T. Aman rice (modern variety-BR23); (iii) cowpea - fallow - T. Aman rice (BR23); and (iv) Boro rice (BRRI dhan47) - Fallow - T.Aman rice (BR23)
				Cowpea (BARI Felon-1)	DS	
10	Gaydon et al (2014)	Satkhira, Bangladesh	2013-14	**Rice** (BRRI Dhan-47)	PTR	Three (3) salinity treatments; boro rice irrigated (CF) with (i) fresh water; (ii) mixed fresh and saline water; and (iii) saline water (dynamically changing in local canal)
11	Radanielson et al (2014)	Infanta, Philippines	2013-14	**Rice** (IR64	PTR	Four (4) salinity treatments; rice irrigated (CF) with (i) fresh water; (ii) alternate fresh and saline water (1 week intervals); (iii) alternate fresh and saline water (2 week intervals); and (iv)

						saline water
12	Radanielson et al (2014)	Los Baños, Philippines	2012-13	**Rice** (IR64)	PTR	Four (4) salinity treatments; rice irrigated (CF) with (i) fresh water; (ii) 4 dS m^{-1} ; (iii) 8 dS m^{-1}; and (iv) 12 dS m^{-1}. Two crops per year (wet and dry seasons)
13	Rashid et al (2009)	Chuadanga, Bangladesh	2005-07	**Rice** (BRRI Dhan-28, BR11)	DSR	Sowing date trial – two (2) seasons each of (i) T.Aman rice (BR11) and (ii) boro rice (DRRI Dhan-28). Five (5) sowing dates for T.Aman; Eight (8) sowing dates for boro.
14	Sena et al (2014)	Karnal, India	2009-11	**Rice** (CSR36; CSR30)	PTR DSR	Three (3) years; two (2) establishment treatments; two (2) varieties; three (3) N fertiliser rates (60, 80, 100 kgN ha^{-1} (for CSR30); 120, 150, 180 kgN ha^{-1} (for CSR30))
15	Choudhury et al (2014)	Meghalaya, India	2009-11	**Rice** (Shahsarang)	PTR	Three (3) seasons; early transplant (7^{th} July); 90 kg N ha^{-1}
16	Subash et al (2014)	Modipuram, UP, India	2007-09	**Rice** (PR106) **Wheat** (PBW343)	PTR DS	R-W-R-W cropping sequence (4 crops)
17	Kumar et al (2014)	Faizabad, UP, India	2000-03, 2010	**Rice** (Sarjoo-52)	PTR	Three (3) dates of transplanting (10 June, 20 June, 30 June)
18	Rathnayake et al (2014)	Batalagoda, Sri Lanka	2010-12	**Rice** (BG366, BGG00, BG250)	DSR	Two (2) crops; three (3) varieties, rainfed conditions
19	Suriyagoda et al (2006); Suriyagoda and Peiris (2014)	Maha-Illuppallama , Sri Lanka	2006-07, 2011	**Rice** (BG300)	DSR	Irrigated with four (4) fertiliser applications (in kg urea ha^{-1}) – 12.5 (basal), 62.5 (14 das), 100 (42 das), 50 (56 das).
20	Suriyagoda et al (2015)	6 dry-zone locations, Sri Lanka	2000-11	**Rice** (BG300, BG359)	DSR	Recommended agronomic practice; varying dates of sowing; varying seasonal climatic conditions over 12 year period

21	Darai et al (2014)	Nepalgunj, Mid-Western Terrai, Nepal	2003-07	**Rice** (Radha-4) **Wheat** (Gautam	PTR DS	Two sequential crops per year for seven years; several N treatment ranging from 0-100 kg N ha^{-1} as well as a 10 t ha^{-1} farmyard manure.;
22	Ganja S. Rai (2014)	Bhur, Bhutan	2010	**Rice** (RC68, IR72, IR780, Bhur Kambja2)	PTR	Four (4) rice varieties; recommended agronomic practice
23	Ahmad et al (2014)	Pothowar, Pakistan	2011-12	**Wheat** (Chakwal-50)	DS	Four (4) irrigation treatments – (i) irrigated to 100% of crop requirement; (ii) 80%; (iii) 60%; and (iv) non-irrigated/rainfed
24	Kim et al (2003)	Shizukuishi, Japan	1998-2000	**Rice** (Akitakomachi)	PTR	Two (2) CO_2 treatments – (i) ambient (350-370 ppm) and (ii) FACE (580-645ppm) ; three (3) N treatments (4, 8, 12 g N m^{-2})
25	Yang et al (2006; 2008)	Wuxi, China	2002-03	**Rice** (Wuxiangjing 14)	PTR	Two (2) CO_2 treatments – (i) ambient (370 ppm) and (ii) FACE (570ppm) ; three (3) N treatments (15, 25, 35 g N m^{-2})
26	Liu et al (2013)	NCP, China	1981-2009	**Rice** (51 local cultivars)	PTR	Cultivar performance under unlimited water and N conditions over 29 years
27	Wang, G.C. et al (2014)	NCP, China	1989-2003	**Wheat** (local vars) **Maize** (local vars)	DS	fertilizer application rate, number of irrigations, and +/- residue
28	Chen et al (2010a)	Luancheng, Hebei, China	1998-2001	**Wheat** (Gaoyou No. 503) **Maize** (Yandan No. 21)	DS	Maize-wheat double-cropping, number of irrigations (0-5)
29	Xiao & Tao (2014)	NCP, China	1980-2009	**Wheat** (cultivar-80, cultivar-00)	DS	Locations x 4, cultivar x 2, N fertilizer rate x 2

30	Wang, J. et al (2013)	Tangyin, NCP, China	1990-1999 2011	**Wheat** (local varieties)	DS	Winter Wheat – Summer Maize rotation, measuring change in wheat phenology across seasons.
31	C. Chen et al (2010b)	Luancheng, Yucheng, Fengqiu – NCP, China	1998-2006	**Wheat** (Gaoyou 503, Zhixuan 1, Keyu 13, Zhengmai 9023) **Maize** (Yandan 21, Yedan 22, 981, Zhengdan 958)	DS	Maize-wheat double-cropping with imposed irrigation treatments
32	Dong et al	Northern China	1981-2003	**Maize** (dongnong 248, Zhongdan 2, Zhengdan 958)	DS	Spring maize production, four (4) regions, three (3) varieties.
33	Zhang et al (2012)	NCP, China	2008-2010	**Wheat** (Nongda211, Han6172, Yanzhan4110)	DS	Three (3) locations; three (3) sowing dates (early, mid, late); three (3) plant densities (150, 300 and 450 plants m^{-2}
34	Wang, S. et al (2012)	Yangtze River Basin, China	2006-2008	**Canola** (Xiangzayou, Zhongshuang , Ningza,	DS	Three (3) sites (Nanjing, Wuhan, and Shimen); three (3) varieties; and six (6) sowing dates.
35	Liu et al (2012)	North-East China	1983-2007	**Maize** (ten hybrids)	DS	Ten (10) sites; ten (10) varieties (one per site)
36	Hochman et al (2015)	Andhra Pradesh, India	2011	**Rice** (WGL-14, BPT-5204, Kavya); **Cotton** (Neeraja, Ankur, Brahma)	PTR DS	Irrigated rice, three (3) varieties, three (3) locations, two (2) practices – recommended and SRI; Cotton – three (3) varieties.

37	Poulton et al (2014)	CARDI, Phnom Penh, Cambodia	2006-08	**Rice** (numerous)	PTR	Fifteen (15) varieties, across three (3) maturity classes (short, medium, long) grown according to recommended practice.
38	Balwinder-Singh et al (2011)	Punjab, India	2009-10	**Wheat** (PBW343)	DS	Two (2) surface residue treatments (+/- mulch); over six (6) irrigation treatments
39	Carberry et al (2011)	Southern Bangladesh	2011-12	**Wheat, Mustard** (numerous)	DS	Seed replication trials in Noakhali, Bhola, Barisal, Jhalakati, all in Southern Bangladesh.
40	Evert Y. Hosang (2014)	Kupang, West Timor, Indonesia	2011	**Maize** (white maize landrace A, B and C; Piet Kuning)	DS	Four 4) varieties; three (3) N application rates (0, 50 and 100 kg ha^{-1} of Urea)
41	Raji Redy (1990?)	Andhra Pradesh, India	1994-95	**Rice** (BPT-5204)	PTR	Sowing date trial; eleven (11) sowing dates, June – January
42	Carberry et al., (2008)	Jessore, Noakhali, Kasipur, Bangladesh	2003-05	**Wheat** (local varieties)	DS	Three (3) locations; four (4) irrigation treatments – (i) rainfed, (ii) 1 irrig, (iii) 2 irrigations, and (iv) three irrigations.

Table 2. Statistics for observed vs simulated RICE grain yield (across different cultivation/irrigation practices)

Crop	Est	Water	*n*	X_{obs}(SD) (kg ha^{-1})	X_{sim}(SD) (kg ha^{-1})	P(t*)	α	β (kg ha^{-1})	R^2	RMSE (kg ha^{-1})	EF
RICE	PTR	CS	218	6250 (2065)	6619 (2563)	0.1	1.1	-250	0.79	1260	0.63
		AWD	18	5385 (1222)	5947 (1513)	0.23	1.1	16	0.79	884	0.79
		RF	29	3547 (1417)	3377 (1867)	0.7	1.24	1037	0.88	714	0.88
		(all PTR)	265	5896 (2131)	6218 (2634)	0.69	1.12	-379	0.83	1019	0.85
	DSR	CS	47	5232 (1103)	5308 (1112)	0.74	0.93	433	0.85	432	0.84
		AWD	0	-	-	-	-	-	-	-	-
		RF	49	4254 (1590)	4555 (1789)	0.38	0.99	358	0.77	903	0.67
		(all DSR)	96	4733 (1452)	4923 (1536)	0.38	0.95	444	0.79	712	0.76
Overall Combined			361	5587 (2038)	5874 (2458)	0.09	1.1	-246	0.83	1084	0.72

Est, crop establishment method (PTR – puddled transplanted rice; DSR – direct-seeded rice); *Water*, water supply method (CS – irrigated and continuously submerged; AWD – irrigated with alternate wetting and drying; RF – rainfed lowland); X_{obs}, mean of measured values; X_{sim}, mean of simulated values; SD, standard deviation; *n*, number of data pairs; P(t*), significance of Student's paired t-test assuming non-equal variances; α, slope of linear regression between simulated and measured values; β, y-intercept of linear regression between simulated and measured values; R^2, square of linear correlation coefficient between simulated and measured values; RMSE, absolute root mean squared error; EF, the modelling efficiency.

* values greater than 0.05 indicates simulated and measured values are the same at 95% confidence level.

Table 3. Statistics for observed vs simulated WHEAT, MAIZE, COTTON, SOYBEAN, and MUSTARD grain yield

Crop	*n*	X_{obs}(SD) (kg ha^{-1})	X_{sim}(SD) (kg ha^{-1})	P(t*)	α	β (kg ha^{-1})	R^2	RMSE (kg ha^{-1})	EF
WHEAT	326	4397 (1794)	4272 (1818)	0.38	0.90	296	0.79	845	0.78
MAIZE	236	5972 (2408)	5973 (2523)	0.99	0.96	232	0.85	1004	0.83
COTTON	8	1769 (617)	1627 (603)	0.65	0.87	89	0.79	303	0.72
MUSTARD	10	1041 (485)	1433 (378)	0.06	0.57	836	0.55	502	-0.19
SOYBEAN	6	2152 (139)	2055 (84)	0.18	-0.44	2999	0.53	214	-1.83
CANOLA	19	2191 (769)	2026 (622)	0.47	0.68	545	0.71	444	0.65

X_{obs}, mean of measured values; X_{sim}, mean of simulated values; SD, standard deviation; *n*, number of data pairs; P(t*), significance of Student's paired t-test assuming non-equal variances; α, slope of linear regression between simulated and measured values; β, y-intercept of linear regression between simulated and measured values; R^2, square of linear correlation coefficient between simulated and measured values; RMSE, absolute root mean squared error; EF, the modelling efficiency.

* means simulated and measured values are the same at 95% confidence level.

Table 4a. Comparing simulated vs observed grain yield and phenology data for APSIM-Oryza using a non-changing rice variety vs a phenology-matched variety for each N-fertiliser treatment, for dataset # 1 (Buresh et al, 1985).

N-treatment (kg N ha^{-1})	**Observed crop yield and season length** (kg ha^{-1} ; days)	**Simulated crop yield and season length** (kg ha^{-1} ; day of year)	
		Unchanging varietal calibration (fixed for 60N treatment)	Phenology-matched calibration (phenology calibrated for each N treatment)
0	3910; 102	3791; 110	3491; 103
30	5072; 107	4561; 110	4509; 108
60	5890; 109	5017; 110	5017; 110
90	6420; 112	5342; 110	5479; 112
120	6700; 113	5546; 110	5780; 113

Table 4b. Indices comparing simulated vs observed data for APSIM-Oryza using a non-changing rice variety vs a phenology-matched variety for each N-fertiliser treatment, dataset #1 (Buresh et al, 1985). The observed standard deviations were 1998 kg ha-1 for biomass, and 1129 kg ha-1 for yield

	BIOMASS		GRAIN YIELD	
	R^2	RMSE	R^2	RMSE
Unchanging variety	0.969	1430	0.9989	841
Phenology-matched variety	0.980	952	0.9958	773

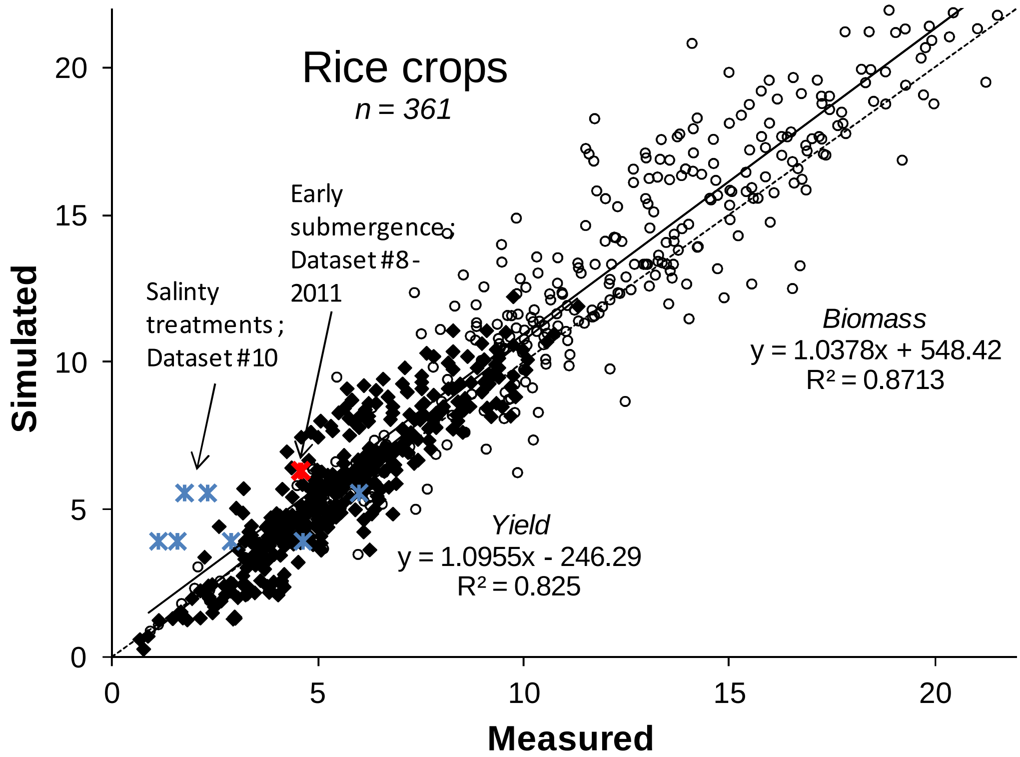


Fig. 1. Comparison between measured and simulated rice grain yields and above-ground biomass (Mg ha^{-1})

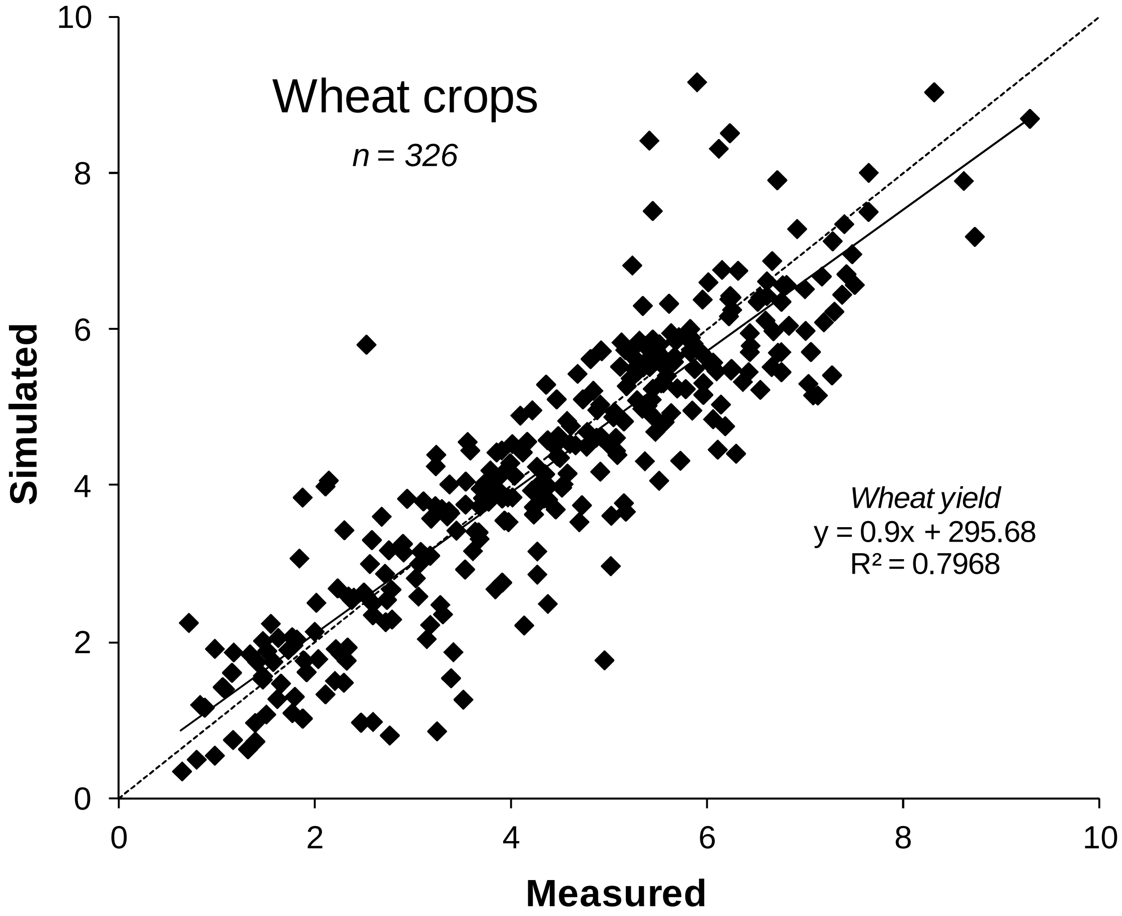


Fig. 2. Comparison between measured and simulated wheat grain yields (Mg ha^{-1})

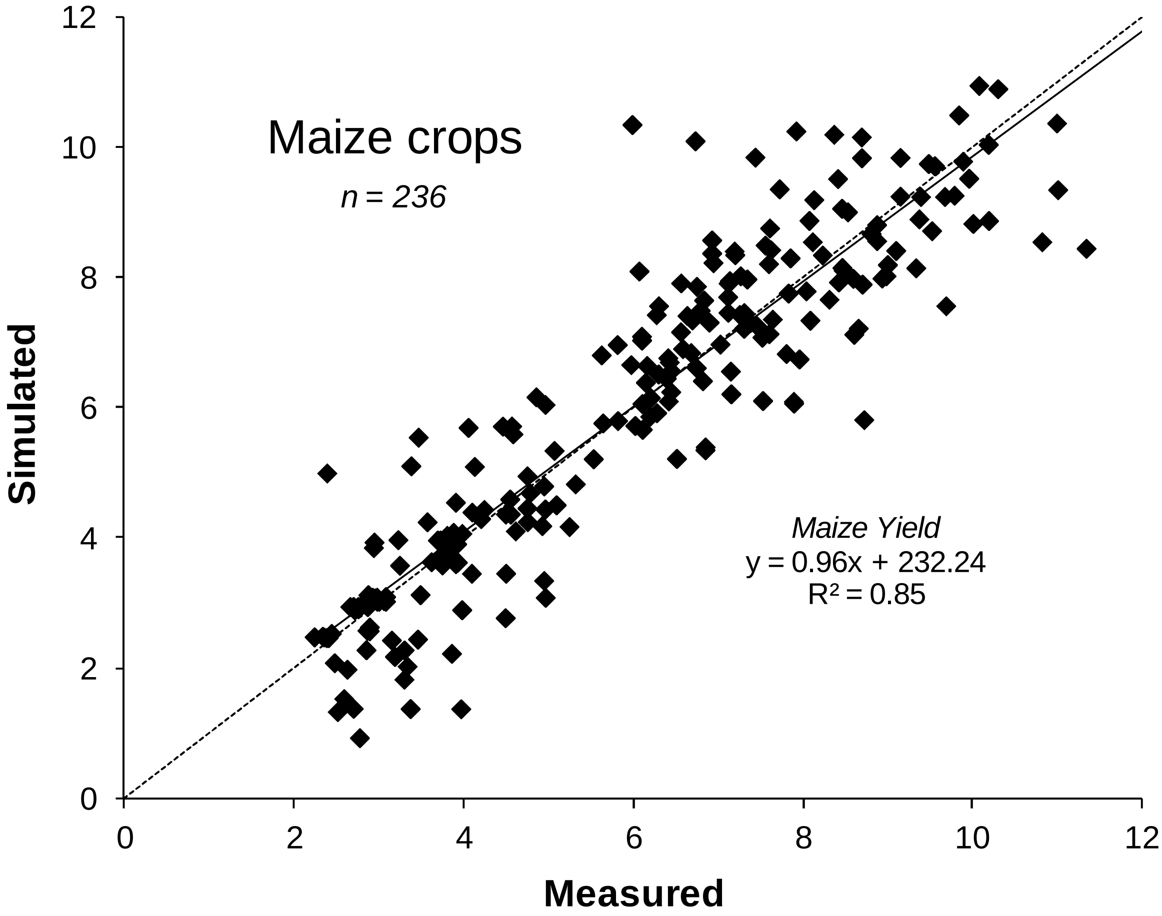


Fig. 3. Comparison between measured and simulated maize grain yields (Mg ha^{-1})

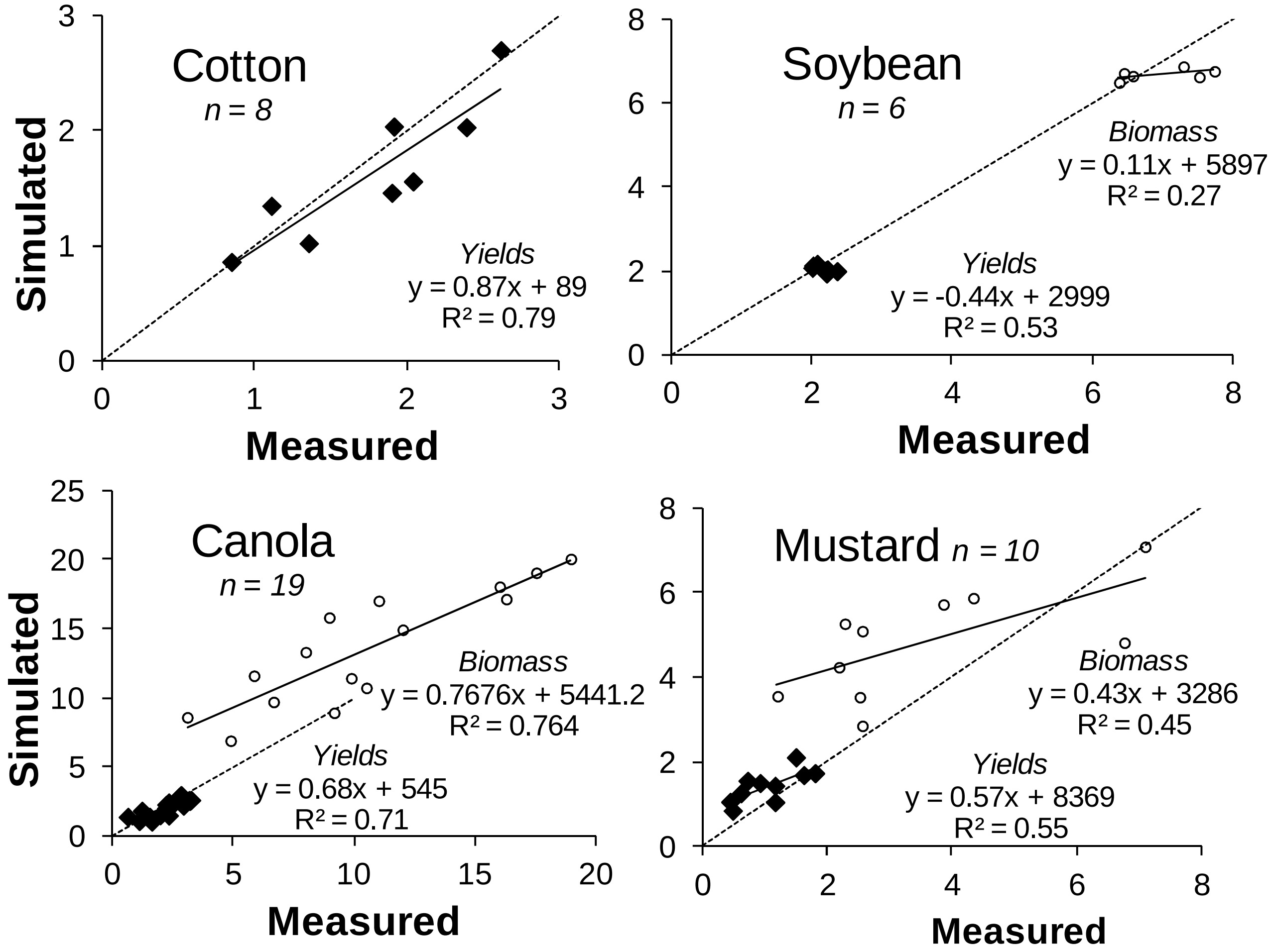


Fig. 4. Comparison between measured and simulated grain yields and above-ground biomass (Mg ha^{-1}) for cotton, soybean, mustard, and canola

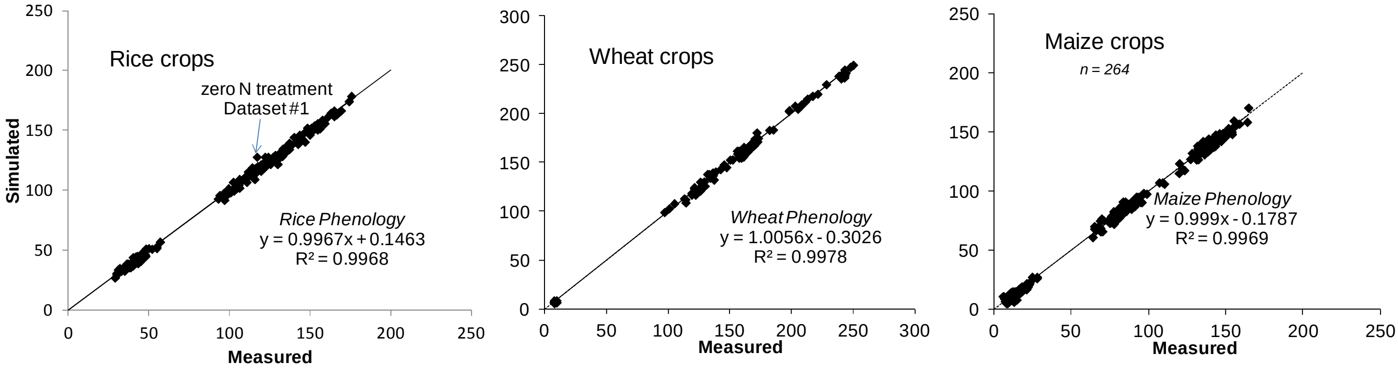


Fig. 5. Comparison between measured and simulated phenology dates for rice, wheat and maize (validation datasets only shown)

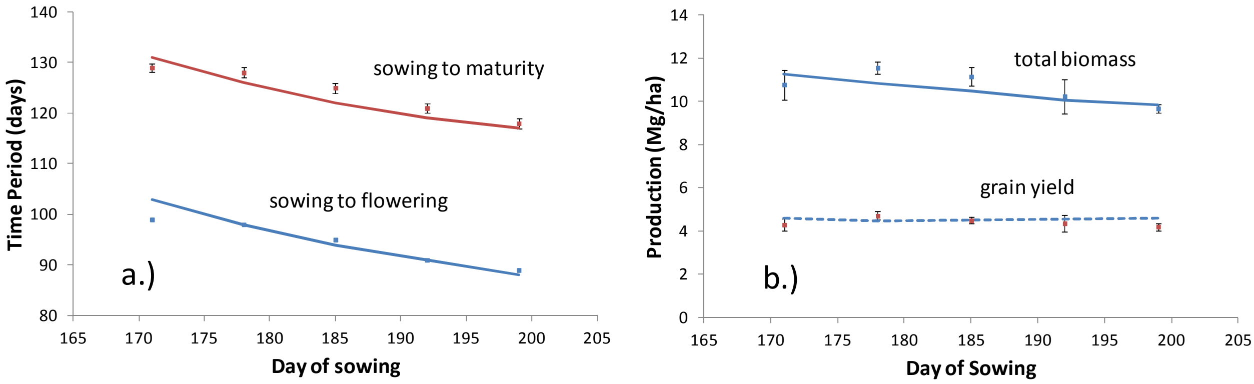
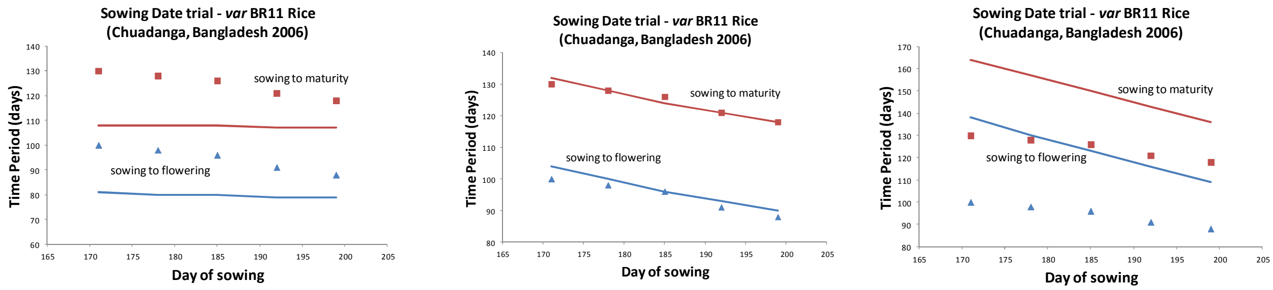


Fig. 6. Simulated and observed data for a T.Aman rice sowing date trial, Chuadanga, Bangladesh (Dataset #13; Rashid et al., 2009). Graphs show **a.)** crop phenology; and **b.)** crop production, for a strongly photoperiod-sensitive rice cultivar (BR11).

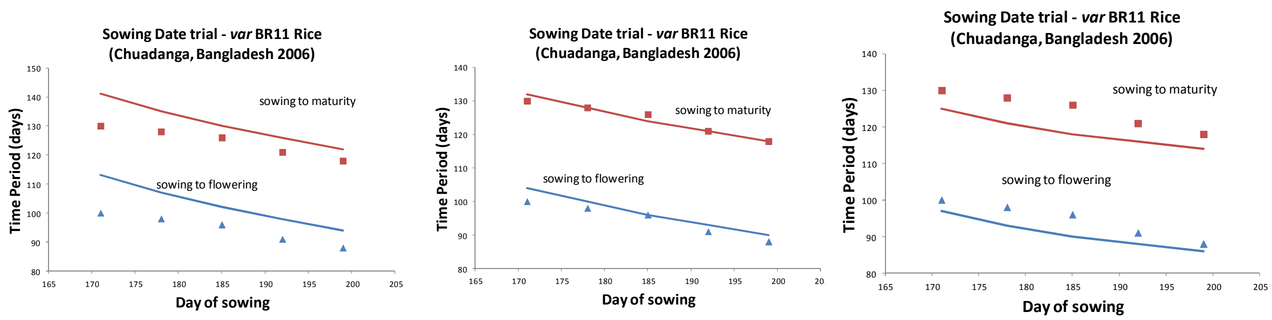


PSSE = 0.2

Photoperiod sensitivity,
PSSE = 0.3

PSSE = 0.4

Fig. 7. Sensitivity of APSIM-Oryza varietal photoperiod sensitivity parameter (PSSE) in simulation of rice sowing date trial, Chuadanga, Bangladesh (Dataset # 13; Rashid et al., 2009).



MOPP = 11.0

Maximum optimum
photoperiod (hr),
MOPP = 11.2

MOPP = 11.4

Fig. 8. Sensitivity of APSIM-Oryza varietal optimum photoperiod parameter (MOPP) in simulation of rice sowing date trial, Chuadanga, Bangladesh (Dataset # 13; Rashid et al., 2009).

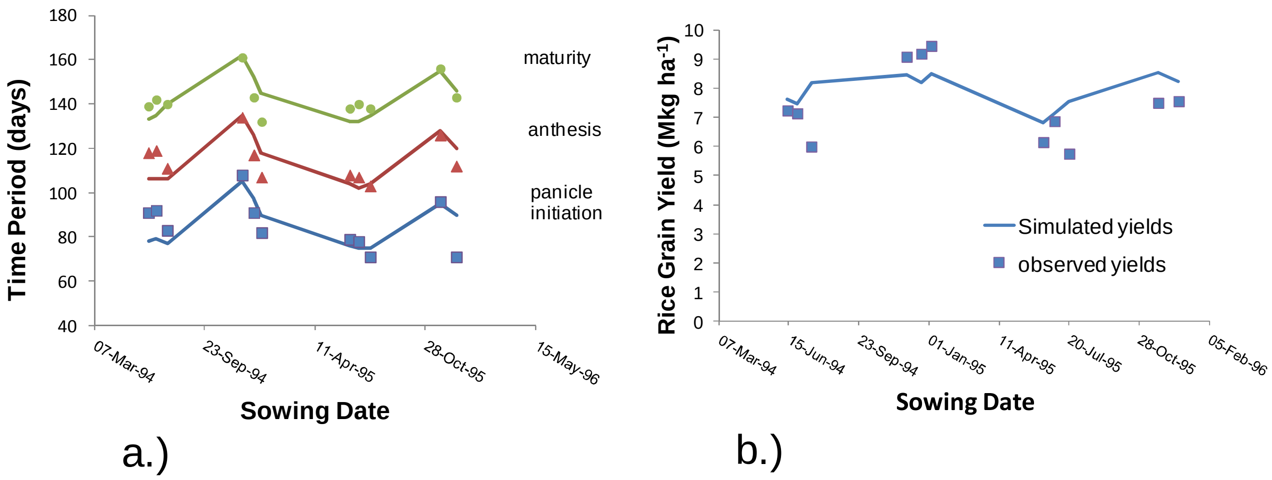


Fig. 9. Simulated and observed data for a rice sowing date trial over two years, Andhra Pradesh, India (Redy et al., 2010; dataset #41). Graphs show **a.)** crop phenology; and **b.)** crop production, for a non-photoperiod-sensitive rice cultivar (BPT-5024), in contrast to figures 12-14.

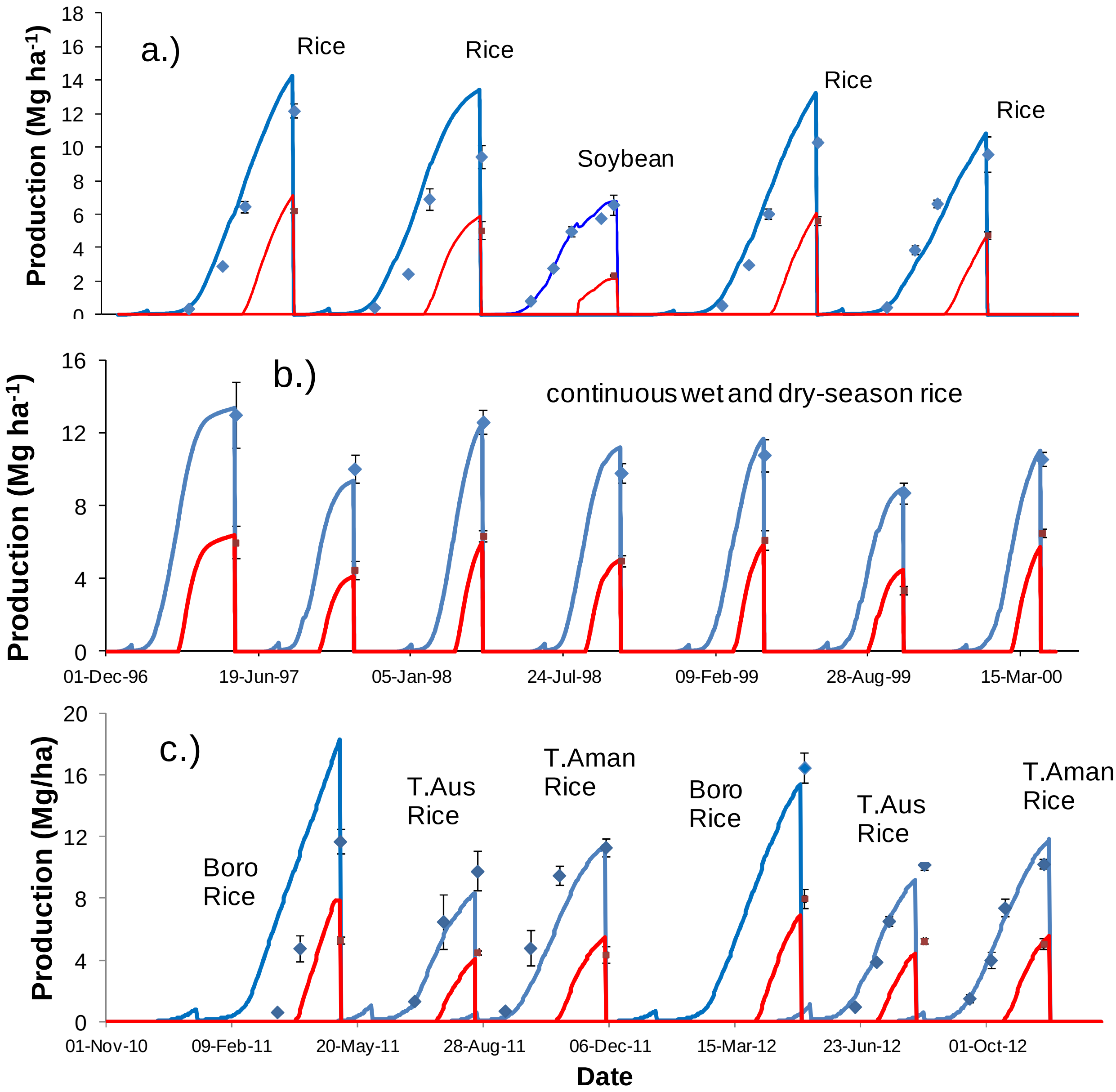


Fig. 10. Three example multi-crop sequence experiments in rice-based systems, simulated using APSIM - each conducted with continuous simulation of multiple crops and fallows without resetting soil variables (water and nutrients) between crops. Treatments illustrated: - (a) Suriadi et al., 2009 (N=150 kg ha^{-1}, continuous flooding, Lombok, Indonesia; dataset # 2); (b) Boucher 2001 (late tillage, minus straw, plus N, at IRRI Los Baños, Philippines; dataset # 4); (c) Gaydon et al., 2013 (T2 – boro-T.Aus-T.Aman rotation at Gazipur, Bangladesh; dataset # 7). The continuous lines represent model output; the discrete points with error bars are the observed values (error bars representing one standard deviation either side of the mean). The blue is above-ground biomass, the red is grain yield.

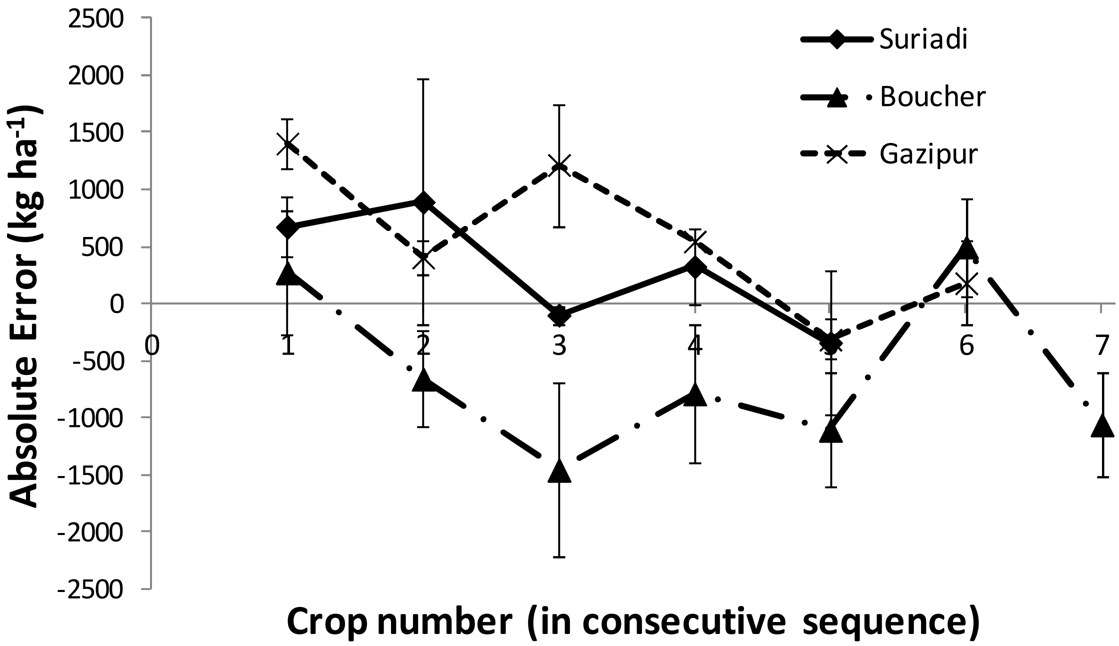


Fig. 11. The dynamics of absolute error in grain yield (kg ha^{-1}) with advancing crop number in three APSIM simulated crop sequence experiments, each conducted with continuous simulation of multiple crops and fallows without resetting soil variables (water and nutrients) between crops. (a) Suriadi et al., 2009 (dataset # 2); (b) Boucher 2001 (dataset # 4); (c) Gaydon et al., 2013 (dataset # 7). The data points above were generated using average error across all treatments in each dataset, and the standard deviation across those treatments.

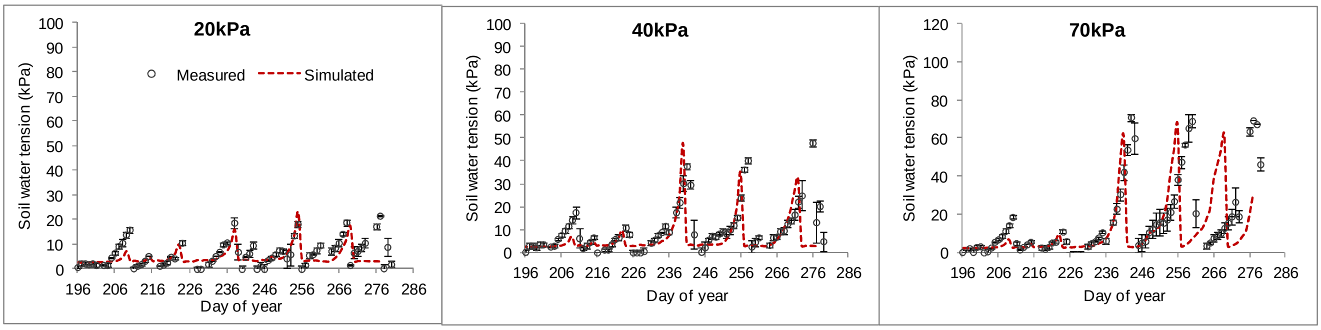


Fig. 12a. Comparison between measured and simulated soil moisture (kPa – 0-15cms) for different water-stress treatments in rice irrigation, Punjab, India – (i) CS – control, continuously submerged/flooded; (ii) AWD, re-flooded at soil suction of 20kPa; (iii) AWD, 40kPa; and (iv) AWD, 70 kPa, for the experiments of Sudhir-Yadav et al (2011) (Dataset #5).

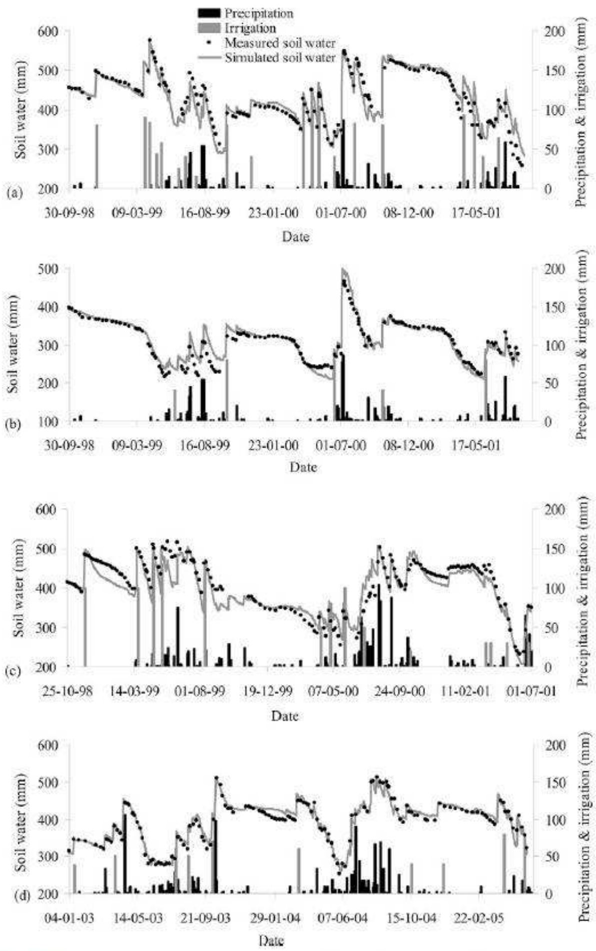


Fig. 8. Simulated and measured soil water in the 0 to 160 cm soil profile at Luancheng (1998–2001) under (a) irrigation applied during critical crop growth stages and (b) irrigation only applied at sowing, and the 0 to 150 cm soil profile at Yucheng (c) (1998–2001) and (d) (2003–2005).

Fig. 12b. Comparison between measured and simulated soil moisture (mm – 0-160cms) for irrigation treatments in wheat irrigation at Luancheng, China, 1998-2001 – (i) irrigation at critical growth stages; (ii) irrigation at sowing only; (iii) at Yucheng (iv) AWD, 70 kPa, for the experiments of Chen et al (2010) (Dataset #31).

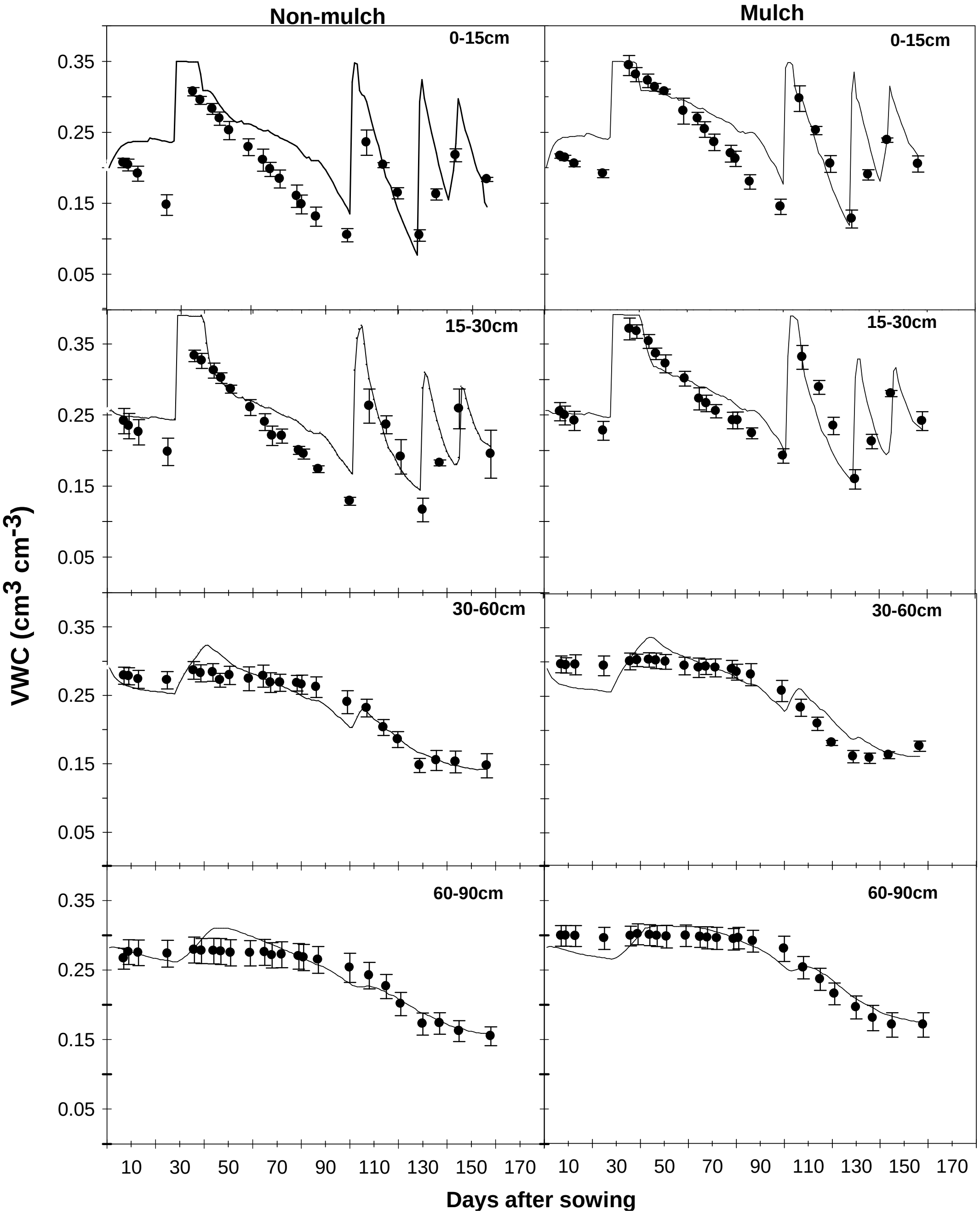


Fig. 12c. Comparison of simulated and measured volumetric soil water content (cm3 cm-3) under wheat in the soil profile (0-90 cm) with and without mulching during the 2007-08 wheat season in irrigation treatment I2, Punjab, India (Balwinder-Singh et al., 2010; dataset # 38)

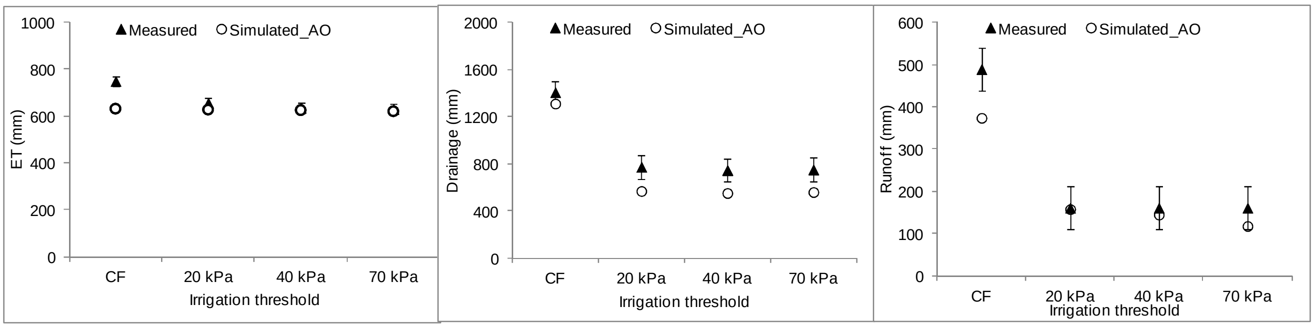


Fig. 13a. Comparison between measured and simulated water balance terms (mm) as a function of different water-stress treatments in rice irrigation – (i) CF – control, continuously submerged/flooded; (ii) AWD, re-flooded at soil suction of 20kPa; (iii) AWD, 40kPa; and (iv) AWD, 70 kPa, for the experiments of Sudhir-Yadav et al (2011) (dataset # 5).

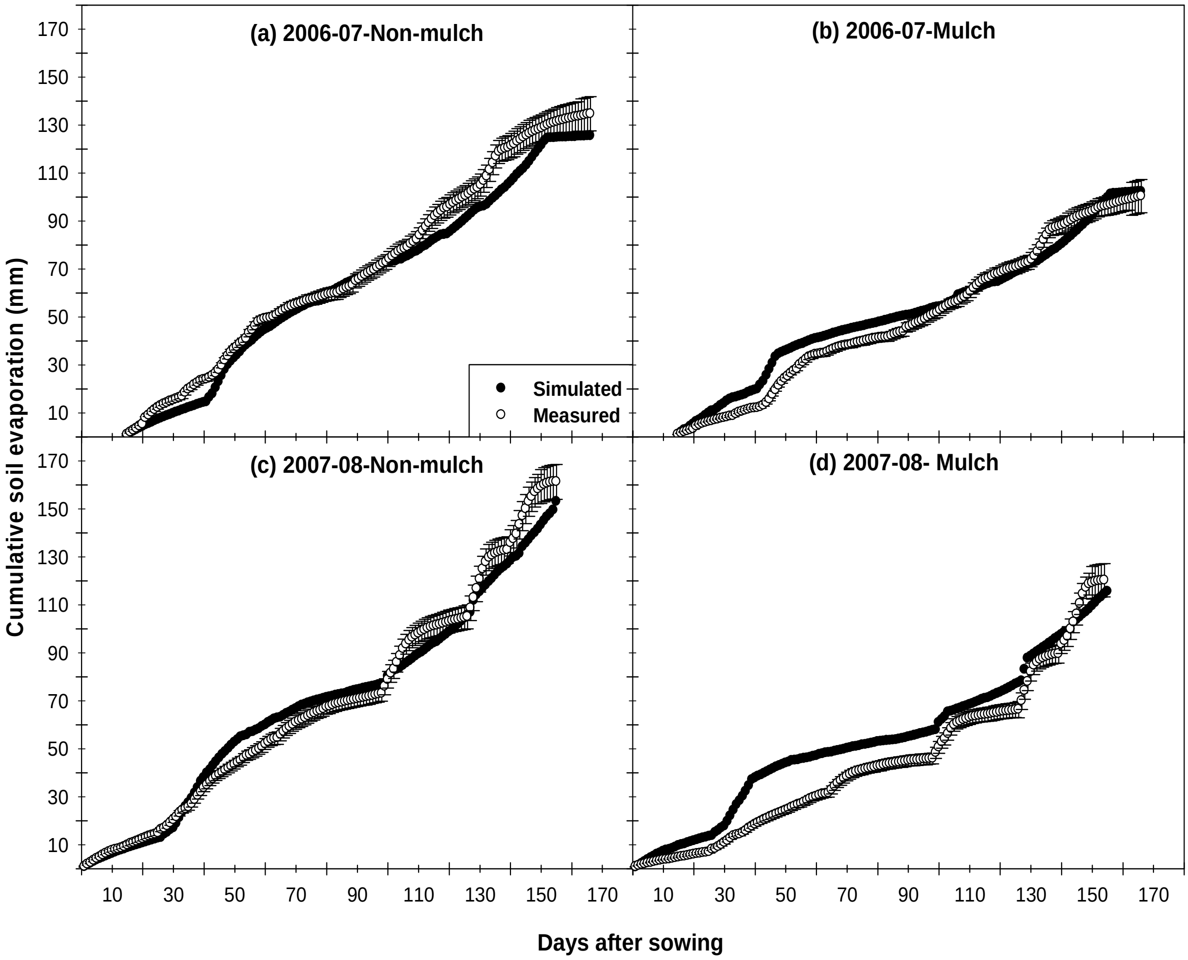


Fig. 13b. Simulated (filled symbols) and observed (hollow symbols) cumulative soil evaporation under mulch and non mulch in 2006-07 (a and b) and 2007-08 (c and d) for irrigated wheat crop, Punjab, India (Balwinder-Singh et al., 2010; dataset # 38).

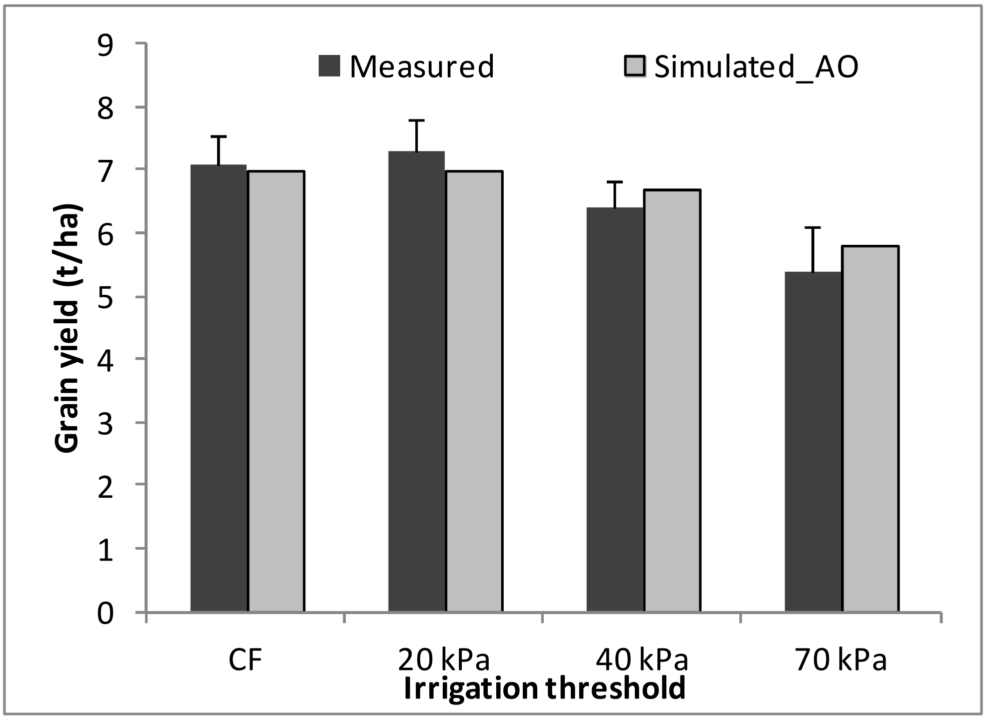


Fig. 14. Comparison between measured and simulated above-ground rice biomass (Mg ha^{-1}) for different water-stress treatments in rice irrigation – (i) CS – control, continuously submerged/flooded; (ii) AWD, re-flooded at soil suction of 20kPa; (iii) AWD, 40kPa; and (iv) AWD, 70 kPa, for the experiments of Sudhir-Yadav et al (2011) (dataset # 5).

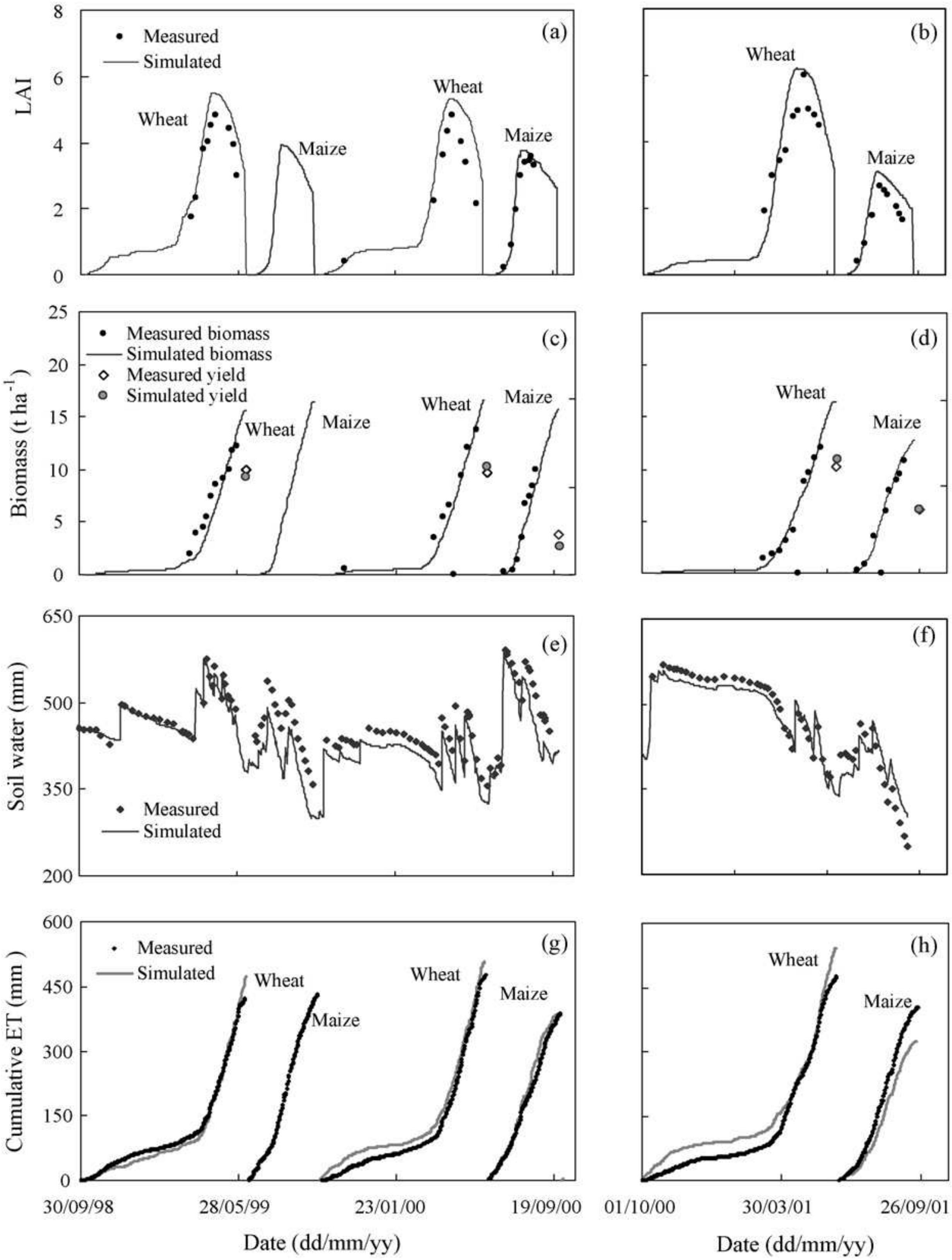


Fig. 15. Comparison of experimental and APSIM simulated LAI (a and b), above-ground biomass and yield (c and d), soil water content (e and f) in the 0–160 cm soil profile and cumulative ET (g and h) for a wheat-maize cropping system at Luancheng, China (dataset #28, Chen et al., 2010a). Figures a, c, e and g show the calibration results using experimental data for 1998–2000 while figures b, d, f and h illustrate the validation using data from the 2000–2001.

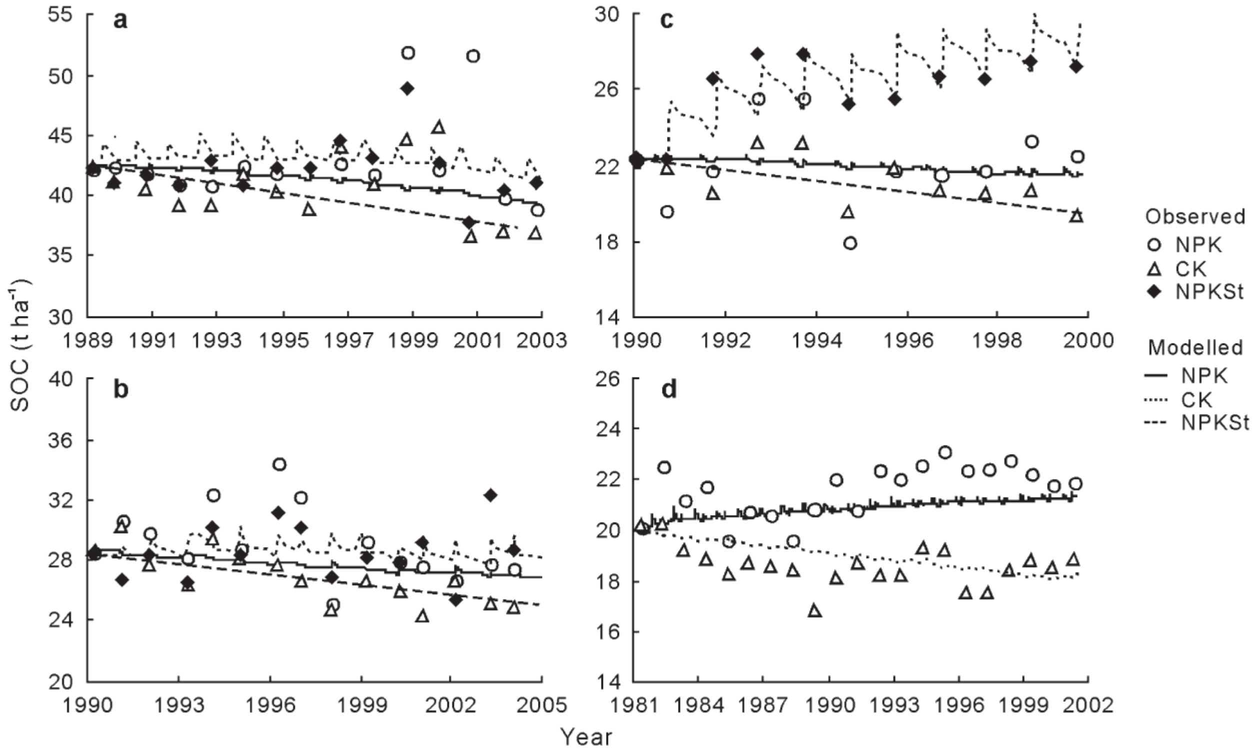


Fig. 16. Comparison between measured and simulated soil organic carbon (t ha^{-1}) for the experiments of Wang et al (2014) (dataset # 27). A mixture of wheat and wheat-maize cropping systems were examined over four (4) Chinese locations, over a period of 20^{+} years with a range of fertiliser and stubble treatments. NPK = application of compound inorganic fertilizers; NPKSt = application of inorganic fertilizers and stubble retention; CK = control. Symbols show the measured values and lines show the simulated values.

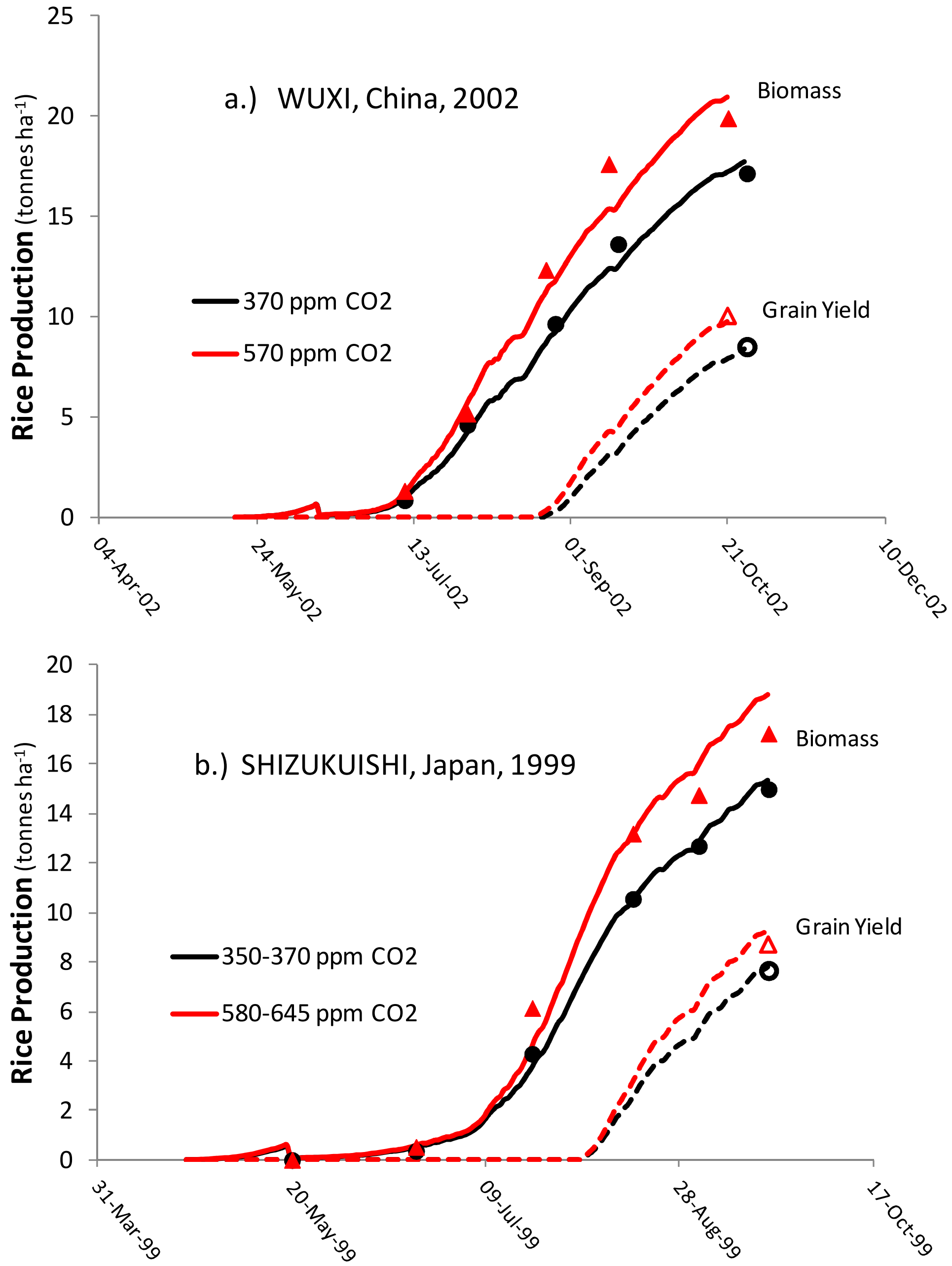


Fig. 17. APSIM-Oryza simulated versus observed rice production (Mg ha^{-1}) for both FACE and ambient CO_2 treatments: (a.) Yang et al., 2006, 2008 (dataset # 25); (b.) Kim et al., 2003 (dataset # 24). Comparison for medium N treatments shown. No replicate variability information (error bars) available.

Appendix 2 – Radanielson et al: Modeling salinity effect paper

Modelling salinity effect on rice growth and rice yield with ORYZA v3 and APSIM-ORYZA

Radanielson, A.M., D.S.Gaydon, T.Li, and O. Angeles

Submitted to Environmental Modelling and Software. Under Review.

Highlights

- ORYZA v3 and APSIM-ORYZA models were improved to account for salinity effects on rice production
- Variability of soil salinity was captured with a simplistic approach considering relationship of soil salt concentration and soil electrical conductivity.
- Dynamic and variability of rice plant responses to salt stress along its growth were adequately represented.
- Parameters for salinity responses were found suitable for salinity tolerance quantification for rice varieties.
- Variation of the trait related to salinity parameters of 5 % would result to 3% of yield improvement.

Abstract

Development and testing of reliable tools for simulating rice production in salt-affected areas are presenting in this paper. New functions were implemented in existing crop models ORYZA v3 (the new version of ORYZA2000) and the cropping systems modeling framework APSIM-ORYZA. Two seasons of field experiments were used to validate both models. The systems model APSIM-ORYZA was able to simulate the observed soil salinity dynamics to an acceptable degree. Both models presented similarly higher accuracy in simulating aboveground biomass, leaf area index, and grain yield. Model index of agreement ranged from 0.86 to 0.99. Variability of yield under stressed and non-stressed conditions was simulated with a RMSE, of 190.75 kg ha^{-1} and 221.76 kg ha^{-1}, respectively, for ORYZA v3 and APSIM-ORYZA, indicating acceptable model performance. With the improved models, opportunities are now available for greater reliability in risk assessment and evaluation of suitable management options for rice production in salt-affected areas.

Key words: Genotype, soil, photosynthesis, transpiration, water

Appendix 3 – Radanielson et al: Overview on salinity modelling paper

Overview on salinity modelling to define an effective representation of rice crop production under salt affected areas

Radanielson, Ando Mariot, Tao Li, Abdelbagi Ismail

Under major revision and to be considered for new submission to Agricultural water management

Background: Improving and maintaining productivity of salt-affected areas are among the challenges to be currently addressed with the resources limitation conditions of rice production in Asia. Developing suitable agronomic practices and tolerant cultivars for these areas are options that agronomists and breeders could consider.

Scope: Modelling tools are available to enhance understanding of salinity dynamics and its effect on crop production. Available soil-based models were effectively used to assess irrigation strategy to limit salinity effect on crop yield. These models were mostly based on detailed soil description and too site-specific. A piecewise linear model of crop yield is generally used to simulate the salinity effect. Crop-based models using this equation have simplified the description of salt stress on crop growth and yield formation. Coupling soil and crop models improved model simulation performance, even though representation of the salinity effect was still limited to a reduction in the water uptake.

Conclusion: Knowledge of key physiological processes of crop responses to salinity, and their genetic control is available. Among these processes, photosynthesis, nutrient uptake and respiration could be considered in developing a new generation of crop model for salinity.

Key words: Crop modelling, physiology, salt stress, soil salinity, water deficit

Appendix 4 – Radanielson et al: Varietal improvement options paper

Varietal improvement options to increase rice productivity in salt affected areas using crop modelling

Ando M. Radanielson, Donald S. Gaydon, Md. Mahbubur Rahman Khan, Apurbo K. Chaki, Md. Atikur Rahman, Olivyn Angeles, Tao Li, A.Ismail

Final draft, to be submitted to Field Crop Research

Highlights:

- Rice crop model ORYZA v3 simulated genotypic variability in rice responses to salinity with acceptable accuracy
- Approach coupling crop modelling and field experimentation allowed quantifying relative yield gain with salinity trait improvement.
- A novel quantitative framework illustrating relative yield change with salinity trait variation has defined BRRI Dhan47 at the optimum tolerance for current salinity conditions in Satkhira
- Improving salinity tolerance trait by 1% resulted in a yield gain of 0.30-0.40%.

Abstract

The complexity of crop salt stress in the field has been disaggregated into environmental and genotypic key factors limiting yield in the improved version of the rice crop model ORYZA v3. This paper details subsequent research work using the model to explore opportunities for improving salinity tolerance in rice. The objective was to identify combinations of plant traits influencing crop salinity response and to quantify yield gain by improving these traits. ORYZA v3 was calibrated and validated with field experimental data collected between 2012 and 2014 in Satkhira, Bangladesh and Infanta, Quezon, Philippines. Confidence in model performance with known varieties in real salt-affected rice-growing environments was established. Following this, scenarios were developed using virtual varieties possessing different combinations of crop model parameter values related to crop salinity response (critical salinity level for photosynthesis (bPN) and transpiration decrease (bTR), rate of growth linear decrease (aSalt) at salinity level above bPn and bTR, and plant phenology (developmental rate). Simulations were performed for 420 combinations with two dates of sowing using 30 years of climate data (1984 to 2014) and a mean seasonal soil salinity dynamic observed from the Satkhira site. Sensitivity analyses of the simulated yields was then performed to identify optimum combinations of traits and to quantify yield variation within the bounds of potential parameter variation. The data showed that, ORYZA v3 performed well in simulating observed rice yields and their variability among known varieties, sites and salinity conditions. In the Satkhira situation, short duration varieties have been found to escape end of season salinity increase while long duration varieties would benefit from an irrigated desalinization period occurring during later stages of crop growth. Combining short duration growth with salt tolerance trait (bTR and bPN) above 12 dS m^{-1} and a resilience trait (aSalt)

of 0.11, in a variety, would allow maintenance of 65-70% of rice yield under increasing salinity levels of up to 16 dS m^{-1} (often occurring in Satkhira region). Improving the tolerance trait by 1% would result in 0.3-0.4 % increase in yield. This would be relevant to using the new tolerant variety with an irrigation management allowing optimum timing of fresh water use and its eventual blending with saline water. Trait-based modelling of rice crop response to soil salinity suggested new opportunities and directions to increase rice productivity in saline environments, based on improvements in phenology and quantifiable salt tolerance traits. Further studies on available genetic variability for the model parameters would be of interest for breeding and to combine modelling and breeding to develop integrative strategies for variety selection with appropriate cropping systems management.

Key words: Genotype, Modelling, ORYZA v3, Rice, Trait selection, Water availability

Appendix 5 – Hochman et al: Smallholder farmers managing climate risk. Part 1

Smallholder farmers managing climate risk in India: 1. adapting to a variable climate

Draft for submission

Zvi Hochman, Heidi Horan, D. Raji Reddy, Gade Sreenivas, Chiranjeevi Tallapragada, Ravindra Adusumilli, Don Gaydon, Kamalesh K. Singh, Christian H. Roth

Abstract

This paper describes an investigation of various adaptations of rice based cropping systems to climate variability in India's Telangana State. All adaptations were generated through participatory engagement and were field tested with local smallholder households before being evaluated through cropping system simulation analysis. This approach contrasts with most research about adaptation of cropping systems to climate variability and climate change that is mostly based on simplifying assumptions about current farmer management practices and where the feasibility of implementing proposed adaptations is rarely tested. In this study, the investigation started with discussions about climate related issues in rice based farming systems between researchers, farmers and NGOs in three villages in three Mandals of the state of Telangana. Participatory intervention was used to identify new practices that could provide more adaptive and robust responses to climate variability. Suggested adaptations were implemented in on-farm experimentation and fields demonstrating these adaptations were monitored and results were discussed with participating farmers. Crop and soil data from these fields were used to locally parameterise the cropping systems simulator APSIM. Local adaptation options that were trialled in the villages were simulated using local soil and long term historical weather data. In each of the case studies, a number of adaptations that were developed and implemented in the villages were shown through simulation to be successful in terms of agricultural production, stability of yields and resource use efficiency. These results led us to the proposition that participatory action research with smallholder farmers, coupled with field testing and simulation analysis can produce practical and productive adaptations to climate variability. Conversely, less integrated approaches may lead to recommendations of unrealistic adaptations or even maladaptations.

Key Words: Climate variability, Simulation, Scenario Analysis, Participatory Action Research, rice, cotton, maize

1. Introduction

The research described in this paper was conducted in the context of a broader integrated research program investigating adaptation to climate change in South and Southeast Asian smallholder rice based cropping systems (The Adaptation to Climate Change in Asia program – ACCA; Roth and Grünbühel 2012). While the overall aim of the research was to investigate adaptations to climate change, it became clear in early discussions with farmers that they did not distinguish between climate variability and climate change. While farmers were well aware of climate variability and its impacts (Nidumolu et al. 2015) they were generally unable to articulate how they adapted their management to cope with this variability (Brown et al. 2015). We decided to take a two staged approach in which we would first investigate adaptations to climate variability and then, to ensure that these are not maladaptations to climate change (Adger et al. 2005), examine the most promising adaptations against future climate change scenarios. This pragmatic approach is also supported in the literature for a range of reasons including that adaptations to climate variability are likely to also be successful adaptation to climate change (Howden et al. 2007), that additionality over adaptation to climate change is elusive (Haman et al. 2012) and that present action to address future change may be unjustified (Asseng and Pannell 2013).

Variability in rainfall is a principal source of fluctuations in food production, particularly in the semi-arid tropical countries such as India (Bantilan and Anupama 2002, Meinke et al. 2006, Cooper et al. 2008, Aggarwal et al. 2010, Balaghi et al. 2010, Coe and Stern 2011). Climatic uncertainty is exacerbated by the lack of a skilful seasonal climate forecasting system over much of the Indian subcontinent (Kar et al. 2012). Such uncertainty diminishes the capacity of farm households to plan for any given season. Consequently, the challenge faced by farmers is to flexibly adjust their management practices and their level of investment in crop production inputs as the season develops in order to avoid either over-investing in crops with poor yield prospects or under-investing in crops with good yield prospects.

This paper is concerned with the role of simulation as a component of a broader participatory framework for developing and testing locally relevant adaptation strategies to address climate risk in smallholder rice based cropping systems. Dynamic, process-based crop and cropping system simulation models are commonly used in studies of climate risk management. Challinor et al. (2009) argued that the generation of knowledge for policy adaptation should be based on a more synergistic and holistic research framework that includes: (i) reliable quantification of uncertainty; (ii) techniques for combining diverse modelling approaches and observations that focus on fundamental processes; and (iii) judicious choice and calibration of models, including simulation at appropriate levels of complexity that accounts for the principal drivers of crop productivity, which may well include both biophysical and socio-economic factors. They argued that such a framework will lead to reliable methods for linking simulation to real-world adaptation options. While such a framework does not currently exist, this project takes on board the need for simulations to be able to account for the principal drivers of crop productivity, to be locally calibrated, to be able to capture farmer decision making rules, to account for socio economic factors and to produce locally credible outputs.

Engaging stakeholders is an essential ingredient in the mobilisation of science to real world problems and a strong case has been made for stakeholder participation in the application of climate science and methods to integrate it into meaningful information that is embedded into the knowledge networks and the social and institutional processes through which farmers make decisions (Carberry et al. 2002, Cash et al. 2005, Sivakumar et al. 2005, Meinke et al. 2006, Meinke et al. 2009, Hochman et al. 2009, Howden et al. 2014). Stakeholder engagement can take place at the policy and at the local (farming household, community) level. In developing locally credible management options that are adaptive to climate variability, local knowledge is important because it is specific to the geographical and cultural features of place and is expressed in terms that are better integrated with social experience (Lebel 2012). In this study we used participatory methods to elicit local ideas about adaptation and to test these ideas both through simulation analysis and with village farmers to ensure that they can be adopted on the ground by smallholder farmers. In adopting this approach we also sought to gain insights into the policy settings that would be required to facilitate these adaptations.

2. Methods

2.1 Case study villages

This study was conducted in the State of Telangana (formerly part of Andhra Pradesh in south India). We selected three case study villages located in three districts in Telangana, varying in rainfall and soils: Warangal, in the Central Telangana agro climatic zone and Nalgonda and Mahabubnagar in the Southern Telangana Zone (Figure 1). Paddy rice, cotton, and to a lesser degree maize are the key kharif (monsoon) crops in these villages. Paddy rice is grown under irrigated conditions mostly using groundwater pumped from bore-wells. Cotton and maize are mostly rainfed. Farming households are diverse, ranging from many marginal and small farmers (less than 2ha) with poor soil and limited or no access to irrigation(household types 2 and3) or with access to irrigation (household type 4), to medium and large farmers with either no or limited access irrigation (household type 5) or with good access to irrigation and good quality soil (household types 6 and 7; Williams et al., 2015). Livelihoods and adaptive capacity vary accordingly (Brown et al. 2015).

[Figure 1]

Natural endowments for agriculture also vary considerably amongst the three villages. Bairanpalli (Warangal district) is a village with better soil and water resources, while Gorita (Mahabubnagar district), and Nemmani (Nalgonda district) are villages with more limited resources. All three villages have highly variable seasonal rainfall (Figure 2). Bairanpalli has a mean growing season rainfall of 755mm and an average annual rainfall of 821 mm, with better soils (mainly Vertisols) and more substantial ground water based irrigation resources. Gorita and Nemmani have growing season rainfalls of 717 mm and

662 mm respectively and average annual rainfalls of 801 mm and 752 mm respectively. Both villages have ground water based irrigation resources that are confined to Vertisols in drainage depressions. Upland soils are mainly poorer, red granitic Alfisols and Ultisols.

2.2 Conceptual framework

The engagement model adopted in this study was based on the FARMSCAPE (Farmers' Advisers', Researchers', Monitoring, Simulation, Communication And Performance Evaluation) action research cycle described by McCown et al. (2009) whereby a soft systems approach (Checkland 1981) was adopted to engaging farmers in their management situation while using hard systems tools for simulation analysis of their management options. The cycle commenced with an invitation to farmers in a village to work through the services of a local NGO with a research team to find ways to better manage crop production in a variable and changing climate. The following steps were taken:

a. Negotiation of issues for joint research
b. On-farm experiments conducted by farmers and monitored by researchers
c. Discussions of results and their implications for management
d. Use of monitoring data to locally specify the simulation model
e. Use of simulation to aid interpretation of results by conducting the experiments over many years using local weather records
f. Use of simulation to conduct virtual experiments beyond the field experiments (what if?)
g. Evaluation of 'what-if' results in terms of multiple criteria (yield, gross margins, net water use) through discussions with local scientists, NGO representatives and other local stakeholders
h. Evaluation of farmers through meetings, focus groups and interviews to ascertain changes in their views, intended actions and actual management
i. Reflection by the research team about insights from previous actions, evaluation of the methodology and changes made to improve the next action cycle
j. Loop back to step a.

2.3 Farmer engagement and on-farm experiments

WASSAN, A lead NGO enlisted a participating local NGO for each village to establish and support a 'farmer climate club'. The fortnightly farmer club meetings typically involved 20 to 30 farmers and notes were taken of the attendance and proceeding of the meetings. Additional meetings were held in which a number of participating scientists were also involved. The local NGOs delivered agro advisory bulletins to their villages for public display twice weekly and facilitated fortnightly meetings to discuss agricultural issues. These bulletins were produced by the research partner from the Professor Jayshankar Telangana State Agricultural University (PJTSAU, formerly ANGRAU) using information supplied by the Indian Meteorology Department

(IMD). PJTSAU scientists also established a manual weather station and trained a local farmer in each village to maintain and record daily temperatures (wet and dry bulb daily minimum and maximum temperatures in a Stevenson screen) and rainfall. A rainfall visualization tool was developed to display the data and progressively compare cumulative in-season rainfall to selected wet and dry years from the past 10 years of local weather station records. PJTSAU scientists also characterised 16 local soils using the methods of Dalgliesh and Foale (1998) to provide the data required to simulate the major soil types at each village. Local knowledge about climate related risk and best management practice was elicited from experienced farmers (Nidumolu et al. 2015) and discussions were held in the villages involving farmers, local NGO and research partners to explore potential adaptation ideas for on- farm experiments. In addition PJTSAU scientists promoted a package of recommendations (the “PJTSAU package”) that was reflected in the agro-advisories produced by PJTSAU from IMD’s medium term district level forecasts and distributed to the villages twice weekly to support farm management.

On-farm experiments with rice, cotton and maize crops were designed to compare farmer’s current practice with the PJTSAU package of recommendations and other proposed adaptation ideas by splitting a field into two parts. A list summarising the on farm trials carried out during the study is provided in Table 1.

[Table 1]

These fields were monitored by sequential measurement of soil water and mineral N status, crop growth stages, above ground dry matter and grain or cotton yields at harvest. In some cases flow meters were used to monitor the amount of irrigation water used. Experimental replication was to be achieved by more than one farmer trialling the same innovation in the same village over two to three seasons. However, the main purpose of on-farm experiments was to test, demonstrate and discuss the practicality of the proposed adaptations rather than to provide experimentally rigorous evidence that they were superior to current practice. Reflections about these trials and farmers’ overall experience of the season were conducted at the end of each kharif season. Such discussions lead to more adaptation ideas and to the design of more on-farm trials in the coming season.

Farmers with small, medium and large land holdings at each of the case study villages reflecting the major household types were interviewed individually to ascertain their production input costs and prices received for rice, cotton and maize crops.

2.4 Cropping systems simulation

Soil and crop data collected from all farmer field sites were used for model parameterisation. The cropping model APSIM (Keating et al. 2003, Holzworth et al. 2014) with APSIM-Oryza (Bouman et al. 2001, Gaydon et al. 2012b) was used to simulate rice, APSIM-Maize (Carberry and Abrecht 1991) to simulate maize crops and APSIM-Ozcot (Hearn 1994) to simulate cotton in this study. The APSIM model was chosen primarily for its ability to closely mimic farmer management actions by programming decision rules within its flexible Manager module.

The simulation results featuring observed and simulated data for individual crops were shared with participating scientists, NGOs, state advisory officers and other local stakeholders in order to create a degree of confidence in the plausibility of simulation results and potential usefulness of the models. This invariably led to discussions about how the model can be used to answer a range of "what-if" questions and subsequently to exploration of adaptation options.

Climate data used depended on the availability of data in close proximity to the case study villages. The observational weather data for the three villages Bairanpalli (18.05^0 N, 79.53^0 E); Gorita (16.62^{o}N, 78.16^{o}E and Nemmani (17.23^{o}N, 79.23^{o}E) were sourced from nearby weather stations (Warangal, Mahabubnagar and Nalgonda respectively). The historical record covered the years 1978-2009, for which daily minimum and maximum temperatures and rainfall data were available. Missing data (16% of observations for Warangal, 10% for Mahabubnagar and 45% for Nalgonda) were in-filled with IMD gridded data. APSIM climate files also require solar radiation, vapour pressure and evapotranspiration. These variables were predicted from rainfall and temperature using empirical relationships based on National Centre for Environmental Prediction/Department of Energy (NCEP; http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis2.html) climate data for locations close to each climate station.

2.5 Adaptation strategies

A number of adaptation strategies emerged from participatory processes in the villages, some reflecting injections of ideas from researchers, some originating from farmer thinking and emerging practice; but in all cases co-developed. Four strategies were selected and each was both tested by farmers and simulated over the historical climate records. The strategies were: 1. Sowing rules for rainfed crops to reduce the risk of seedling failure due to a dry spell immediately after sowing; 2. Strategic irrigation of rainfed crops to increase yields and reduce the chance of crop failures due to prolonged within-season dry spells; 3. Reduced irrigation of rice to prevent the depletion of local groundwater resources; and 4. Reducing the area sown to rice in order to save and redirect water for strategic irrigation of rainfed crops.

Adaptation 1. Sowing Rules

The question about when farmers sow rainfed crops started as a conversation between researchers. It seems that while some farmers will sow these crops as soon as the start of the monsoon season (defined as two consecutive days where rainfall exceeds 2.5 mm) is officially declared by IMD, agronomic data from locally conducted experiments suggested that a cumulative rainfall of 50 to 75 mm is required to ensure seedlings survive a dry period immediately after sowing. Surveys and farmer climate club group discussions confirmed that re-sowing of seed is a common problem and that a wide range of beliefs and practices regarding when to sow existed in the three case study villages.

The sowing window for rainfed crops such as cotton and maize is between June 1 and July 17. If sowing criteria are not met by 17 July, the crop is not sown (Nidumolu et al. 2015). Given this sowing window, four main variations to the sowing rule were explored:

1. Sow at 'onset of monsoon' following the IMD's definition (i.e. 2 consecutive days in which daily rainfall >= 2.5mm)
2. Sow when cumulative rainfall equals or exceeds 75 mm (accumulated over 4, 7, 10 or 14 days)
3. Sow when cumulative rainfall equals or exceeds 50 mm (accumulated over 4, 7, 10 or 14 days)
4. Sow when soil moisture in top 15cm is at 50% of the soil's plant available water capacity (PAWC) in Vertisols (hereafter referred to as black soils) or at 66% of PAWC in Alfisols and Ultisols (hereafter referred to as red soils).

Simulations were used to test the above proposed sowing rules. Because the APSIM cotton and maize models do not have specific algorithms for defining the conditions under which seedlings die, we proposed plausible rules based on plant available soil water (PAW) as a fraction of PAWC, which were subsequently coded into the APSIM Manager module. These rules were calibrated to reflect the experience of farmers in participating villages over the past ten seasons (Nidumolu et al. 2015). Additional details on the parameterisation approaches taken are provided in the Supplementary Data **section.**

Adaptation 2. Strategic Irrigation of rainfed crops

While cotton and maize crops are regarded as rainfed crops in Telangana a few farmers in the Bairanpalli village, who were applying supplementary irrigation to these crops, were interested to explore how to make the best use of limited irrigation water. After discussion with farmers in the three villages, and testing of various options via on farm experiments and simulation, the following rule was proposed for this adaptation: Apply an irrigation of 50mm when soil moisture falls below 50% of PAWC subject to:

- at least 14 days between irrigations
- a maximum of 3 irrigations per season
- for cotton, start irrigations after 30 days after sowing (DAS) and stop at 120 DAS
- for maize, start irrigations after 14 DAS and stop at 21 days after anthesis.

Because water is a limited and dwindling resource in the study area, irrigation of rainfed crops must come from savings made by reduced irrigation of paddy rice. This can be achieved by either reducing the per hectare irrigation through measures such as alternate wetting and drying (Wu 1999; Belder et al. 2004) or by reducing the area sown to rice. These two options are the basis for adaptations 3 and 4.

Adaptation 3. Reduced Irrigation of Rice

Paddy rice sowing was simulated for all scenarios according to the following farmer rule: Start nursery on the 7th of June and transplant seedlings at least 25 days after sowing (DAS) when cumulative rainfall exceeds 35 mm. If minimum rainfall (35mm) had not fallen in 50 days at Bairanpalli, transplant at 50 DAS. If minimum rainfall (35mm) had not fallen in 60 days at Gorita or Nemmani, transplant at 60 DAS.

Four irrigation options were identified:

1. Irrig-1. Aiming to maintain a pond depth of 10 cm by irrigating every second day to top up the pond to 10cm if required.
2. Irrig-2: Maintain 5cm pond depth – irrigate every day to top up pond to 5 cm if required. This option was based on farmer practice.
3. AWD1: Alternate wetting and drying - irrigate when pond depth = 0cm, fill to 5cm
4. AWD2: Alternate wetting and drying - irrigate 2 days after pond depth = 0cm, fill to 5cm

In addition, a modified form of System of Rice Intensification (SRI; Glover 2011) was trialled at one of the villages (Nemmani) but is not investigated here because it was rejected by all the farmers as too time demanding despite slightly higher yields than those of the conventional irrigation field and because some important aspects of SRI cannot be adequately simulated with the current version of the Oryza model.

The current practice was compared with the proposed adaptations in terms of their grain yields, GM and net water use.

Adaptation 4. Reduced Rice Area for Strategic Irrigation of rainfed crops

Options investigated for sourcing water for strategic irrigation of rainfed crops from reduced paddy area were based on extending previous research on increasing total production per m^3 of irrigation water (Fereres and Soriano 2007; Gaydon et al. 2012a, Hochman et al. 2013) by alternative uses of limited irrigation resources. The treatments investigated varied by household type (Williams et al. 2015) and particularly by farm size. We considered 3 representative farm sizes and their associated household types: 1. A small farm with 5 acres (2 ha) of which 2 acres were paddy and 3 acres were cotton or maize; 2. A medium farm with 8 acres (3.2 ha) of which 2 acres were paddy and 6 acres were cotton or maize; 3.A large farm with 15 acres (6.5 ha) of which 3 acres were paddy and 12 acres were cotton or maize.

The small farms represent household type 4 who own a small farm with access to irrigation. The medium and large farms represent household types 6 and 7 who own medium to large farms with access to irrigation. In addition household types 2, 3 and 5 who currently have no or limited access to irrigation can adopt this practice if they can negotiate access to irrigation from neighbouring farmers.

For all farm types we assumed the Rice Irrig-2 and rainfed cotton or maize using the starting soil water sowing rules as the current practice. A minimum of half an acre of rice was retained in adaptation options to ensure rice self-sufficiency for a family of 5 people. A summary of the treatments for each farm type is provided in Table 2.

[Table 2]

All the options in Table 2 were simulated for representative red and black soil types at the three Indian villages using historical weather data (1978-2009). Simulation outputs included estimates of annual yields and net water used (irrigation minus deep drainage blow the root zone).

2.6 Gross margin data

Data to determine gross margins were collected in household surveys and used for calculating the GM values of various adaptation options for small, medium and large household types. Table 3 is an example from Gorita village for rice cotton and maize crops. Cost and income data were collected and are represented in Indian Rupees (INR). At the time of writing (April 2 2015) 1 INR was equivalent to 0.016 USD.

[Table 3]

Post simulation analysis enabled the calculation of GM using cost and income data collected from the representative case study households. Adaptations could thus be evaluated on multiple criteria: yield, average GM per ha, the stability (coefficient of variation; CV) of GM and net water productivity (GM/net water used).

3. Results

A comparison between Warangal's and Mahabubnagar's minimum and maximum temperatures, solar radiation and rainfall during the monsoon season is provided (Figure 3). Warangal tends to be wetter than Mahabubnagar in the first half of the kharif season but drier in the second. It is warmer throughout the season with the difference being greater in the minimum temperatures. Data for Nalgonda (not shown because of the high proportion of missing data) was similar to Mahabubnagar.

[Figure 3]

Sixteen farmers from the three villages conducted field experiments that were closely monitored to provide a minimum data set for simulation modelling with APSIM (see Supplemental Publication). The data was used to derive the genetic parameters for specifying the developmental stages of common crop varieties used in these villages. The relationship between observed and simulated crops (Figure 4) should not be regarded as a validation of the model because the data was used to calibrate the variety-specific phenology parameters of the crop modules. However, these results showed that the model can be well specified for cotton, rice and maize in southern India. Given that these modules have been validated in other counties in South Asia, there is an increasingly persuasive body of evidence that the APSIM model can be a useful tool in simulating rice based cropping systems in South and South East Asia (Gaydon et al. 2015).

[Figure 4]

Farmers' experiences with their field trials, especially the adaptation treatments such as strategic irrigation of cotton and maize (irrigation on 50% PAW) and SRI were the subject of lively discussions at the climate club meetings. These discussions informed other farmers, researches and NGO participants about the feasibility and desirability of these practices from the farmers' practical point of view. Such discussions were influential in informing researchers' decisions on which adaptations were worthy of further investigation by simulation.

Adaptation 1. Sowing Rules

On a black soil at Bairanpalli, the 'sow at the onset of monsoon (2 day start)' rule ensured a sowing opportunity in all years at the expense of seedling failure in 16% of years. Waiting for either 50 mm to be accumulated over a 7 day period during the sowing window (50 mm in 7 day start) or for soil moisture in the top 15 cm layer to reach 50% of PAWC (soil_water_start) resulted in no sowing opportunity in 9% of years but no seedling failures. All other rules were less optimal tradeoffs between sowing opportunity and seedling failure (Table 4).

On a red soil at Gorita (Table 4), the 'sow at the onset of monsoon (2 day start)' rule resulted in no sowing opportunity in 10% of years and in seedling failure in 11% of years. Waiting for 50mm accumulated over the whole sowing window (50 mm start) resulted in a sowing opportunity in all years with seedling failures reduced to 3% of years. Waiting for moisture in the top 15 cm layer to reach 66% of PAWC (soil_water_start) resulted in no sowing opportunity in 3% of years but no seedling failures. All other rules were less optimal tradeoffs between sowing opportunity and seedling failure.

On a red soil at Nemmani (Table 4), the sow at the onset of monsoon (2 day start) rule resulted in no sowing opportunity in 6% of years and in seedling failure in 23% of years. Waiting for 50mm (accumulated over the whole sowing window (50 mm start) also resulted in no sowing opportunity in 6% of years with seedling failures reduced to 13% of years. Waiting for moisture in the top 15 cm layer to reach 66% of PAWC (soil_water_start) resulted in no sowing opportunity in 16% of years but no seedling failures. All other rules were less optimal tradeoffs between sowing opportunity and seedling failure.

[Table 4]

Adaptation 2. Strategic Irrigation of rainfed crops

Strategic irrigation of cotton and maize crops in each of the three case study villages shifted the yield and GM probability distribution throughout the entire range of yield outcomes as illustrated for Gorita by Figure 5. In particular, the probability of cotton yields below 2 t/ha, maize yields below 4 t/ha and GMs below 30,000 INR/ha were dramatically reduced for both crops in the three villages (Table 5).

[Figure 5 and Table 5]

Adaptation 3. Reduced Irrigation of Rice

The three reduced irrigation adaptations were evaluated against current farmer practice in terms of their rice yields, their GMs and the net water use. Net water use, calculated as irrigation minus drainage beyond the root zone, is a measure of the contribution of the farm to the depletion of groundwater resources. These comparisons are shown for Bairanpalli and Gorita fields (Figure 6).

In the Bairanpalli simulations (Figure 6a), consistent differences were observed in the amount of net water used in the alternative irrigations (Irrig 1 > Irrig 2 > AWD1 > AWD2). The difference between the Irrig 2 (current farmer practice) and the AWD2 option represents a saving of about 61 mm/ha or 19% of farmer practice. Small positive differences in yield were observed in response to reduced irrigation (AWD2 > AWD1 > Irrig 2 > Irrig 1) and these yield gains were reflected in improved GMs as both water and electricity are fully subsidised.

In the Gorita simulations (Figure 7b), consistent differences were observed in the amount of net water used in the alternative irrigations (Irrig 1 > Irrig 2 = AWD1 > AWD2). The median difference between the Irrig 2 (current farmer practice) and the AWD2 options represents a saving of about 62 mm/ha or 18% of farmer practice. In contrast with Bairanpalli, small negative yield and GM differences were observed in Gorita in response to reduced irrigation (Irrig 1 > Irrig 2 > AWD1 > AWD2). Hence there is a trade-off in Gorita between conserving groundwater resources and GMs.

[Figure 6]

Adaptation 4. Reduced Rice Area for Strategic Irrigation of rainfed crops

The results of this adaptation option are illustrated for the Gorita village in Figure 7. For the small rice cotton farm (Figure 7a), current practice produced a mean annual GM of 32,266 INR/ha, a net water use of 106.9 mm/ha/yr and a water productivity (expressed as GM per mm of net water used) of 302 INR/mm. Adaptation option 3 resulted in the highest average annual GM of 79,998 INR/ha at the expense of a less sustainable net water usage of 130.1 mm/ha/yr but a higher water productivity of 615 INR/mm. Adaptation option 4 resulted in a slightly reduced average annual GM of 79,200 INR/ha but a much lower net water use of 74.6 mm/ha/yr resulting in a higher water productivity of 1,061 INR/mm.

For the medium rice cotton farm in Gorita (Figure 7b), current practice produced a mean annual GM of 25,620 INR/ha and a net water use of 44.9 mm/ha/yr and a water productivity of 570 INR/mm. Adaptation option 3 resulted in a much higher annual GM of 69,690 INR/ha at the expense of a higher net water use of 62.9 mm/ha/yr, resulting in a higher water productivity of 1,107 INR/mm.

For the large rice cotton farm in Gorita (Figure 7c), current practice produced a mean annual GM of 48,484 INR and a net water use of 24.3 mm/ha/yr resulting in a water productivity of 1,996 INR/mm. Each adaptation option increased both average annual GM and net water usage (each 7 mm increasing GM by 10,000 INR). Adaptation option 5 resulted in the highest annual GM of 95279 INR/ha and the highest net water use of 54.0 mm/ha/yr resulting in a lower water productivity of 1,769 INR/mm. Interestingly, the highest net water use in a large farm is still lower than any of the options explored for the small farm and the higher net water productivity in the large farm is still much higher than the net water productivity in the small and medium farms.

For the small rice maize farm in Gorita (Figure 7d), current practice produced a mean annual GM of 32,051 INR/ha, a net water use of 94.6 mm/ha/yr and a water productivity of 339 INR/mm. Adaptation option 4 resulted in the highest average annual GM of 48,653 INR/ha and the lowest net water usage of 30.1 mm/ha/yr. This option had the highest water productivity at 1,619 INR/mm.

For the medium rice maize farm in Gorita (Figure 7e), current practice produced a mean annual GM of 36,620 INR/ha, a net water use of 29.5 mm/ha/yr and a water productivity of 1,241 INR/mm. Adaptation option 3 resulted in the highest average annual GM of 57,262 INR/ha and the lowest net water usage of 16.5 mm/ha/yr. This option had the highest water productivity at 3,465 INR/mm.

For the large rice maize farm in Gorita (Figure 7f), current practice produced a mean annual GM of 38,755 INR/ha, a net water use of 7.8 mm/ha/yr and a water productivity of 4,961 INR/mm. Adaptation option 5 resulted in the highest average annual GM of 60,343 INR/ha and the lowest net water usage of 6.0 mm/ha/yr. This option had the highest water productivity at 10,055 INR/mm.

[Figure 7]

An analysis of the same adaptation options for the villages of Nemmani (red soils) and Bairanpalli (black soils) showed similar results to those in Gorita (Figure 8). Overall, in each case GM per hectare per year, net water used and net water productivity were higher when the paddy rice area was reduced and water was spared for strategic irrigation of cotton or maize crops. There were two exceptions. The first exception was for large farms in Bairanpalli when spared water was used to irrigate maize. Although adaptation option 5 resulted in a negative net water use of 41 mm/ha/yr (recharging the aquifer), current practice had the highest GM (71,905 INR /ha/yr) and the highest net water productivity of 17,674 INR/mm. The second exception was for large (rice cotton) farms in Nemmani where current practice produced the lowest net water use (59 mm/ha/yr) though the highest GM (73,939 INR/ha/yr) and the highest net water productivity (858 INR/mm) were calculated for adaptation option 5.

[Figure 8]

4. Discussion

Participatory engagement and on farm trials

The participatory cycle was adapted from the FARMSCAPE experience (Carberry et al. 2002; McCown et al. 2009). As with the Australian experience, this approach produced useful insights into plausible adaptations based on farmers' and researchers' intuition and indigenous knowledge. It provided a means of ensuring that these adaptations were practical to implement or at least made researchers aware of obstacles to their implementation. Simulation was used to check that these adaptations are successful in terms of increased productivity, reduced risk and resource use efficiency. However, in contrast to the Australian experience in which farmers participated in the 'what-if' process of specifying virtual experiments, researchers in this project decided that this step in the participatory cycle was unlikely to work with less well educated Indian farmers and so, to the extent that this was possible, other participants (local scientists and NGO staff) represented farmers' views at these sessions. Nevertheless, focus group discussions and farmer surveys indicated that members of the farmer climate clubs accepted the veracity of the simulation results and focused on issues relating to the practicalities of their implementation.

The process adopted in this study combined local knowledge with scientific knowledge (e.g. Nidumolu et al. 2015) and ensured that the adaptations option investigated were not only successful in theory but were also implementable in practice by the targeted household types. Barriers to adoption were readily identified and could be considered in terms of policy settings that could overcome them.

Model Performance

The comparison of observed and predicted yields shows that the APSIM model was well calibrated for the three crop types (rice, cotton and maize) grown locally when simulated using local weather data, with local soils data, crop genetic coefficients (capturing crop development stages from sowing to maturity) and actual crop management (time of sowing, sowing density, fertilizer application rates and dates and irrigation rates and dates). The good fit (RMSD = 602; r^2 = 0.96) between observed and predicted data was achieved without modifications to default respiration, photosynthesis or harvest index parameters in any of the crop modules. These results reinforce the more thorough evaluation of the APSIM model in cropping systems in southern Asia (Gaydon et al. 2015) and provide a high degree of confidence in using these APSIM crop modules as climate adaptation research tool.

Adaptation 1. Sowing rules for rainfed crops

For the three villages studied, the sowing rule based on the 'soil water start' consistently resulted in no seedling failures while simultaneously having the lowest proportion of crops not sowed that achieved zero failures. This compared with the ‘2 day start rule’ which in Bairanpalli and Nemmani resulted in the lowest number of crops not sown (0% and 6.3% of seasons respectively) but in a higher proportion of seasons with seedling failures (16% and 23% respectively). Hence, there is a trade-off in these two villages between having crops sown every year with the ‘2 day start rule’ and getting no seedling failures with the ‘soil water start’ rule. In Gorita the ‘2 day start rule’ is less effective than the ‘soil water start’ rule as it has both a higher percentage of crops not sown (10% versus 3%) and 11% of sown crops with failed seedlings. For each of the villages, one of the rainfall based rules proved to be a good proxy for the ‘soil water start’ rule. The rainfall based rules have the advantage over soil water based rules in that they can be more objectively estimated at the village level provided there is a rain gauge and a person available to record and display the data.

The value of applying the sowing rules is that they prevent the need to re-seed crops adding cost in seed and labour and the opportunity cost of using scarce labour resources for re-seeding instead of deploying it to other time-critical operations such as weed control. In addition to savings for individuals who follow the sowing rule, in years when an erratic start to the monsoon is widespread, premature seeding could result in such widespread failures that there may not be sufficient seed available to distribute to farmers when a second sowing opportunity presents itself.

All household types found the sowing rules to be simple to understand and to apply. The only negative response we noted was by a farmer who claimed that waiting for the sowing rule cost him loss of yield due to later sowing. This is a valid concern that might apply in a given season even though analysis of yield potential across the range of seasons shows higher yield and GM probabilities for both maize and cotton in all three villages (data not shown). The issue is that farmers who view each season as a separate event may not be open to making decisions on the balance of probabilities. Nevertheless, seedling failures have been observed often in the three villages and the sowing rule message is gaining credibility with both farmers and policy makers. Another practical limitation for households that lease land is that they only gain access to the land at a late stage and may miss the first opportunity to sow regardless of which rule they choose to follow.

Using simulation to compare alternate sowing rules has also been used in Sub Saharan Africa (Dingkuhn et al. 2003), where optimal rules were shown to be superior to local rules. However, these authors conceded that issues of nitrogen availability and weed control may negate this advantage. In this study weeds, pests and diseases were well controlled and we were able, using simulation, to account for nitrogen availability. Hence the effects of the sowing rule were determined independently from other factors.

Adaptation 2. Strategic Irrigation of rainfed crops

Strategic irrigation of cotton and maize crops was shown to be a successful adaptation in the three villages. It was particularly valuable in reducing the number of years in which very low or negative income occurs. These results are consistent with the findings for a range of field crops that a well designed deficit irrigation regime can optimize water productivity over an area (Fereres and Soriano 2007). There are however a number of barriers to adoption of this adaptive technology. The first problem is lack of access to irrigation water, especially in Gorita and Nemmani villages, where not every farmer has access to irrigation water and the cost of establishing a bore-well is also a barrier. Technically there is also the difficulty of farmers knowing when PAW is at 50% of PAWC. This means that they cannot be confident of when the irrigation rule is triggered. The appearance of soil cracks, wilting of leaves and using push probes are partial solutions to this problem that were trialled in the villages and require further refinement. Traditionally, irrigation is allocated to paddy rice in preference to field crops such as maize and cotton and this barrier to adoption was the subject of the next two adaptation options.

Adaptation 3. Reduced Irrigation of Rice

Reduced irrigation of paddy rice crops via AWD had contrasting yield and subsequently GM responses in Bairanpalli with its less permeable black soils, where small but consistent yield gains were simulated, and Gorita with its more permeable red soil, where consistent yield losses were simulated. Significant reductions in the amount of irrigation water used were simulated in both villages. These observations are consistent with the findings of Belder et al. (2004).

Regardless of whether or not there was a trade-off between water saving and yields, farmers were resistant to this adaptation. Two factors were mentioned in discussion: 1. there is a high risk of irrigation being further delayed due to frequent electricity blackouts; and 2. there is a significant additional management effort required to properly implement AWD. The second issue is particularly significant for part time farmers (household types 2, 3 and 6 in Williams et al. 2015) for whom there are high opportunity costs of labour as they rely on income earned from their labour outside the farm.

Adaptation 4. Reduced Rice Area for Strategic Irrigation of rainfed crops

The adaptation option of reducing the area planted to rice and using the saved water for strategic irrigation of rainfed crops led to greater GMs per hectare per farm. One exception was where the dryland crop was maize on large farms in Bairanpalli where rainfall deficit for kharif maize was too infrequent to make up for the reduced income from rice. For all farm types there were always some options that reduced the net water used per hectare except for large rice-cotton farms in Nemmani where irrigating cotton increased net water use. The option that minimised net water use and maximised net water productivity over the whole farm was often the one that reduced the rice area to either 1.0 or 0.5 ha and spread the saved irrigation water over the largest area of dryland crop. The two exceptions (maize in Bairanpalli and cotton in Nemmani) were for large farms on which GMs and net water productivity were already relatively high under current practice.

Interesting differences were observed between rice-maize and rice-cotton farms. In comparisons across the three farm types and for all options the rice-cotton system provides the greater GMs per hectare. However, because cotton crops required more supplemental irrigation than maize crops using the same irrigation rules, net water usage was less and water productivity was higher in rice-maize systems.

Interesting differences were also observed between small, medium and large farms. For current practices the larger the farm the higher the GM per hectare and the higher the net water productivity for both rice-cotton and rice-maize systems. While the difference in GM was greater in the rice-cotton system, the difference in net water productivity is much greater in the maize-rice systems. The differences in GM mainly reflect differences in inputs, costs and prices received for their produce. The difference in net water productivity reflects the greater water requirements of cotton crops and consequentially the greater amount of deep drainage under maize crops. This difference is amplified with the strategic irrigation options. For Gorita village, the water productivity of current practice on large rice-cotton farms was higher (1,996 INR/mm compared with 1,769 INR/mm) than for the progressive strategic irrigation options, even though they provide the higher GMs. Conversely, the water productivity of current practice on large rice-maize farms was much lower (4,961 INR/mm compared with 10,055 INR/mm) than the progressive strategic irrigation options.

Currently there is some adoption of supplementary irrigation, though in practice farmers do not appear to be following ‘strategic’ rules to maximise the efficient use of such irrigations. Despite the clear potential of this adaptation to improve income and save water, there are barriers to adoption. Barriers to more strategic use of supplemental irrigation were discussed earlier under adaptation 2. For many farmers another barrier is that their rainfed crops may be located away from their irrigation facilities and it may not be practical to use their saved water in these fields. This barrier can be overcome by institutional measures that encourage farmers to share or trade water among other farmers in their villages and beyond.

5. Conclusions

This study has uniquely combined a number of approaches to the study of adaptation to climate variability: 1. participatory action research, 2. cropping systems simulation, 3. investigation of multiple adaptation options of varying levels of complexity and departure from current practice, 4. analysis of adaptation options in terms of multiple criteria including yield, gross margin, gross margin stability and net water productivity, and 5. analysis of adaptations for different household types. Each of these elements contributed to the richness of our understanding of the adaptation options.

The research combined soft systems participatory action research with the hard science of simulation modelling to elicit and then rigorously check farmers’ and researchers’ intuitive hunches. The adaptation options were tested by farmers in their own fields to ensure that they were practical and attractive to local farmers. Farmer group discussions, focus group discussions and individual interviews identified practical, traditional and institutional barriers to the adoption of adaptation options.

This study was also ambitious in scope in that it investigated a number of adaptation options of varying degrees of complexity and departure from "business as usual". The sowing rule adaptation is relatively simple and can be readily implemented with some extension effort, while the final adaptation 'reduced rice area for strategic irrigation of rainfed crops' requires new practices at the whole farm level, departure from tradition and possibly collaboration arrangements between farmers in a village.

Enriching the analysis of adaptation options by evaluation their outcomes in terms of multiple criteria was equally important in demonstrating how single criteria analysis is likely to overlook important trade-offs. Even in the simple case of the sowing rules, there were tradeoffs between two risks, risk of not sowing a crop that would succeed against the risk of sowing a crop that would fail. Only by considering both risks can a best bet option be correctly identified. In the 'reduced rice area of strategic irrigation of rainfed crops' adaptation systems that had the highest GM per hectare per year were not the same as those that had the highest net water productivity. While farmers are likely to opt for the system with the highest GM, given the severe depletion of groundwater, policy makers may chose to facilitate the adoption of cropping systems with higher net water productivity.

Finally, the issue of whether or not these adaptations to climate variability are also effective adaptations to climate change remains to be resolved. This question is the subject of a companion paper (Hochman et al. 2015) in which we ask if adaptations to climate variability are also climate smart. That is, are they effective as adaptations to medium term climate change and do they mitigate future climate change.

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Table 1. Farmer experiment fields, crops, treatments and yields in three participating villages in Telangana

Farmer	Village	Crop	Treatment	Soil type	year	Season	Yield (kg/ha)	Irrigation
7	Bairanpalli	Cotton	SI[1]	Black	2011	Kharif	2080	1 x 50mm
3	Bairanpalli	Cotton	AFI[2]	Black	2011	kharif	3400	2 x 50mm
3	Bairanpalli	Cotton	AP[3]	Black	2010	kharif	1825	Rainfed
7	Bairanpalli	Cotton	FP[4]	Black	2011	Kharif	900	1 x 50mm
3	Bairanpalli	Cotton	FP	Black	2011	kharif	2430	2 x 50mm
3	Bairanpalli	Cotton	FP	Black	2012	kharif	1137	Rainfed
8	Gorita	Cotton	SI	Red	2011	Kharif	1500	2 x 50mm
9	Gorita	Cotton	AFI	Red	2011	Kharif	2500	2 x 50mm
2	Gorita	Cotton	AP	Red	2010	Kharif	625	Rainfed
9	Gorita	Cotton	FP	Red	2011	Kharif	2080	2 x 50mm
8	Gorita	Cotton	FP	Red	2011	Kharif	880	Rainfed
2	Gorita	Cotton	FP	Red	2012	kharif	2000	Rainfed
5	Nemmani	Cotton	SI	Red	2011	Kharif	2400	2 x 50mm
4	Nemmani	Cotton	AP	Red	2010	Kharif	1430	Rainfed
5	Nemmani	Cotton	FP	Red	2011	Kharif	1880	1 x 50mm
14	Nemmani	Cotton	FP	Red	2011	Kharif	630	Rainfed
1	Nemmani	Cotton	FP	Red	2012	kharif	1500	Rainfed
2	Gorita	Maize	SI	Red	2011	Kharif	4500	1 x 50mm
6	Gorita	Maize	SI	Red	2012	kharif	6750	1 x 50mm
16	Gorita	Maize	FP	Red	2010	Kharif	1500	Rainfed
12	Bairanpalli	Rice	AP	Black	2011	Rabi	7400	irrigated
10	Bairanpalli	Rice	AP	Black	2010	Kharif	6500	irrigated
10	Bairanpalli	Rice	AP	Black	2012	kharif	7750	irrigated
10	Bairanpalli	Rice	FP	Black	2010	Kharif	5800	Irrigated
12	Bairanpalli	Rice	FP	Black	2011	Rabi	7200	Irrigated
10	Bairanpalli	Rice	FP	Black	2012	kharif	7500	irrigated
2	Gorita	Rice	AP	Red	2010	Kharif	7000	irrigated
13	Gorita	Rice	AP	Red	2012	kharif	6000	irrigated
2	Gorita	Rice	FP	Red	2010	Kharif	5900	Irrigated
15	Gorita	Rice	FP	Red	2011	Kharif	4380	Irrigated
13	Gorita	Rice	FP	Red	2012	Kharif	5600	Irrigated

11	Nemmani	Rice	AP	Red	2010	Rabi	6300	irrigated
5	Nemmani	Rice	AP	Black	2011	Kharif	6125	irrigated
5	Nemmani	Rice	AP	Black	2011	Rabi	6620	irrigated
11	Nemmani	Rice	FP	Red	2010	Rabi	5500	Irrigated
5	Nemmani	Rice	FP	Black	2011	Kharif	4775	irrigated
5	Nemmani	Rice	FP	Black	2011	Rabi	6500	Irrigated
16	Nemmani	Rice	SRI[5]	Black	2011	kharif	5825	irrigated
14	Nemmani	Rice	SRI	Black	2011	kharif	6400	irrigated
5	Nemmani	Rice	SRI	Black	2011	Rabi	6670	irrigated

[1]Strategic Irrigation (apply 50mm when ASW<50% PAWC)
[2]Alternate furrow irrigation (only every second inter row furrow is irrigated)
[3]The Agricultural University's package of recommendations
[4]Farmer's normal practice
[5]System of Rice Intensification

Table 2. Summary of modelling scenarios tested with APSIM for three farm sizes and options allocating a varying proportion of land to irrigated rice and to strategically irrigated cotton (or maize).

Size of farm	Current practice		Option 1 Use water saved to irrigate cotton with strategic irrigation rules		Option 2 Use water saved to irrigate cotton with strategic irrigation rules		Option 3 Use water saved to irrigate cotton with strategic rules, but unlimited no. of irrigations		Option 4 Use water saved to irrigate cotton with strategic irrigation rules		Option 5 Use water saved to irrigate cotton with strategic irrigation rules	
	Irrig. rice (ha)	RF cotton (ha)	Irrig. rice (ha)	Cotton (ha)	Irrig. rice (ha)	Cotton (ha)	Irrig. rice (ha)	Cotton (ha)	Irrig. rice (ha)	RF cotton (ha)	Irrig. rice (ha)	RF cotton (ha)
Small (2 ha)	0.8	1.2	0.6	1.4	0.4	1.6	0.4	1.6	0.2	1.8	NA	NA
Medium (3.2 ha)	0.8	2.4	0.6	2.6	0.2	3.0	nd	nd	nd	nd	nd	nd
Large (6 ha)	1.2	4.8	1.0	5.0	0.8	5.2	0.6	5.4	0.4	5.6	0.2	5.8

Table 3. Data for gross margin calculations for small, medium and large farms in Gorita.

Production Costs	Small Farm-5 acres			Medium Farm-8 acres			Large Farm-15 acres		
	Rice	Cotton	Maize	Rice	Cotton	Maize	Rice	Cotton	Maize
Farm acreage	2.0	3.0	3.0	2.0	6.0	6.0	3.0	12.0	12.0
Seed qty (kg/acre)	50.0	0.6	4.0	30.0	0.5	7.0	30.0	0.45	7.0
Cost of seed (INR/kg)	17	1660	400	22	1600	100	18	1700	80
Cost of Seed (INR/acre)	850	996	1600	660	800	700	540	765	560
Fert. (kg/acre)	200	250	100	250	300	100	200	100	100
Cost of Fertiliser (INR/acre)	1600	1900	850	2000	2500	1200	1700	1200	1200
No carts manure	8	0	0	4	0	20	4	4	4
Area manure used on (acres)	2.0	0	0	1.5	0	4	1.5	3.0	3.0
Cost manure/cart	400	0	0	500	0	200	200	200	200
Cost of Manure (INR/acre)	1600	0	0	1333	0	667	533	267	267
Cost of Pesticides (INR/acre)	500	800	800	300	450	300	350	1500	400
Hired Lab (person days/acre)	20	30	10	60	80	15	30	30	10
Cost Hired Labour/day/person	100	100	100	100	120	100	100	100	100
Cost of Hired Labour (INR/acre)	2000	3000	1000	6000	9600	1500	3000	3000	1000
Cost of Hired Implements (INR/acre)	2500	1600	0	1800	1600	0	0	0	0
Total Cost (INR/acre)	9050	8296	4250	12093	14950	4367	6123	6732	3427
Income									

Value of output (INR/quintal)	850	3000	700	950	3100	800	1050	3200	800

Table 4. The percent of years in which crops are not sown or in which sown crops fail due to seeling deaths when various sowing rules are applied to cotton crops at Bairanpalli, Gorita and Nemmani villages in Telangana. Shaded areas represent optimal tradeoffs between exploiting sowing opportunities and seedling deaths.

	Bairanpally		Gorita		Nemmani	
Sowing Rule	Crops sown (%)	Crops fail (%)	Crops sown (%)	Crops fail (%)	Crops sown (%)	Crops fail (%)
75 mm in 4 days	56.2	0	28.1	11.1	15.6	0
75 mm in 7 days	62.5	0	48.4	6.7	37.5	0
75 mm in 10 days	71.9	0	64.5	5.0	43.7	0
75 mm in 14 days	75.0	0	27.4	4.3	53.1	0
75 mm	90.3	0	93.5	3.4	87.5	17.9
50 mm in 4 days	84.4	0	65.6	4.8	43.7	0
50 mm in 7 days	90.6	0	81.2	3.8	59.4	0
50 mm in 10 days	90.6	3.4	87.5	3.6	65.6	0
50 mm in 14 days	90.6	6.9	93.7	10.0	75.0	4.2
50 mm	96.9	16.1	100	3.1	93.7	13.3
2 day >2.5 mm	100	16.1	90.3	10.7	93.7	23.3
Soil water start	90.6	0	96.9	0	84.4	0

Table 5. Seed cotton and maize yield and gross margin responses to strategic irrigation of rainfed crops in Bairanpalli, Gorita, and Nemmani villages in Telangana (excluding years in which crops were not sown).

	Bairanpalli cotton		Bairanpalli maize		Gorita cotton		Gorita maize		Nemmani cotton		Nemmani maize	
	Rain	irrig	rain	irrig	Rain	irrig	rain	irrig	rain	irrig	rain	irrig
Mean Yield (t/ha)	2.7	3.8	8.7	9.2	2.2	3.6	6.1	8.7	1.9	3.4	5.2	7.8
Mean GM (INR/ha)	45755	71399	65424	69221	36285	70557	44757	65715	34987	75392	37336	58705
CV Yield (%)	32.6	25.5	15.0	7.2	50.6	24.7	47.7	10.5	48.2	23.6	51.5	17.2
CV GM (%)	48.6	33.5	16.1	7.7	76.0	31.0	52.0	11.2	74.6	29.7	57.1	18.4
Probability of Yield < 2 (cotton) or < 4 (maize) t/ha	15.0	1.6	0	0	48.4	0	23.9	0	55.0	1.6	29.8	1.3
Probability of GM < 30000 INR/ha	21.5	2.1	0	0	47.9	0	27.2	0	45.8	0.5	33.2	1.9
Mean Irrigation (mm)	0	100	0	38	0	119	0	96.8	0	143	0	106

CV Irrigation (mm)	0	55.1	0	103.6	0	41.4	0	48.0	0	12.7	0	44.2

Figure Titles:

Figure 1. Location of the 3 case study villages in Telangana, South India. Each circle represents a case study village.

Figure 2. Cumulative monsoon season rainfall probability distribution in weather stations near the three study villages.

Figure 3. Comparison of weather data for the monsoon period (Jun-Nov) of the years 1978-2009 for Warangal (blue bars and lines) and Mahabubnagar (red bars and lines) in Telangana, India of: (a) average monthly rainfall (mm; whiskers show Standard deviation above the mean), (b) average daily solar radiation (MJ/m^2), (c) average maximum daily temperatures (^0C), and (d) average minimum daily temperatures (^0C).

Figure 4. The relationship between observed and simulated cotton, rice and maize crops. The solid line indicates the 1:1 line; Y = 0.964 Observed + 162; root mean square deviation = 604 kg/ha; r^2 = 0.96.

Figure 5. Seed cotton and maize yield responses (probability of exceedence) to strategic irrigation (blue lines) compared with rainfed (red lines) in Gorita, Telangana: a) seed cotton yields; b) cotton gross margins; c) maize grain yields; and d) maize gross margins.

Figure 6. The impact of irrigation rules ("irrig1" blue lines, "irrig2" red lines, "AWD1" green lines, "AWD2" purple lines) on: a) rough rice yields at Bairanpalli; b) rough rice yields at Gorita; c) gross margins at Bairanpally; d) gross margins at Gorita; e) net water use at Bairanpalli and f) net water use for the years 1978-2009.

Figure 7. Effects of rice substitution adaptation options. Gross margin (blue bars) and net water use (red dots) on farms growing rice and cotton crops in a) small farm, b) medium farm and c) large farm, and for farms growing rice and maize crops in d) small farm, e) medium farm and f) large farm for the years 1978-2009 in Gorita, Telangana.

Figure 8. Cross village comparisons of the effects of rice substitution adaptation options on gross margin (blue bars are Bairanpally, green bars Gorita, and red bars Nemmani) and net water use (dots: blue for Bairanpally, green for Gorita, and red for Nemmani) on (a) farms growing rice and cotton crops in a) small farm, b) medium farm and c) large farm, and (b) for farms growing rice and maize crops in d) small farm, e) medium farm and f) large farm for the years 1978-2009.

Figures:

Figure 1.

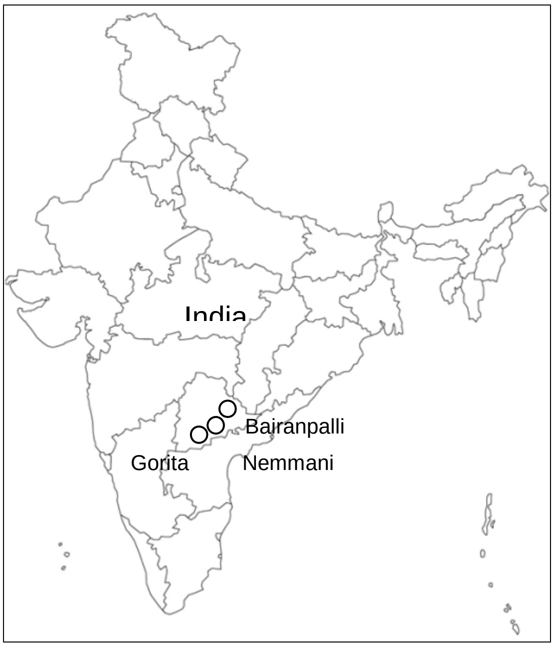
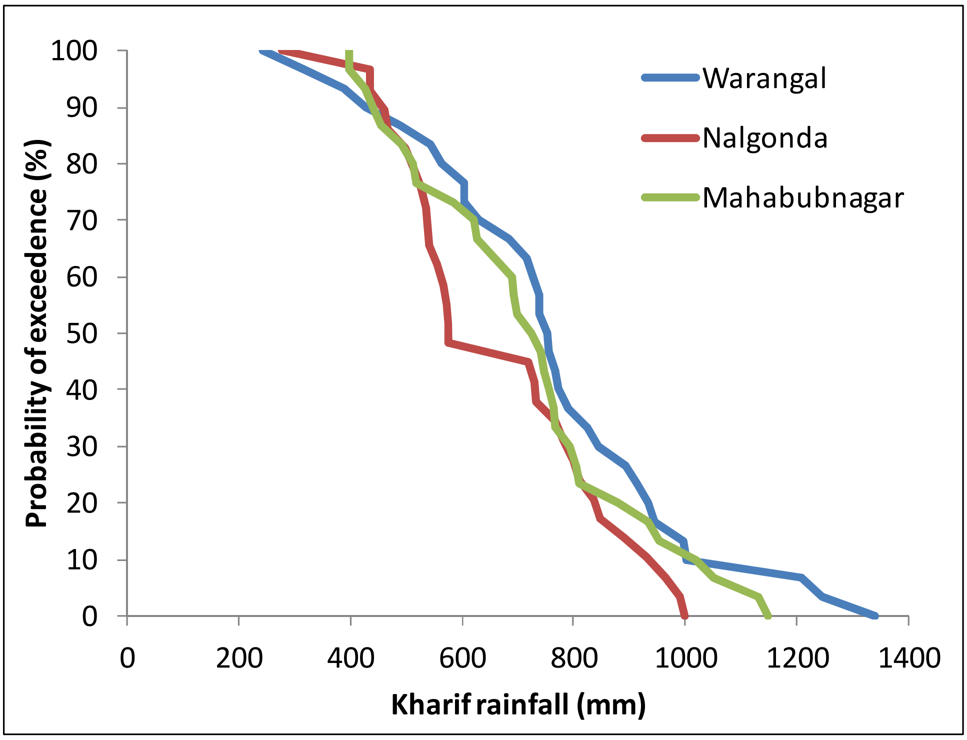
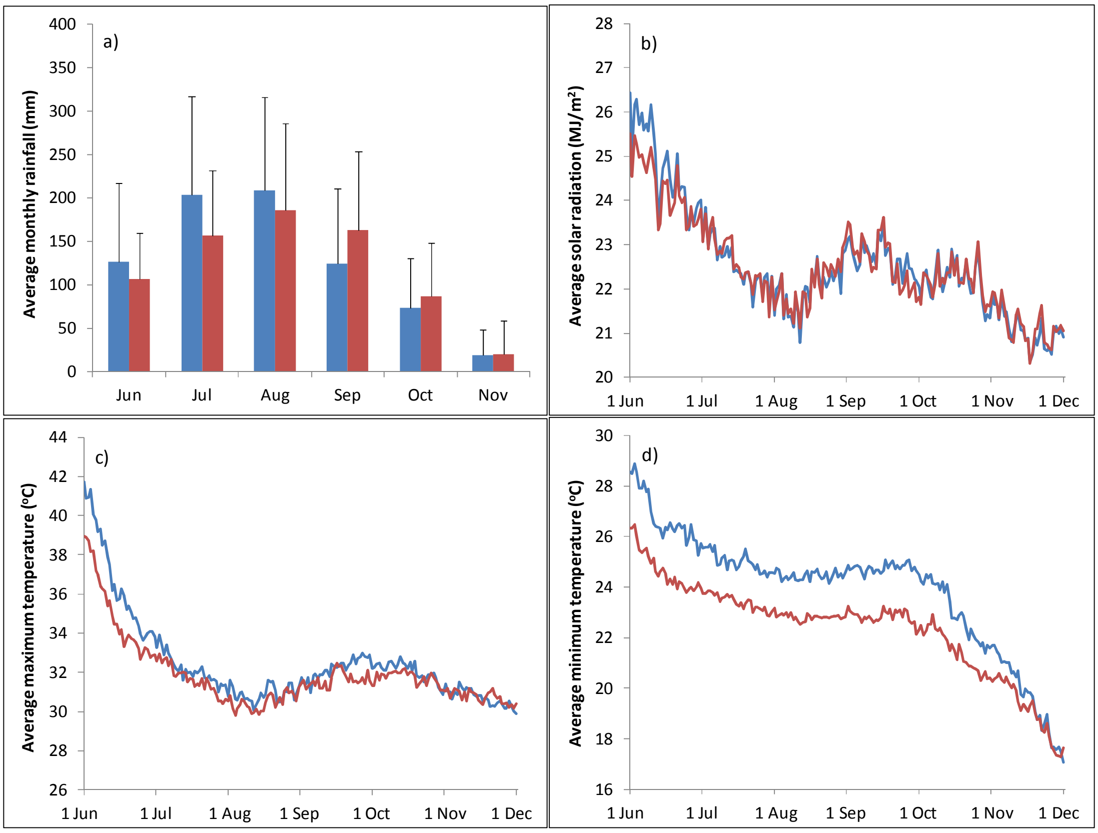


Figure 2.



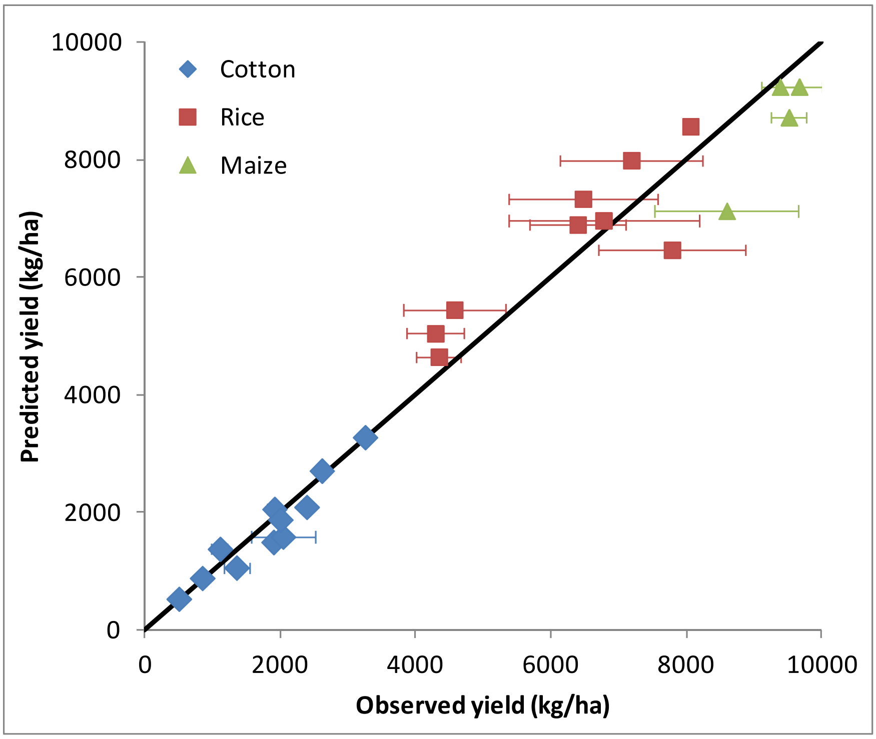
Warangal
Nalgonda
Mahabubnagar
Probability of exceedence (%)
100
90
80
70
60
50
40
30
20
10
0
0
200
400
600
800
1000
1200
1400
Kharif rainfall (mm)

Figure 3.



a)
Average monthly rainfall (mm)
400
350
300
250
200
150
100
50
0
Jun
Jul
Aug
Sep
Oct
Nov
b)
Average solar radiation (MJ/m²)
28
27
26
25
24
23
22
21
20
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
c)
Average maximum temperature (ºC)
44
42
40
38
36
34
32
30
28
26
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
d)
Average minimum temperature (ºC)
30
28
26
24
22
20
18
16
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec

Figure 4.



Cotton
Rice
Maize
Predicted yield (kg/ha)
Observed yield (kg/ha)
0
2000
4000
6000
8000
10000
0
2000
4000
6000
8000
10000

Figure 5.

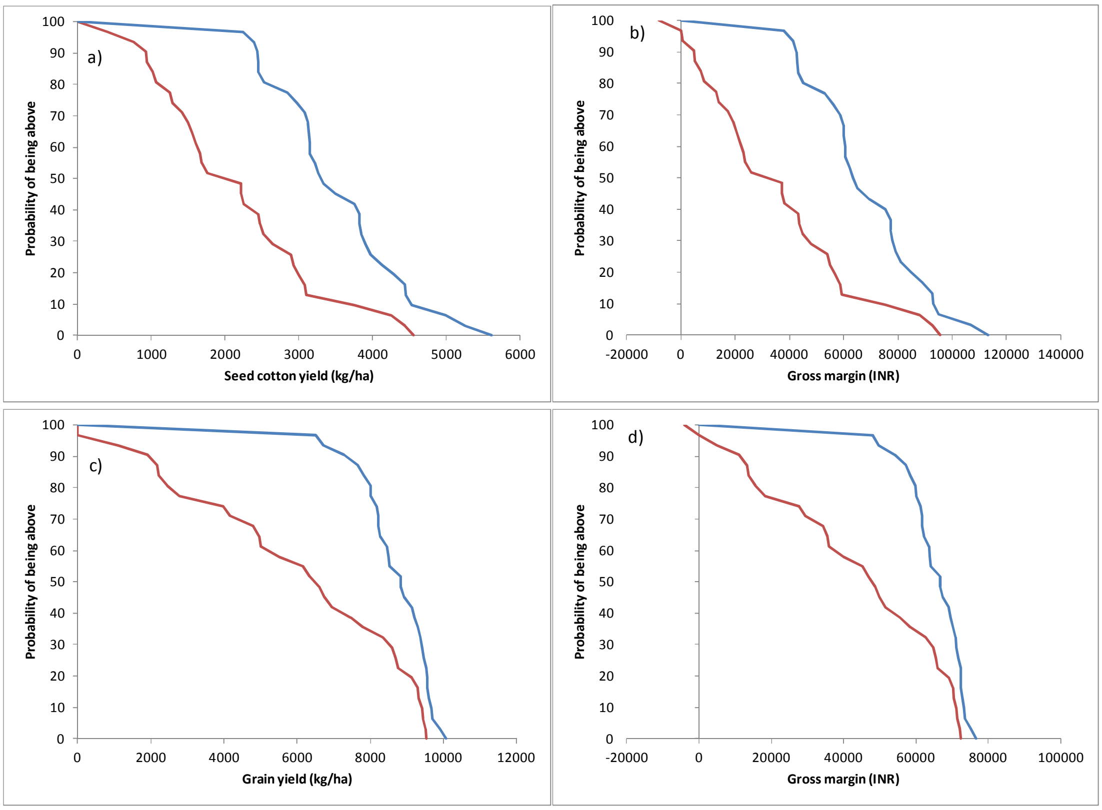

a)
Probability of being above
Seed cotton yield (kg/ha)
b)
Probability of being above
Gross margin (INR)
c)
Probability of being above
Grain yield (kg/ha)
d)
Probability of being above
Gross margin (INR)

Figure 6.

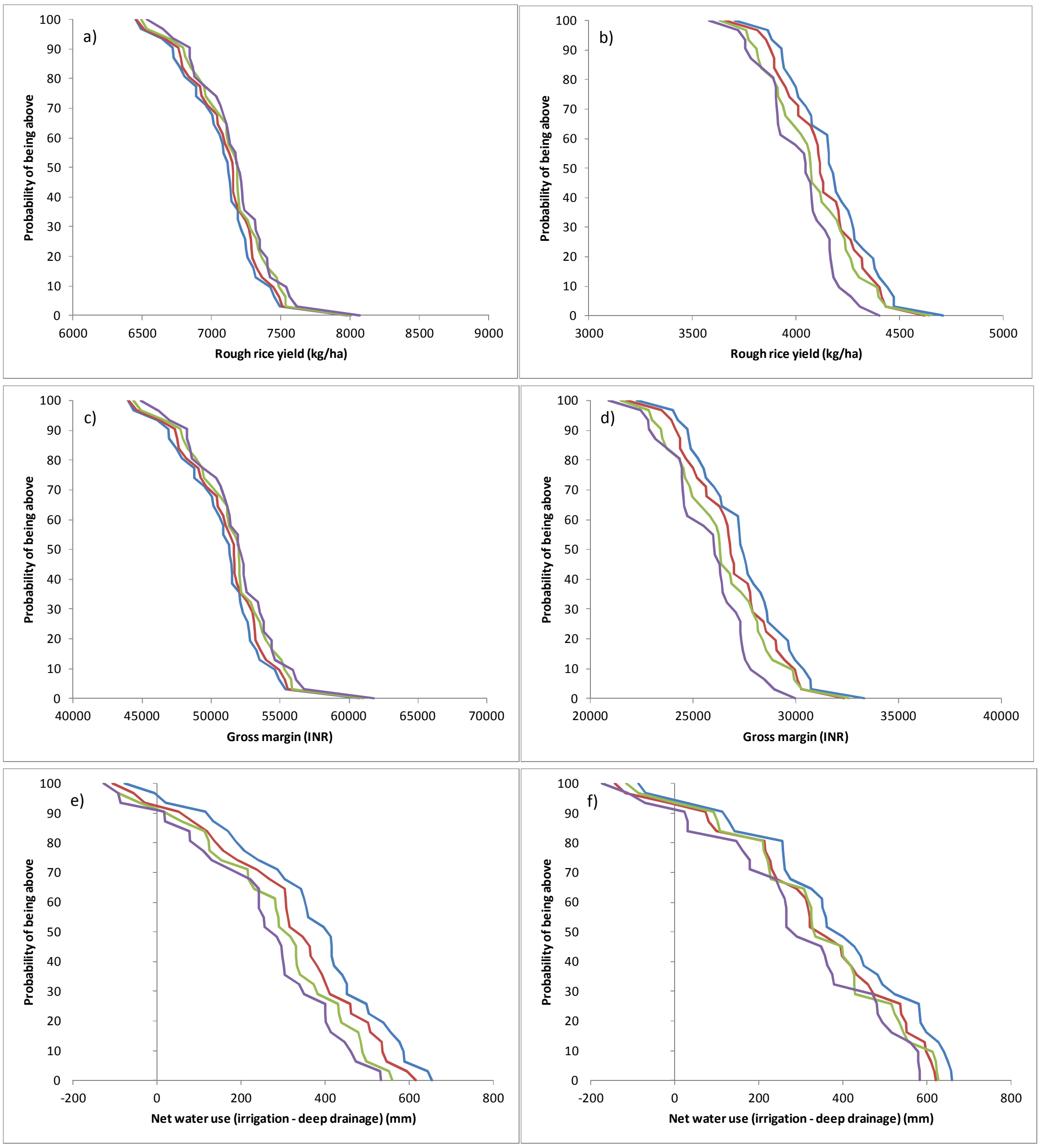

a)
b)
c)
d)
e)
f)
Probability of being above
Rough rice yield (kg/ha)
Gross margin (INR)
Net water use (irrigation - deep drainage) (mm)

Figure 7.

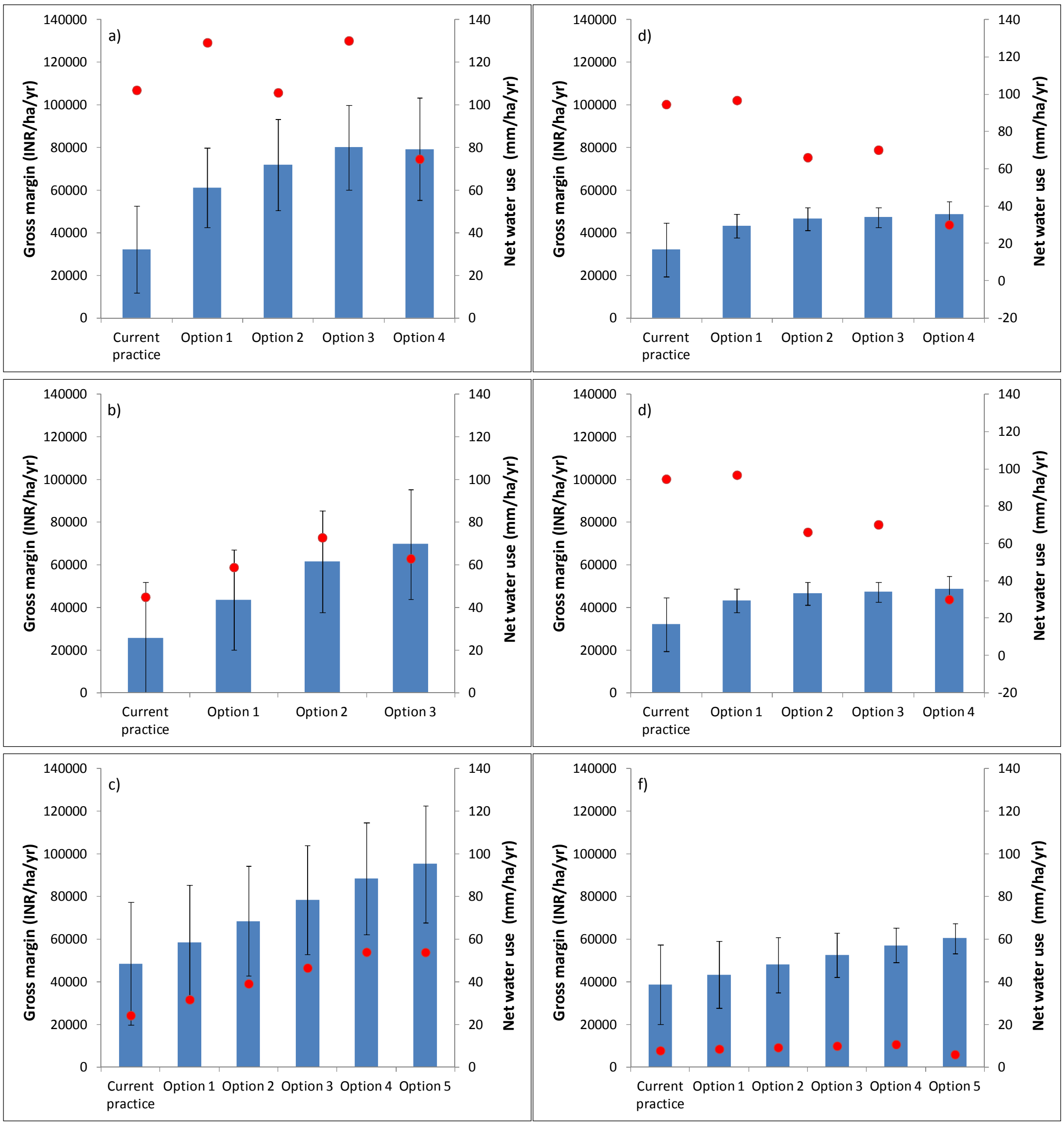
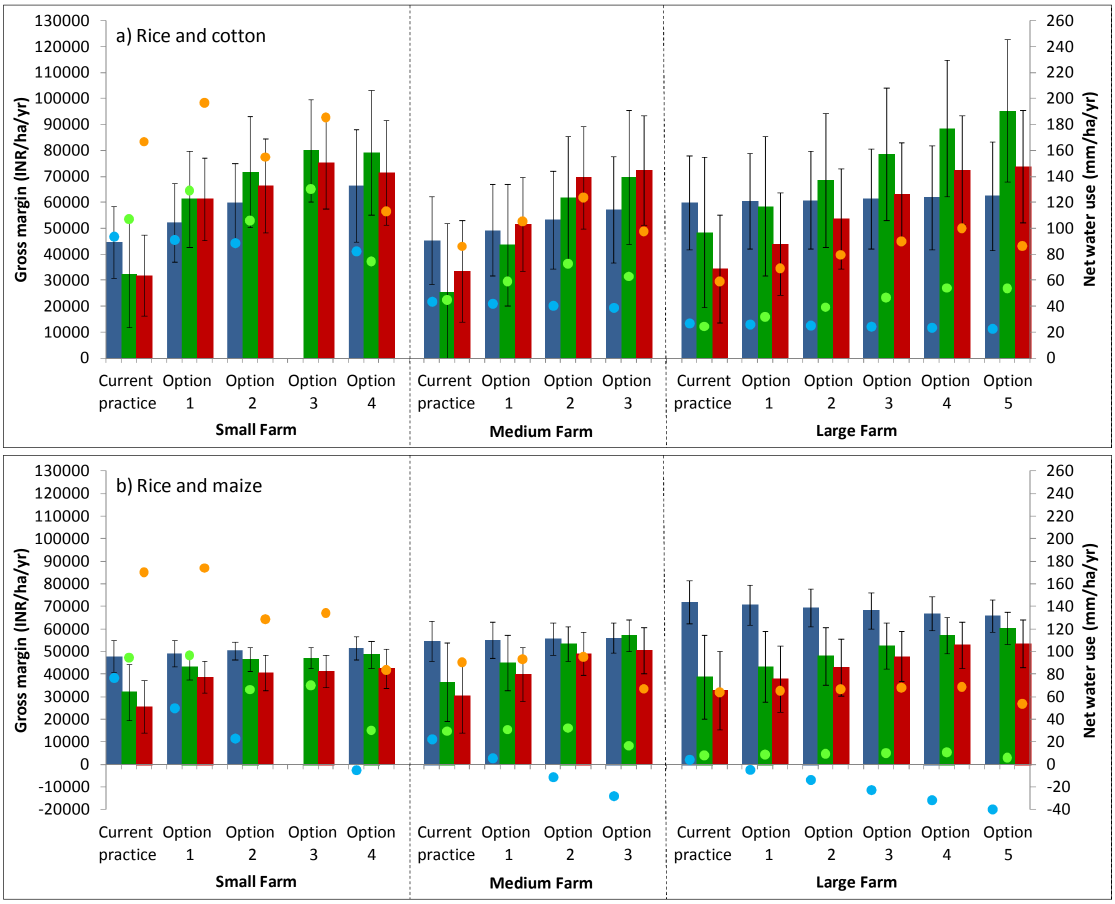

a)
b)
c)
d)
d)
f)
Gross margin (INR/ha/yr)
Net water use (mm/ha/yr)
Current practice
Option 1
Option 2
Option 3
Option 4
Option 5
0
20000
40000
60000
80000
100000
120000
140000
-20
0
20
40
60
80
100
120
140

Figure 8.



a) Rice and cotton
Gross margin (INR/ha/yr)
Net water use (mm/ha/yr)
Current practice
Option 1
Option 2
Option 3
Option 4
Option 5
Small Farm
Medium Farm
Large Farm
b) Rice and maize
Gross margin (INR/ha/yr)
Net water use (mm/ha/yr)
Small Farm
Medium Farm
Large Farm

1. Smallholder farmers managing climate risk in India: 1. adapting to a variable climate – Supplementary Data

SD 1. APSIM parameterisation

For cotton we created the rule based on a soil moisture index (SMI = 1- (soil water –crop lower limit LL15)/(drained upper limit DUL – LL15)) which assumes values close to 0 when soil is wet and close to 1 when the soil is dry. If over the first 3 weeks after sowing SMI index exceeded 0.7 then seedling stress severity was calculated using equation 1:

Seedling Stress = 3.33 * SMI – 2.33 equation 1.

Daily Seedling Stress values are accumulated over three weeks and if at the end of three weeks the cumulative seedling stress exceeds the value of seven, seedlings are assumed not to survive. A similar rule was applied to maize seedlings. Using the same SMI, if over the first 3 weeks after sowing the index exceeded 0.9 seedling stress severity was calculated using equation 2:

Seedling Stress = 10 * SMI – 9 equation 2.

Daily Seedling Stress values for maize are accumulated over three weeks and if at the end of three weeks the cumulative seedling stress exceeds the value of six, seedlings are assumed not to survive. The Seedling Stress index functions for cotton and maize are illustrated in Figure SD1.

[Figure SD1]

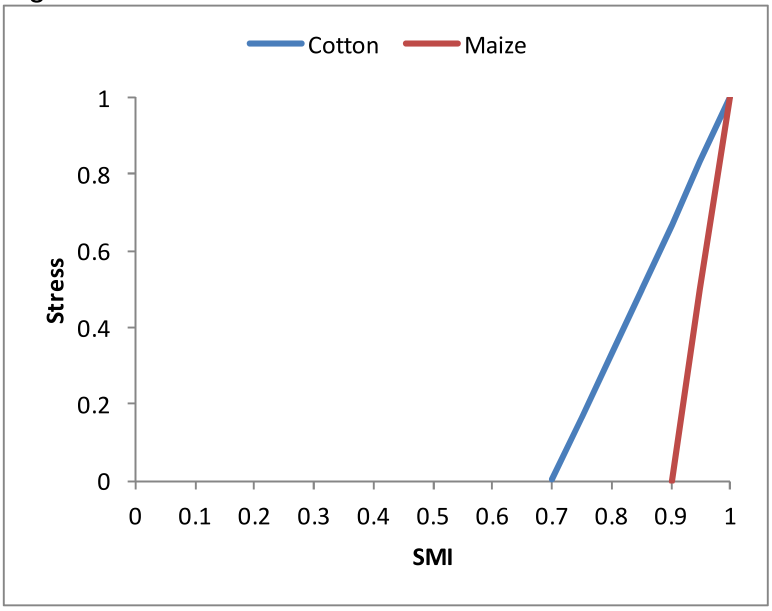
SD - Figures and Tables

1. Titles

Figure SD1. Seedling stress functions used to accumulate seedling stress indices for cotton and maize crops.

2. Figures

Figure SD1.



Appendix 6 – Hochman et al: Smallholder farmers managing climate risk. Part 2.

Smallholder farmers managing climate risk in India: 2. is it climate-smart?

Zvi Hochman, Heidi Horan, D. Raji Reddy, G. Sreenivas, Chiranjeevi Tallapragada, Ravindra Adusumilli, Don Gaydon, Alison Laing, Philip Kokic, Kamalesh K. Singh, Christian H. Roth

Final draft for submission.

Abstract

This paper describes an investigation into adaptations of rice based cropping systems to future climate scenarios in Telangana, India. Most research about adaptation of crops to climate change at a regional scale is based on simplifying assumptions about current and future weather and about current farmer management practices, while the impacts of adaptations are usually measured only in production terms and the feasibility of implementing proposed adaptations is rarely tested. In this study, all adaptations were generated through participatory engagement, and were field tested with local smallholder households after being first evaluated through cropping system simulation analysis. Evaluations were from the perspective of adaptations to historical climate variability with outcomes assessed in terms of production, profitability and environmental consequences, including greenhouse gas emissions before they were evaluated as climate-smart adaptations to medium term climate change. In an earlier phase of the study, participatory intervention at household level was used to identify and evaluate new practices that were shown to be effective adaptations to today's variable climate. Here we test the applicability of these adaptations to likely climate scenarios in 2021-2040. Local climate records were used to statistically downscale outputs from two global circulation models providing contrasting climate change scenarios for each location. The adaptations to climate variability that were tested with the cropping systems simulator APSIM on local historical weather data are here simulated with future climate data sets. In each of the case studies, the adaptations were evaluated in terms of their simulated gross margin, yield, yield stability, gross margin stability, N_2O and CO_2 emissions and, where irrigation treatments were varied, net water use, irrigation water productivity, contribution to the recharge of aquifers and nitrogen leached from the root zone. Results were presented in sustainability polygons. Compared with variability in historic yields the simulated yield changes in 2021-2040 climate scenarios were modest and their direction was dependent on the global circulation model used. The sustainability polygons for benchmark and future climate scenarios clearly showed that adaptation options mostly resulted in tradeoffs between productivity and environmental outcomes and between competing environmental outcomes. These results lead to the conclusion that participatory action research with smallholder farmers, coupled with field testing and simulation analysis can produce practical and productive adaptations to climate variability that are usually but not always robust for locally downscaled CC scenarios to 2021-2040.

Key Words: Climate Change, Simulation, APSIM, rice, maize, cotton

1. Introduction

Climate change has already impacted agriculture and food production (Trenberth 2011, Lobell et al. 2011, Coumou and Rahmstorf 2012, Liu and Allan 2013). Further increases in mean temperature and evapotranspiration; changes in rain patterns; increased variability both in temperature and rain patterns; changes in water availability; the frequency and intensity of 'extreme events' and sea level rise are projected by climate models (Rummukainen 2012, Taylor et al. 2012). Such changes are expected to have profound impacts on agriculture (Easterling et al. 2007, Gornall et al. 2010, Beddington et al. 2012). However, climatic impacts on agriculture could be heterogeneous and ambiguous (Knox et al. 2012) and vulnerability can be expected to vary between crops and regions and with people's socio-economic conditions (Kates et al. 2012, Dow et al. 2013). In addition to adapting to gradual climatic changes driven by greenhouse gas emissions farmers must also cope with year-to-year climate variability.

Effective adaptation of agriculture to climate change will mostly result in gains to those who take the adaptive action and while governments can encourage adaptation through investment in R&D and appropriate policy settings, it requires individuals to act in their own perceived interests. Consequently, adaptation to climate change will at most be motivated by a medium term outlook such as 5 to 25 years ahead. Farmers and other stakeholders might be persuaded to adapt to near term climate change but are unlikely to consider adaptation to longer term timelines (Kokic et al. 2011 and references cited within). Further, the rate of change in rural development in smallholder agriculture in South and Southeast Asia is such that farming beyond 2020 is likely to be comprehensively transformed. Additionally, with agricultural livelihoods often being precarious and climate dependent, adaptations will only be implemented if farmers are convinced that they will provide at least some immediate gains. In other words, climate change adaptations can only be contemplated if they are also successful adaptations to current climate variability (Robertson and Murray Prior 2014).

An emerging concept for dealing with multiple aspects of climate change is climate-smart agriculture (http://www.fao.org/climate-smart-agriculture/41760-0c193f4f5f7f53aa75f8927278f97362e.pdf). Climate-smart agricultural practices are those which aspire to contribute towards three outcomes: i. Sustainable and equitable increases in agricultural productivity and incomes; ii. Greater resilience of food systems and farming livelihoods; and iii. Reduction of greenhouse gas emissions associated with agriculture. We adopt these criteria in our investigation of a number of adaptations that were derived from a related study that combined simulation with a participatory framework for developing and testing locally relevant adaptations to climate variability in three villages in semi-arid tropical India (Hochman et al. 2015).

1.1 Climate Change Projections for India

Climate change projections for India using the Coupled Model Inter-comparison Project 5 (CMIP5) ensemble found that, by the 2030s, under a business-as usual representative concentration pathway (between RCP6.0 and RCP8.5) scenario, mean warming in India relative to preindustrial times is likely to be in the range 1.7–2.0°C while precipitation is projected to increase by 4% to 5% compared to the 1961–1990 baseline. A trend for increased frequency of extreme precipitation days (e.g. > 40 mm/day) is projected for the 2060s and beyond (Chaturvedi et al. 2012).

Barnwal and Kotani (2013) observed that while a number of simulation studies using global circulation model (GCM) scenarios predicted increased rice production in India (Mohandass et al. 1995, Lal et al. 1998, Rathore et al. 2002, Aggarwal and Mall 2002), other more recent studies showed negative impacts (Auffhammer et al. 2006, Cline 2007, Aggarwal 2008).

1.2 Case Study Villages

The three case study villages are located in three districts in the Telangana state (formally part of Andhra Pradesh) in south India: Warangal, in the Central Telangana agro climatic zone and Nalgonda and Mahabubnagar in the Southern Telangana Zone. Paddy rice, cotton, and to a lesser degree maize are the key kharif (monsoon) crops in these villages. Paddy rice is grown under irrigated conditions mostly using groundwater pumped from bore-wells. Cotton and maize are mostly grown as rainfed crops. The average holding size in the area is around 2 ha with predominantly smallholder farmers. The villages were selected to reflect the considerable variation in natural endowments for agriculture. Bairanpalli (Warangal district) is a village with better soil and water resources, while Gorita (Mahabubnagar district), and Nemmani (Nalgonda district) are villages with more limited resources. More details about the study villages are provided in Hochman et al. (2015).

1.3 Using Simulation Models

Dynamic, process-based crop and cropping system simulation models are commonly used in studies of climate change impact and risk (Tubiello and Ewert 2002, Challinor et al. 2009, White et al. 2011, Angulo et al. 2013). The APSIM model (Keating et al. 2003, Holzworth et al. 2014) was chosen for this study for a number of reasons. Recent work has demonstrated that APSIM-Oryza is a reliable tool for simulating rice based cropping systems in South and South East Asia (Gaydon et al. 2015). APSIM captures the CO_2 enrichment effects on photosynthesis via modifiers of radiation use efficiency (RUE). Transpiration is a function of daily DM increment multiplied by transpiration efficiency (TE) which depends on vapour pressure deficit (vpd) and CO_2-level. Actual transpiration and photosynthesis are limited if available soil water is insufficient to meet transpiration demand. In APSIM-Maize RUE's sensitivity to CO_2 is described by a user-defined input ratio while in Oryza, CO_2 response is simulated at the leaf-level and both the initial light-use efficiency of a single leaf and the CO_2 assimilation rate at light saturation are sensitive to CO_2 with a mimic of rubisco kinetics simulated hourly and scaled up over sunlit and shaded leaves to canopy assimilation (Jansen 1990).

The APSIM model has been applied for over a decade to assess the impacts of climate change as well as adaptation and mitigation strategies. It has been used to determine climate change impacts for various region and crop combinations with analysis extended beyond crop production to consider environmental indicators of cropping systems as well to explore the abatement of greenhouse gas (GHG) emissions through reduced N_2O emissions and/or increased soil organic sequestration (Holzworth et al. 2014). Although APSIM's simulation of soil C balance (and hence emissions) has been validated in a number of studies in both flooded (Gaydon et al., 2012b) and non-flooded soil environments (Huth et al., 2010) , the model makes no attempt to segregate gaseous C losses from soil organic matter cycling between carbon dioxide (CO_2) and methane (CH_4). This necessitates additional consideration of the global warming impact of simulated C-emissions when the cropping system is alternately flooded and non-flooded (such as a rice-wheat system), due to the different global warming potential of CO_2 and CH_4 (21 times the effect of CO_2 for same mass). Importantly, APSIM was also chosen due to its

Manager module’s capability to closely mimic farmer management decision logic and subsequent actions.

2. Methods

2.1 Cropping Systems Simulation

The cropping system model APSIM was used with APSIM-Oryza (Bouman and Van Laar 2006, Gaydon et al. 2012a, b) to simulate rice, with APSIM-Maize (Carberry and Abrecht 1991) to simulate maize crops and with APSIM-Ozcot (Hearn 1994) to simulate cotton. All simulations in this study were based on local parameterization that was established for the study villages as described in the earlier paper (Hochman et al. 2015).

2.2 Climate data and future climate scenarios

The baseline data set used daily historic weather data (1978-2009) recorded in Indian Meteorology Department (IMD) weather stations in close proximity to the case study villages. For future climate projections we used the linear, mixed-effect state-space (LMESS) method to generate location specific projections to 2021-2040 (Kokic et al. 2011), drawing on historical data for the case study locations and using outputs from two contrasting Global Circulation models (ECHAM5 for a relatively cooler and GFDL CM2.1 for a relatively hotter future climate) under the A2 SRES emissions scenario (approximately equivalent to representative concentration pathway RCP6) to 2021-2040.

The LMESS methodology was applied as described in Kokic and Crimp (2011). A multivariate state-space modelling approach was used to establish empirical relationships between GCM variables and location-specific climate. In so doing, we maintained important information regarding local observed trends and variability but also introduced important drivers of change from the GCMs. The state-space approach was used to jointly model quantiles of rainfall and temperature at monthly level, then a bootstrap simulation procedure (Efron, 1982) based on quantile matching was used to simulate future daily climate (Kokic et al. 2011). APSIM climate files also require solar radiation, vapour pressure and evapotranspiration. These variables where predicted from rainfall and temperature using empirical relationships based on NCEP reanalysis climate data for locations close to each climate station. This approach ensures that the future simulated climate is coherent across variables and temporally, and displays distributional characteristics highly consistent with point level climate data.

2.3 Adaptation Strategies

Four adaptations that were tested in Hochman et al. (2015) and found suitable for managing climate variability were also tested here as adaptations to the two contrasting climate change scenarios in the same locations:

Adaptation 1. Sowing Rules

The sowing window for rainfed crops such as cotton and maize is between June 1 and July 17. While there is no generally accepted farmer practice with regards to when farmers sow rainfed crops, some farmers will sow these crops as soon as the monsoon season breaks locally (defined as two consecutive days where rainfall exceeds 2.5 mm). Given this sowing window, four main variations to the sowing rule were explored:

1. Sow at ‘onset of monsoon’ following the IMD’s definition (i.e. 2 consecutive days in which daily rainfall >= 2.5mm) – termed 2 day rule
2. Sow when cumulative rainfall equals or exceeds 75 mm (accumulated over 4, 7, 10 or 14 days) – termed 50 mm rule
3. Sow when cumulative rainfall equals or exceeds 50 mm (accumulated over 4, 7, 10 or 14 days) – termed 75 mm rule
4. Sow when soil moisture in top 15cm is at 50% of the soil’s plant available water capacity (PAWC) in Vertisols (hereafter referred to as black soils) or at 66% of PAWC in Alfisols and Ultisols (hereafter referred to as red soils) – termed soil moisture rule.

These four adaptations were evaluated, using benchmark and future climate scenarios, in terms of their grain yields (t/ha), yield stability (CV of yield), gross margins (INR/ha; 1 USD ~ 65 Indian Rupees) based on data from a survey of household costs and prices received), gross margin stability (CV of GM), and the intensity of carbon (C/t yield) and nitrous oxide (N_2O/t yield) emissions.

Adaptation 2. Strategic Irrigation of rainfed crops

The common farmer practice is to grow cotton and maize as rainfed crops. Strategic irrigation of cotton and maize crops was deployed according to the rule: apply 50mm when soil moisture falls below 50% of PAWC subject to -

1. at least 14 days between irrigations
2. maximum of 3 irrigations per season
3. for cotton start irrigations after 30 days after sowing (DAS) and stop at 120 DAS
4. for maize start irrigations after 14 DAS and stop at 21 days after anthesis

The soil moisture sowing rule was used for both rainfed and strategically irrigated options and for all three climate scenarios. The strategic irrigation adaptation was evaluated relative to purely rainfed crops, using benchmark and future climate scenarios, in terms of their grain yields (t/ha), yield stability (CV of yield), gross margins (INR/ha) based on data from a survey of household costs and prices received), gross margin stability (CV of GM), and the intensity of carbon (C/t yield) and nitrous oxide (N_2O/t yield) emissions.

Adaptation 3. Reduced Irrigation of Rice

Current farmer irrigation practice was identified as aiming to maintain a pond depth of 10 cm by irrigating every second day to top up the pond to 10cm if required. All adaptation options were simulated according to the following rules:

> Start nursery on the 7th of June and transplant seedlings at least 25 days after sowing (DAS) when cumulative rainfall exceeds 35 mm. If minimum rainfall (35mm) had not fallen in 50 days at Bairanpalli, transplant at 50 DAS. If minimum rainfall (35mm) had not fallen in 60 days at Gorita or Nemmani, transplant at 60 DAS.

The current practice (Irrig-1) was compared with three proposed adaptations:

1. Irrig-1. Aiming to maintain a pond depth of 10 cm by irrigating every second day to top up the pond to 10cm if required.

2. Irrig-2: Maintain 5cm pond depth – irrigate every day to top up pond to 5 cm if required. This option was based on farmer practice.
3. AWD1: Alternate wetting and drying - irrigate when pond depth = 0cm, fill to 5cm
4. AWD2: Alternate wetting and drying - irrigate 2 days after pond depth = 0cm, fill to 5cm

The four irrigation management adaptations were evaluated, using benchmark and future climate scenarios, in terms of their grain yields (t/ha), yield stability (CV of yield), gross margins (INR/ha) based on data from a survey of household costs and prices received), gross margin stability (CV of GM), net water use (irrigation – recharge), irrigation water productivity (INR/ML) and the intensity of carbon (C/t yield) and nitrous oxide (N_2O/t yield) emissions.

Adaptation 4. Reduced Rice Area for Strategic Irrigation of rainfed crops

This adaptation combines the three adaptations discussed above into an integrated, whole farm management package. Options investigated for sourcing water for strategic irrigation of rainfed crops from reduced paddy area varied by household type and particularly by farm size. We considered 3 representative households: 1. A small farm with 5 acres (2 ha) of which 2 acres were paddy and 3 acres were cotton; 2. A medium farm with 8 acres (3.2 ha) of which 2 acres were paddy and 6 acres were cotton; 3.A large farm with 15 acres (6.5 ha) of which 3 acres were paddy and 12 acres were cotton. For all farm types we assumed the rice Irrig-2 from adaptation 3 and rainfed cotton or rainfed maize using the starting soil water sowing rules as the current farmer practice. A minimum of half an acre of rice was retained in adaptation scenarios to allow self sufficiency for a family of up to 5 people. A summary of the treatments for each farm type is provided in Table 1.

[Table 1]

All the options in Table 1 were simulated for red and black soil types at the three villages using historical weather data (1978-2009) and outputs representing 2021-2040 scenarios from the two contrasting Global Circulation models ECHAM5 and GFDL CM2.1. Simulation outputs included yields; net water used; soil carbon status; soil nitrate leached beyond the root zone; and nitrous oxide emissions. Gross margins were calculated using cost and income data collected from the representative case study households. Post simulation analysis enabled the calculation of gross margins and this enabled the calculation of average gross margins and stability, represented by the coefficient of variation (CV) of gross margins. Environmental impacts were calculated as intensities (e.g. nitrous oxide emissions/ rupee value of product).

In considering how climate-smart competing adaptations are, the outputs listed in the paragraph above are represented as sustainability polygons (Ten Brink *et al.* 1991, Moeller et al. 2014). These polygons allow for an integrated graphic representation of multiple sustainability indicators. They are designed to provide a holistic visual summary of how sustainable (or climate-smart) competing adaptation practices are. Each sustainability indicator is represented by a relative value from 1 to 0 where 1 is the most desirable outcome (highest or lowest depending on context (e.g. highest gross margin per ha or lowest carbon emission per ton of yield). For a desirable attribute (e.g. gross margin per ha) the relative sustainability value for any adaptation is calculated as the value of the adaptation divided by the value calculated for the highest among the competing adaptation options. For an undesirable attribute (e.g. carbon emissions per ton of yield) the sustainability value of an adaptation is calculated by dividing the lowest value among competing adaptations by the value of that adaptation. When all sustainability indicators are presented in a polygon and assuming equal weighting for all indicators, the most climate-smart practice would encompass the largest area. Ideally the most climate-smart practice will have all values close to 1.0. However, when this is not the case we have to consider tradeoffs among the desirable indicators. Choice of which adaptation is the most climate-smart may require subjective weighting of the various sustainability indicators. Relative weighting of indicators is essentially subjective but might be informed by the importance assigned to each indicator but also by the range of values that each indicator displays. We therefore also display the range of absolute values for each of the sustainability indicators.

3. Results

The observational weather data for two Indian villages (Bairanpally and Gorita) were sourced from nearby weather stations (Warangal and Mahbubnagar respectively). The data spanned the period from 1978 to 2009. Missing data (16% of observations in Warangal and 10% in Mahbubnagar) were in-filled with IMD gridded data. A comparison between the two villages' minimum and maximum temperatures and rainfall during the monsoon season is provided in Figure 1. Warangal (Figure 1a) tends to be wetter than Mahbubnagar (Figure 1b) in the first half of the kharif season (June to August) but drier in September and October. It is warmer throughout the season with the difference being greater in the minimum temperatures (Figure 1c,d,e,f). Data for the third village (Nemmani) were intermediate between the other two and are not shown here (for a comprehensive set of results see the *Supplementary Publication*). Both GCMs project future climate scenarios for 2021-2040 with warmer minimum temperatures than the historical record. Only the GDFL CM2.1 model projects warmer maximum temperatures, especially in July and August. Only small changes are projected for rainfall with both models projecting a wetter June for both locations with less consistent monthly changes projected for the remainder of the season. Overall, for Warangal and Mahbubnagar in 2021-2040, the climate projections of the GFDL CM2.1 model are warmer, especially in their maximum temperatures, than the climate projected by ECHAM5 (Figure 1).

[Figure 1]

Adaptation 1. Sowing Rules

With both ECHAM5 and GFDL CM2.1 predicting higher future rainfall in June, the likelihood of a sowing opportunity was higher for almost all sowing rules in both villages. For historical weather data (1978-2009) on a black soil at Bairanpally the 2 day sowing rule ensured a sowing opportunity in all years, however, it also resulted in seedling failures in 16.1% years for cotton and 18.8% years for maize. Of the remaining sowing rules the two with optimal tradeoffs between sowing opportunity and seedling failure for cotton are the 50 mm in 7 days and the soil moisture sowing rules. For maize, the two sowing rules with optimal tradeoffs between sowing opportunity and seedling failure are the 75 mm and the soil moisture sowing rules. For a future (2012-2040) Bairanpally climate generated with the GFDL CM2.1 model, the 2 day sowing rule ensured a sowing opportunity in all years. However, it also resulted in seedling failures in 35% of years for cotton and 40% of years for maize. Of the remaining sowing rules there were four with optimal tradeoffs between sowing opportunity and seedling failure for cotton and maize: 50 mm in 4 days, 50 mm in 7 days, 50 mm in 10 days and the soil moisture rule. For a future (2012-2040) Bairanpally climate generated with the ECHAM5 model, the 2 day sowing rule ensured a sowing opportunity in all years. However, it also resulted in seedling failures in 20% of years for both cotton and maize. Of the remaining sowing rules there were four with optimal tradeoffs between sowing opportunity and seedling failure for cotton and maize: 50 mm in 4 days, 50 mm in 7 days, 50 mm in 10 days and the soil moisture rule (Table 2).

[Table 2]

For the historical weather data (1978-2009) on a red soil in Gorita the 2 day sowing rule resulted in no sowing opportunity in 9.7% of years and in seedling failures in 10.7% of years for cotton and 10.3% of years for maize. The two sowing rules with optimal tradeoffs between sowing opportunity and seedling failure for cotton are the 50mm and soil moisture sowing rules. For maize the optimal tradeoff is between the 50mm and 75mm sowing rules. For a future (2012-2040) Gorita climate generated with the GFDL CM2.1 model, and seedling failure for cotton: the 2 day sowing rule resulted in no sowing opportunity in 5% of years and in seedling failures in 31.6% of years for cotton and in 36.8% of years for maize. The optimal tradeoff between no sowing opportunity and seedling failure was with the 50 mm sowing rule and the soil moisture rule for both cotton and maize. For cotton the 70 mm sowing rule produced the same result as the 50 mm sowing rule. For a future (2012-2040) Gorita climate generated with the ECHAM5 model, the 2 day sowing rule resulted in no sowing opportunity in 10% of years and in seedling failures in 16.7% of years. The 75 mm, 50 mm, and soil moisture sowing rules ensured a sowing opportunity every year and resulted in no seedling failures for both cotton and maize crops (Table 3).

[Table 3]

For both Gorita and Bairanpally, those sowing rule adaptations that that were most successful in reducing the risk of seedling failure at the smallest cost in terms of missed sowing opportunities under the historical climate scenario were also among the most successful adaptations under both the ECHAM5 and GFDL CM2.1 scenarios for 2021-2040. For both villages, the value of these adaptations was increased when compared with the increased risk of failure associated with the alternative ‘2 day start’ rule.

The simulated effects of implementing different sowing rules (2 day rule against the two rules with the most optimal sowing opportunity versus crop failure tradeoffs) on the long-term mean values of six sustainability indicators: yield, gross margin (GM), yield stability, GM stability, N_2O and C emissions of cotton and maize crops grown in Bairanpally and Gorita are represented as sustainability polygons in Figures 2 and 3 respectively.

For cotton crops in Bairanpally using observed weather data, the 2 day rule had lower sustainability indicator values than the soil moisture and the 50 mm in 7 days rules which were approximately equal to each other for all indicators. In particular the yield stability indicator, the yield indicator, the GM and GM stability indicators had values in the range of 0.70 to 0.83. The N_2O and carbon emission intensities were only marginally lower (Figure 2a). For maize crops in Bairanpally using observed weather data, the 2 day rule had lower sustainability indicator values than the soil moisture and the 75mm rules while the 75mm rule had higher indicators than the soil moisture rule for the yield stability and GM stability indicators. In particular the yield stability and the GM stability indicators for the 2 day rule had values in the range of 0.53, yield and GM indicators were around 0.8 and the N_2O and carbon emission intensities were only marginally lower (Figure 2b). For cotton crops in Bairanpally using future ECHAM5 generated weather data, the 2 day rule had lower sustainability indicator values than the soil moisture and the 50mm in 7 days rules which were approximately equal to each other for all indicators. The same indicators that were lower for the 2 day rule in the observed weather data simulations were even lower for the ECHAM5 scenario (Figure 2c). For maize crops in Bairanpally using future ECHAM5 generated weather data, the 2 day rule had lower sustainability indicator values than the soil moisture and the 75 mm rules while the 75 mm rule had higher sustainability indicators than the soil moisture rule for the yield stability and GM stability indicators but a lower sustainability indicator values for carbon emission. As with cotton, the same indicators that were lower for the 2 day rule in the observed weather data simulations were the same or even lower for the ECHAM5 scenario (Figure 2d). For both cotton and maize crops in Bairanpally using future GFDL CM2.1 scenario, the 2 day rule becomes less sustainable for each of the indicators.

[Figure 2]

For cotton crops in Gorita using observed weather data, no single sowing rule had the highest result for all sustainability indicators though differences were relatively small (all indicators being greater than 0.84). The 2 day rule had lower sustainability indicator values for yield stability and GM stability than the soil moisture and the 50mm rules. The soil moisture rule had the lowest sustainability indicator values for carbon and nitrous oxide emissions, while the 50 mm rule had all its sustainability indicator values close to 1.0 (Figure 3a). For maize crops in Gorita using observed weather data, indicators for Yield and GM were equal for the three sowing rules. For all other sustainability indicators the soil moisture rule was superior to the 2 day rule and the 50 mm rule. For yield stability, and GM stability the 50 mm had a higher indicator than the 2 day rule while for carbon and nitrous oxide emissions the 2 day rule had higher sustainability indicator values than the 50 mm rule (Figure 3b). For cotton crops in Gorita using future ECHAM5 generated weather data, the 50 mm rule had highest or equal highest vales for all sustainability indicators. The 2 day rule had lower sustainability indicator values for yield, yield stability, GM and GM stability than the soil moisture and the 50mm rules but was approximately equal to the 50 mm rule for carbon and nitrous oxide emission indicators. The soil moisture rule was approximately equal to the 50 mm rule for yield, yield stability, GM and GM stability but had lower indicators for carbon and nitrous oxide emissions (Figure 3c). Compared with historic results, ECHAM5 cotton scenarios in Gorita resulted in higher yields and GM outcomes and lower emission results at the expense of less stability in yield and GM outcomes (Figure 3a,c). For maize crops in Gorita using future ECHAM5 generated weather data, the soil moisture rule was more or equally sustainable than the other rules for all sustainability indicators. The 2 day rule had lower sustainability indicator values than the soil moisture and the 50 mm rules for all sustainability indicators while the 50 mm rule had approximately equal indicators for yield and GM indicators but intermediate values for the stability and emission indicators (Figure 2d). Compared with the observed simulation maize scenarios, the indicators for the soil moisture rules were more sustainable under the ECHAM5 scenarios. For cotton crops in Gorita using the future GFDL CM2.1 scenarios, the yield and yield stability indicators for the soils moisture and 50 mm rules were approximately equal and both were superior to the 2 day rule. Indicators for yield and GM stability and carbon emissions were approximately equal for all three rules while for nitrous oxide emissions indicators for the 50 mm rule were more sustainable than for the soil moisture rule which was more sustainable than for the 2 day rule (Figure 3e). Compared with the observed cotton simulation scenarios, the indicators for the soil moisture and 50 mm rules were more sustainable under the GFDL CM2.1 scenario with the exception of carbon emissions which were slightly higher (Figure 3a,e). Under the GFDL CM2.1 scenario for maize in Gorita the 50 mm rule had the highest or equal highest vales for all the sustainability indicators. The soil moisture rule had equal values for the yield, GM and stability indicators. However, it resulted in dramatically poorer values for both the carbon and nitrous oxide emission indicators. The 2 day rule was less sustainable than the 50 mm rule for all indicators but not as high in emissions as the soil moisture rule (Figure 3f). Compared with the historical record scenario, the GFDL CM2.1 scenario for maize in Gorita under the 50 mm rule results were quite similar. GFDL CM2.1 scenario resulted in slightly lower yield and GM outcomes, yield and GM stability were slightly improved and nitrous oxide emissions were slightly lower while carbon emissions were slightly higher (Figure 3b,f).

[Figure 3]

Adaptation 2. Strategic Irrigation of rainfed crops

Strategic irrigation of cotton crops in each of the three case study villages increased the yield probability distribution throughout the entire range of yield outcomes. In particular, the probability of yields exceeding 2 t/ha in Gorita and Nemmani and 3 t/ha in Bairanpally was dramatically increased. This trend was true for the historical record as well as the ECHAM5 and GFDL CM2.1 scenarios for 2021-2040.

For both rainfed and strategically irrigated cotton in Bairanpally the yields under the ECHAM5 scenario were stochastically dominant over the benchmark projections over the whole yield range. The GFDL CM2.1 scenario in Bairanpally was intermediate between the benchmark and ECHAM5 scenarios. For rainfed cotton in Nemmani there was no clear difference between the three climate scenarios while for strategically irrigated cotton in Nemmani GFDL CM2.1 yield projections were stochastically dominant over the benchmark scenario, whereas the ECHAM5 yield projections were dominant over about 95% of the probability range. For both rainfed and strategically irrigated cotton crops in Gorita, yields projected for ECHAM5 and GFDL CM2.1 scenarios for 2021-2040 were stochastically dominant over the benchmark scenario (Figure 4).

When comparing sustainability polygons across the three climate scenarios (baseline climate, ECHAM5 future climate and GFDL CM2.1 future climate) for cotton crops at Bairanpally (Figure 5a,c,e) similar results were obtained regardless of the climate scenario: seed cotton yields, gross margin, carbon emissions and nitrous oxide emissions were all improved by strategic irrigation while yield stability and GM stability were marginally worse with strategic irrigation. However, it should be noted that this slightly increased instability is around a much higher mean. For maize in Bairanpally (Figure 5b,d,f) all sustainability indicators were improved under the three scenarios and the most dramatic improvements were in yield stability and GM stability.

A comparison of sustainability polygons for the three climate scenarios for both cotton and maize crops at Gorita (Figure 6) shows that all sustainability indicators for the strategic irrigation adaptation were superior for each of the three climate scenarios. Similar results were observed for the Nemmani village (data not shown).

Adaptation 3. Reduced Irrigation of Rice

The impact of reduced irrigation options on rice production and sustainability in Bairanpally and Gorita villages under the three climate scenarios are illustrated in Figure 7. In Bairanpally, the rough rice yields and gross margins of the four irrigation options were almost equal to each other under the three climate scenarios. While their values differed slightly with the future climate scenarios, their positions on the sustainability polygon were not affected. Gross margin stability is near equal for all four irrigation options in the baseline climate and GFDL CM2.1 scenarios. Interestingly, in the ECHAM5 scenario the AWD2 option gained a slight advantage over the other three irrigation options (Figure 7 a,b,c).

Net water use and irrigation water productivity in Bairanpally are clearly differentiated between the different irrigation options such that their sustainability rating is irrig-1 < irrig-2 < AWD1 < AWD2. While the net water use and irrigation water productivity amounts changed with climate scenarios, the relative positions of the four options remained about the same (Figure 7 a,b,c).

The nitrous oxide emissions in Bairanpally, while relatively small, clearly reflect the opposite sustainability indicators to those of the net water use and the irrigation water productivity indicators. The irrigation options rated irri-1 > irri-2 > AWD1 > AWD2 in all three climate scenarios. The carbon emissions of irrig-1 and AWD1 are similar to each other and lower than for AWD2 which is slightly lower than irrig-2 in the historical climate scenario. These relative positions are maintained for the ECHAM5 and GFDL CM2.1 scenarios, with the fairly trivial exception that the slight difference between irrig-2 and AWD2 was reversed in the GFDL CM2.1 scenario (Figure 7 a,b,c).

In Gorita, as in Bairanpally, the rough rice yields and Gross margins of the four irrigation options were close to each other under the three climate scenarios. While their values differ slightly with the future climate scenarios, their positions on the sustainability polygon are not affected. In contrast with Bairanpally, gross margin stability in Gorita for the four irrigation options differed in the baseline climate with AWD2 being the most stable. However this advantage is reversed in the ECHAM5 and GFDL CM2.1 scenarios (Figure 7 d,e,f).

Net water use in Gorita, as in Bairanpally, is clearly differentiated between the different irrigation options such that their sustainability rating is irrig-1 < irrig-2 < AWD1 < AWD2 for each of the three climate scenarios. Similarly, irrigation water productivity was highest for the AWD2 treatment in the three climate scenarios (Figure 7 d,e,f).

The nitrous oxide emissions in Gorita, while relatively small and of similar magnitude, tend to reflect the opposite sustainability indicators to those of the net water use and the irrigation water productivity indicators in each of the three climate scenarios. For the historical climate scenario the carbon emissions ranking were AWD1 < AWD2 < irrig-1 < irrig-2 and these relative positions were maintained for the ECHAM5 and GFDL CM2.1 scenarios (Figure 7 d,e,f).

Adaptation 4. Reduced Rice Area for Strategic Irrigation of rainfed crops

For the small farm in Gorita growing rice and cotton under the benchmark climate scenario, current practice produced a mean annual gross margin of 32,266 INR/ha, a net water use of 106.9 mm/ha/yr and a water productivity (expressed as GM per mm of net water used) of 302 INR/mm. Adaptation option 3 resulted in the highest average annual GM of 79,998 INR/ha at the expense of a less sustainable net water usage of 130.1 mm/ha/yr but a higher water productivity of 615 INR/mm. Adaptation option 4 resulted in a slightly reduced average annual GM of 79,200 INR/ha but a much lower net water use of 74.6 mm/ha/yr resulting in a higher water productivity of 1,061 INR/mm. Similar results were observed for the two future (2021-2040) climate scenarios ECHAM5 and GFDL CM2.1 (Figure 8).

Comparisons of the sustainability polygons for the different adaptation options for small farms growing rice and cotton crops at Gorita using the baseline climate (1978-

2009) and the future climate scenarios for 2021-2040 generated with the ECHAM5 and GFDL CM2.1 models are presented in Figure 9. For the benchmark climate, the current practice is least sustainable in terms of its gross margin, gross margin stability, carbon and nitrous oxide emissions, irrigation water used and irrigation water productivity. It is however the most sustainable in terms of aquifer recharge and leached nitrogen. Adaptation option 4 is most sustainable in terms of the amount of irrigation water used, irrigation water productivity and nitrous oxide emissions. It is close to best for carbon emissions and is intermediate for gross margin stability and for nitrogen leached. It does however make the least contribution to groundwater recharge. Adaptation option 3 is superior to option 4 in its gross margin stability. It is also marginally superior to option 4 for gross margin, recharge, and carbon emissions. However, it is less sustainable in terms of the irrigation amount, irrigation water productivity, and nitrous oxide emissions. Adaptation options 1 and 2 tend to be intermediate between the current practice and adaptation option 3 (Figure 9a). While the absolute values of the sustainability indicators varies with climate scenarios, the relative positions of the sustainability indicators remained the same (Figures 9 a,b,c).

For the medium farm in Gorita, under the benchmark climate scenario, current practice produced a mean annual gross margin of 25,620 INR/ha and a net water use of 44.9 mm/ha/yr and a water productivity of 570 INR/mm. Adaptation option 3 resulted in a much higher annual GM of 69,690 INR/ha at the expense of a higher net water use of 62.9 mm/ha/yr, resulting in a higher water productivity of 1,107 INR/mm. Similar results were observed for the two future (2021-2040) climate scenarios ECHAM5 and GFDL CM2.1 (Figure 10).

Comparison of the sustainability polygons for the different adaptation options for medium farms growing rice and cotton crops at Gorita using the baseline climate (1978-2009) and the future climate scenarios for 2021-2040 generated with the ECHAM5 and GFDL CM2.1 models are presented in Figure 11. For the benchmark climate scenario, the current practice is least sustainable in terms of its gross margin, gross margin stability, carbon and nitrous oxide emissions, irrigation water used and irrigation water productivity. It is however the most sustainable in terms of aquifer recharge and leached nitrogen. Adaptation option 3 is most sustainable in terms of gross margin achieved, gross margin stability, the amount of irrigation water used, irrigation water productivity, nitrous oxide and carbon emissions, and nitrogen leached. It is however the least sustainable in terms of groundwater recharge and the amount of nitrogen leached. Adaptation options 1 and 2 are intermediate relative to current practice and adaptation option 3. While the absolute values of the sustainability indicators varies with climate scenarios, the relative positions of the sustainability indicators remained the same (Figures 11 a,b,c).

For the large farm in Gorita, under the benchmark climate scenario, current practice produced a mean annual gross margin of 48,484 INR and a net water use of 24.3 mm/ha/yr resulting in a water productivity of 1,996 INR/mm. Each adaptation option increased both average annual GM and net water usage (each 7 mm increasing GM by 10,000 INR). Adaptation option 5 resulted in the highest annual GM of 95,279 INR/ha and the highest net water use of 54.0 mm/ha/yr resulting in a lower water productivity of 1,769 INR/mm. similar results were observed for the two future (2021-2040) climate scenarios ECHAM5 and GFDL CM2.1 (Figure 12).

Comparison of the sustainability polygons for the different adaptation options for large farms growing rice and cotton crops at Gorita using the baseline climate (1978-2009) and the future climate scenarios for 2021-2040 generated with the ECHAM5 and GFDL CM2.1 models are presented in Figure 13. For the benchmark climate scenario, as with the medium farm, the current practice for the large farm is least sustainable in terms of its gross margin, gross margin stability carbon and nitrous oxide emissions, irrigation water used and irrigation water productivity. It is however the most sustainable in terms of aquifer recharge and leached nitrogen. Adaptation option 5 is most sustainable in terms of gross margin achieved, gross margin stability, the amount of irrigation water used, irrigation water productivity, nitrous oxide and carbon emissions, and nitrogen leached. It is however the least sustainable in terms of groundwater recharge and the amount of nitrogen leached. Adaptation options 1 to 4 are intermediate relative to current practice and adaptation option 5. While the absolute values of the sustainability indicators varies with climate scenarios, the relative positions of the sustainability indicators remained the same (Figures 13 a,b,c).

Similar observations were made when maize substituted cotton in the cropping system and when the same treatments were applied at Bairanpally (Appendix A).

4. Discussion

It is noteworthy, though not surprising given the expected rate of climate change to 2021-2040 (Chaturvedi et al. 2012), that the projected changes from either GCM models are relatively modest (Figure 1). This is reflected in seed cotton yield potential for both the rainfed and strategically irrigated crops where the differences in the distributions of simulated yields between the historical record, the ECHAM5 and the GFDL CM2.1 scenarios was small relative to the range of yield outcomes due to year to year variability (Figure 4). The presence of both positive and negative yield consequences depending on future climate scenario and village reflects earlier ambiguities about medium term consequences of climate change as reported by Barnwal and Kotani (2013).

The sustainability polygons for strategic irrigation of cotton and maize crops for each of the three climate scenarios tend to show that the adaptations which improve yield outcomes tend to also improve the whole set of sustainability outcomes. This is a win-win (x6) situation for yield and yield stability, gross margin and gross margin stability, and for reduced carbon and nitrous oxide emissions (Figures 5,6). A similar win-win was observed for sowing rules for cotton and maize in Bairanpally (Figure 2). However, in Gorita (Figure 3) the relative positions of the various sustainability indices for each of the sowing rules varied with crops and climate scenarios such that a clear win-win rule could not be identified except for maize in the ECHAM5 climate scenario (Figure 3d) where the soil moisture rule was best or equal best for all indicators and the 50mm rule for the GFDL CM2.1 (Figure 3f).

The sustainability polygons for reduced irrigation of rice adaptations similarly demonstrated a win-win situation, although it is less obvious from the polygons. For example, the AWD2 adaptation in Bairanpally was most sustainable for rice yield and yield stability, gross margin and gross margin stability, net water use and water productivity, yet it appears to have the poorest emissions performance with the highest nitrous oxide emissions and close to the highest carbon emissions. In reality though, the net global warming potential (GWP) of the system is likely to be lower than for Irrig-1 and Irrig-2 due to the significantly reduced proportion of methane CH_4 (and increased CO_2) in the simulated C-emissions (CH_4 has 21 times the GWP of the same mass of CO_2). This is driven by larger time periods with drying (aerobic) rather than continuous flooded (anaerobic) soil conditions in AWD rice systems. An earlier theoretical scepticism regarding reduced GWP of AWD rice systems (Johnson-Beebout et al. 2009) has been replaced by a large consensus of recent experiments indicating net reductions in GWP of between 45-90% compared with continuously flooded rice systems (Linquist et al. 2015), when contributions from CO_2, CH_4 and N_2O are considered. (Figure 7).

The sustainability polygons for adaptations involving reduced rice area for strategic irrigation of rainfed crops demonstrated clear tradeoffs between sustainability indicators. In this case, for each farm type the current practice was most sustainable in terms of the amount of nitrogen leached from the root zone and the amount of recharge beyond the root zone. However, this option was invariably least sustainable in terms of overall gross margin, gross margin stability, amount of water used for irrigation, irrigation water productivity as well as carbon and nitrous oxide emissions. The same tradeoff applied to each of the three climate scenarios. Here too there is no option that can consistently fulfil the three aspirations of climate-smart agriculture.

The greater recharge consistently observed for the current practice is a consequence of more irrigation being applied across the whole farm and this effect is offset by the overall lower net water used in this option. Another consequence of reduced rice area adaptations is that more N is leached as a consequence of increased N leaching from the root zone of supplementally irrigated cotton and maize crops. However, the difference in N leached between the various treatments is relatively small (2-10 kg/ha/yr). Unless N leaching becomes a major sustainability issue it is likely that most stakeholders would agree that one of the lower rice area options is overall most sustainable. The ability to identify sustainable adaptations that hold for a range of situations in terms of future climate scenarios and villages is encouraging, especially given that this adaptation is the most transformative one considered in this study.

The assumption that adaptation to historical climate variability can be assumed to hold for future climate scenarios, when viewed through the wider sustainability perspective, held true for the strategic irrigation adaptation and for the reduced rice area for strategic irrigation of rainfed crops. However, it clearly did not hold for the sowing rules and for the reduced irrigation of rice adaptations where different options might prove best in different future climate scenarios. The implication of this finding is that while it is still best to adapt to historic climate variability as suggested by Robertson and Murray Prior (2014) a vigilant eye must be kept on the consequences of such adaptations to ensure that they are still best as time progresses.

5. Conclusions

This paper examines the performance of farmer tested adaptations to climate variability against two contrasting scenarios of medium term climate change using up to eight sustainability indicators that are consistent with the aspirations of 'climate-smart agriculture'. The indicators chosen have implications for food security, for economic viability, for maintaining the water resource and for reducing greenhouse gas emission intensity. Our results show that we can sometimes expect adaptations to result in tradeoffs between different desirable outcomes. The implication of this finding is that farmers and policy makers will need to prioritise or weight the various sustainability indicators.

The finding that the impacts of climate change scenarios for 2021-2040 are variable and small in comparison with existing climate variability does not imply that longer term climate change is unimportant. However, given that farmers are more likely to adapt to current climate variability, the assumption that such adaptations will hold for medium term climate change was tested in this study. We found that this assumption held for some adaptations but not for others. This finding serves as a warning that as climate changes, even in subtle ways, adaptations will need to be re-apprised.

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Tables:

Table 1. Summary of modelling scenarios tested with APSIM for three farm sizes and options allocating a varying proportion of land to irrigated rice and to strategically irrigated cotton (or maize).

Size of farm	**Current practice (irrigated rice and rainfed cotton)**		**Option 1** **Use water saved to strategically irrigate cotton**		**Option 2** **Use water saved to strategically irrigate cotton**		**Option 3** **Use water saved to strategically irrigate cotton with unlimited no. of irrigations**		**Option 4** **Use water saved to strategically irrigate cotton**		**Option 5** **Use water saved to strategically irrigate cotton**	
	Irrig. rice (ha)	RF cotton (ha)	Irrig. rice (ha)	Cotton (ha)	Irrig. rice (ha)	Cotton (ha)	Irrig. rice (ha)	Cotton (ha)	Irrig. rice (ha)	RF cotton (ha)	Irrig. rice (ha)	RF cotton (ha)
Small (2 ha)	0.8	1.2	0.6	1.4	0.4	1.6	0.4	1.6	0.2	1.8	na[1]	na[1]
Medium (3.2 ha)	0.8	2.4	0.6	2.6	0.2	3.0	na[1]	na[1]	na[1]	na[1]	na[1]	na[1]
Large (6 ha)	1.2	4.8	1.0	5.0	0.8	5.2	0.6	5.4	0.4	5.6	0.2	5.8

[1]na = not applicable. These treatments do not comply with the strategic rules

Table 2. The percent of years in which crops are not sown or in which sown crops fail when various sowing rules are applied to cotton and maize crops grown on black soils at Bairanpally contrasting historic climate (1978-2009) with future climate projections using the GFDL CM2.1(2021-2040) and ECHAM5 (2021-2040) models.

Sowing rule	Observed Weather			GFDL CM2.1			ECHAM5		
	Not sown (%)	Cotton fails (%)	Maize fails (%)	Not sown (%)	Cotton fails (%)	Maize fails (%)	Not sown (%)	Cotton fails (%)	Maize fails (%)
2 day	**0.0**[1]	**16.1**	**18.8**	**0.0**	**35.0**	**40.0**	**0.0**	**20.0**	**20.0**
75mm in 4 days	43.8	0.0	0.0	45.0	0.0	0.0	45.0	0.0	0.0
75mm in 7 days	37.5	0.0	0.0	20.0	0.0	0.0	20.0	0.0	0.0

75mm in 10 days	28.1	0.0	0.0	15.0	0.0	0.0	15.0	0.0	0.0
75mm in 14 days	25.0	0.0	0.0	10.0	0.0	0.0	10.0	0.0	0.0
75mm	**9.7**	0.0	**0.0**	10.0	0.0	5.6	10.0	0.0	5.6
50mm in 4 days	15.6	0.0	3.7	**5.0**	**0.0**	**5.3**	**5.0**	**0.0**	**0.0**
50mm in 7 days	**9.4**	**0.0**	6.9	**5.0**	**0.0**	**5.3**	**5.0**	**0.0**	**0.0**
50mm in 10 days	9.4	3.4	3.4	**5.0**	**0.0**	**5.3**	**5.0**	**0.0**	**0.0**
50mm in 14 days	9.4	6.9	6.9	5.0	10.5	10.5	5.0	5.3	5.3
50mm	3.1	16.1	16.1	5.0	10.5	10.5	5.0	5.3	5.3
Soil moisture	**9.4**	**0.0**	**3.4**	**5.0**	**0.0**	**5.3**	**5.0**	**0.0**	**0.0**

[1]For each climate scenario by crop combination bold numbers indicate rules with pareto-optimal outcomes.

Table 3. The percent of years in which crops are not sown or in which sown crops fail when various sowing rules are applied to cotton and maize crops grown on red soils at Gorita contrasting historic climate (1978-2009) with future climate projections using the GFDL CM2.1(2021-2040) and ECHAM5 (2021-2040) models.

Sowing rule	Observed Weather			GFDL CM2.1			ECHAM5		
	Not sown (%)	Cotton fails (%)	Maize fails (%)	Not sown (%)	Cotton fails (%)	Maize fails (%)	Not sown (%)	Cotton fails (%)	Maize fails (%)
2 day	9.7	10.7	10.3	5.0	31.6	36.8	10.0	16.7	16.7
75mm in 4 days	71.9	11.1	11.1	75.0	0.0	0.0	70.0	0.0	0.0
75mm in 7 days	51.6	6.7	6.3	50.0	0.0	0.0	45.0	0.0	0.0
75mm in 10 days	35.5	5.0	4.8	20.0	6.3	6.3	20.0	0.0	0.0
75mm in 14 days	25.8	4.3	4.2	20.0	6.3	6.3	15.0	5.9	5.9
75mm	**6.5**	3.4	**0.0**	**0.0**	**5.0**	10.0	**0.0**	**0.0**	**0.0**
50mm in 4 days	34.4	4.8	4.8	30.0	7.1	7.1	30.0	7.1	7.1
50mm in 7 days	18.8	3.8	3.8	15.0	5.9	5.9	10.0	5.6	5.6
50mm in 10 days	12.5	3.6	3.6	10.0	5.6	5.6	5.0	5.3	10.5
50mm in 14 days	6.3	10.0	6.7	0.0	10.0	10.0	0.0	10.0	15.0
50mm	**0.0**	**3.1**	**3.1**	**0.0**	**5.0**	**5.0**	**0.0**	**0.0**	**0.0**
Soil moisture	**3.1**	**0.0**	3.2	**5.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

[1]For each climate scenario by crop combination bold numbers indicate rules with pareto-optimal outcomes.

Figure Titles:

Figure 1. Comparison of historical and future climate scenarios for average monthly rainfall (mm; whiskers show standard deviation above the mean) at a) Warangal and b) Mahabubnagar, average maximum daily temperature (ºC) at c) Warangal and d) Mahabubnagar and average minimum daily temperatures (ºC) at e) Warangal and f) Mahabubnagar in Telangana, India. Blue lines and columns represent the observational record (1978-2009); green represents ECHAM5 projection (2021-2040) while red represents the GFDL CM2.1 projection (2021-2040).

Figure 2. Comparison of yield, gross margin, yield stability, gross margin stability, N2O and C emissions of crops grown using the IMD 2 day sowing rule and the remaining two sowing rules with optimal tradeoffs between sowing opportunity and seedling failure at Bairanpally for a) cotton using baseline climate (1978-2009), b) maize using baseline climate, c) cotton using ECHAM5 future climate (2021-2040), d) maize using ECHAM5 future climate, e) cotton using GFDL CM2.1 future climate (2021-2040) and f) maize using GFDL CM2.1 future climate. Blue lines represent IMD 2 day sowing rule, red lines represent 50mm in 7 days sowing rule and green lines represent soil moisture sowing rule for a), c) and e) (cotton). Blue lines represent IMD 2 day sowing rule, red lines represent 75mm sowing rule and green lines represent soil moisture sowing rule for b), d) and f) (maize). Ranges for each variable are shown in parentheses.

Figure 3. Comparison of yield, gross margin, yield stability, gross margin stability, N2O and C emissions of crops grown using the IMD 2 day sowing rule and the remaining two sowing rules with optimal tradeoffs between sowing opportunity and seedling failure at Gorita for a) cotton using baseline climate (1978-2009), b) maize using baseline climate, c) cotton using ECHAM5 future climate (2021-2040), d) maize using ECHAM5 future climate, e) cotton using GFDL CM2.1 future climate (2021-2040) and f) maize using GFDL CM2.1 future climate. Blue lines represent IMD 2 day sowing rule, red lines represent 50mm sowing rule and green lines represent soil moisture sowing rule for a)-f). Ranges for each variable are shown in parentheses.

Figure 4. Seed cotton yield response (probability of exceedance) of crops sown using the soil moisture sowing rule for a) rainfed crops at Bairanpally, b) crops grown using strategic irrigation at Bairanpally, c) rainfed crops at Gorita, d) crops grown using strategic irrigation at Gorita, e) rainfed crops at Nemmani and f) crops grown using strategic irrigation at Nemmani. Blue lines represent historical record (1978-2009); green represents ECHAM5 projection (2021-2040) while red represents the GFDL CM2.1 projection (2021-2040).

Figure 5. Comparison of yield, gross margin, yield stability, gross margin stability, N2O and C emissions of rainfed and strategically irrigated crops grown using the soil moisture sowing rule at Bairanpally for a) cotton using baseline climate (1978-2009), b) maize using baseline climate, c) cotton using ECHAM5 future climate (2021-2040), d) maize using ECHAM5 future climate, e) cotton using GFDL CM2.1 future climate (2021-2040) and f) maize using GFDL CM2.1 future climate. Blue lines represent rainfed crops, red lines represent strategically irrigated crops. Ranges for each variable are shown in parentheses.

Figure 6. Comparison of yield, gross margin, yield stability, gross margin stability, N2O and C emissions of rainfed and strategically irrigated crops grown using the soil moisture sowing rule at Gorita for a) cotton using baseline climate (1978-2009), b) maize using baseline climate, c) cotton using ECHAM5 future climate (2021-2040), d) maize using ECHAM5 future climate, e) cotton using GFDL CM2.1 future climate (2021-2040) and f) maize using GFDL CM2.1 future climate. Blue lines represent rainfed crops, red lines represent strategically irrigated crops. Ranges for each variable are shown in parentheses.

Figure 7. Comparison of yield, gross margin, yield stability, gross margin stability, N2O and C emissions, irrigation water productivity and net water use of rice crops grown using four different irrigation strategies at a) Bairanpally using baseline climate (1978-2009), b) Gorita using baseline climate, c) Bairanpally using ECHAM5 future climate (2021-2040), d) Gorita using ECHAM5 future climate, e) Bairanpally using GFDL CM2.1 future climate (2021-2040), f) Gorita using GFDL CM2.1 future climate (2021-2040). Blue lines represent irrigations strategy Irrig-1, red lines Irrig-2, green lines AWD1 and purple lines AWD2.

Figure 8. Gross margin (blue bars) and net water use (irrigation-recharge, red dots) for adaptation options used on small farms at Gorita growing rice and cotton for a) baseline climate (1978-2009), b) future climate ECHAM5 (2021-2040) and c) future climate GFDL CM2.1 (2021-2040).

Figure 9. Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N2O emission, aquifer recharge and N leached for each of the adaptation options used on small farms at Gorita growing rice and cotton for a) baseline climate (1978-2009), b) future climate ECHAM5 (2021-2040) and c) future climate GFDL CM2.1 (2021-2040). Blue lines represent current practice, red lines option 1, green lines option 2, purple lines option 3 and orange lines option 4. Ranges for each variable are shown in parentheses.

Figure 10. Gross margin (blue bars) and net water use (irrigation-recharge, red dots) for adaptation options used on medium farms at Gorita growing rice and cotton for a) baseline climate (1978-2009), b) future climate ECHAM5 (2021-2040) and c) future climate GFDL CM2.1 (2021-2040).

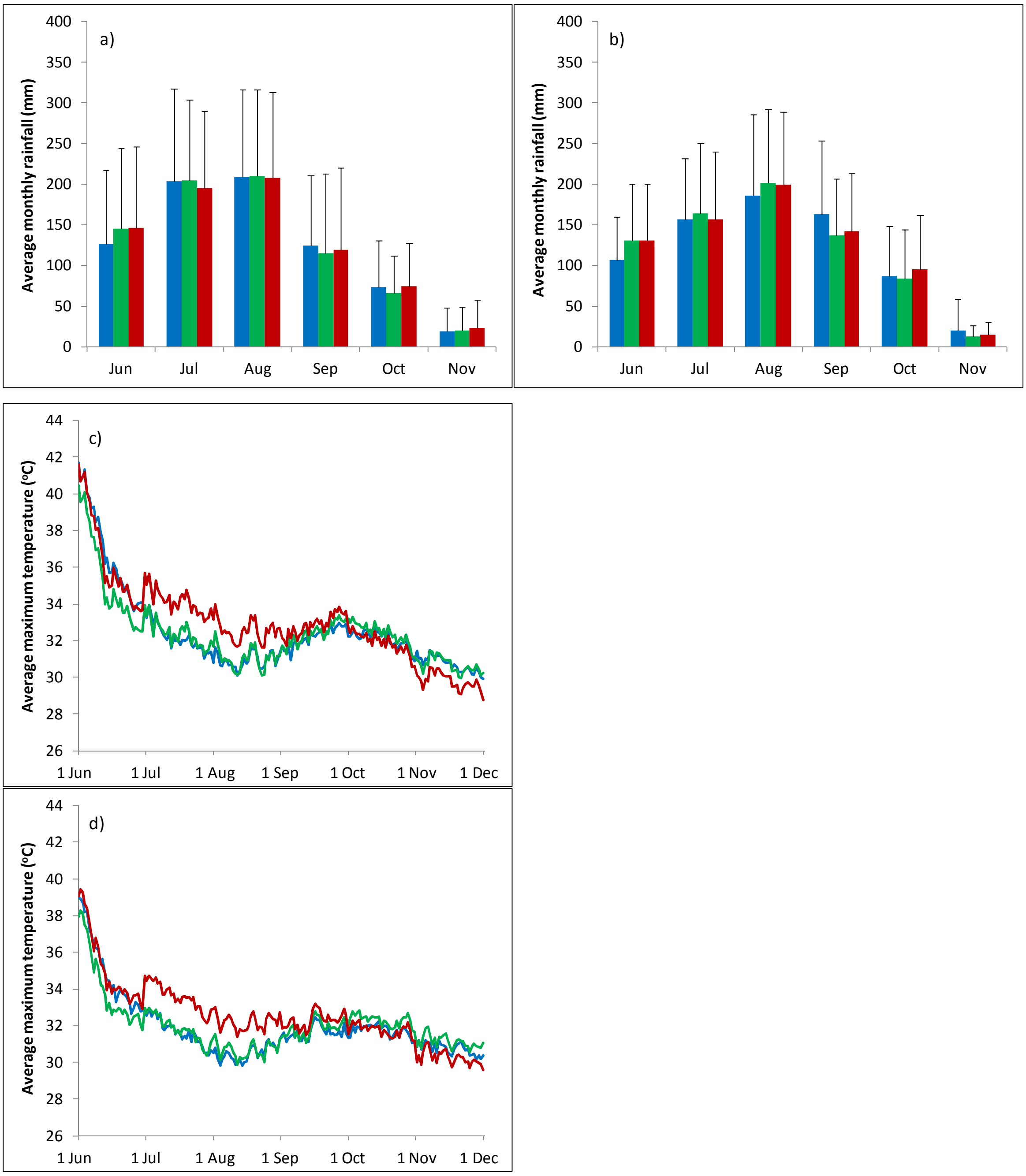
Figure 11. Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N2O emission, aquifer recharge and N leached for each of the adaptation options used on medium farms at Gorita growing rice and cotton for a) baseline climate (1978-2009), b) future climate ECHAM5 (2021-2040) and c) future climate GFDL CM2.1 (2021-2040). Blue lines represent current practice, red lines option 1, green lines option 2 and purple lines option 3. Ranges for each variable are shown in parentheses.

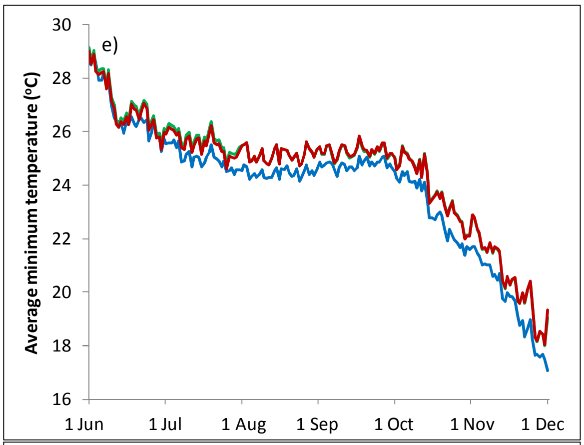
Figure 12. Gross margin (blue bars) and net water use (irrigation-recharge, red dots) for adaptation options used on large farms at Gorita growing rice and cotton for a) baseline climate (1978-2009), b) future climate ECHAM5 (2021-2040) and c) future climate GFDL CM2.1 (2021-2040).

Figure 13. Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N2O emission, aquifer recharge and N leached for each of the adaptation options used on large farms at Gorita growing rice and cotton for a) baseline climate (1978-2009), b) future climate ECHAM5 (2021-2040) and c) future climate GFDL CM2.1 (2021-2040). Dark blue lines represent current practice, red lines option 1, green lines option 2, purple lines option 3, orange lines option 4 and light blue lines option 5. Ranges for each variable are shown in parentheses.

Figures:

Figure 1.




e)
Average minimum temperature (ºC)
30
28
26
24
22
20
18
16
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec

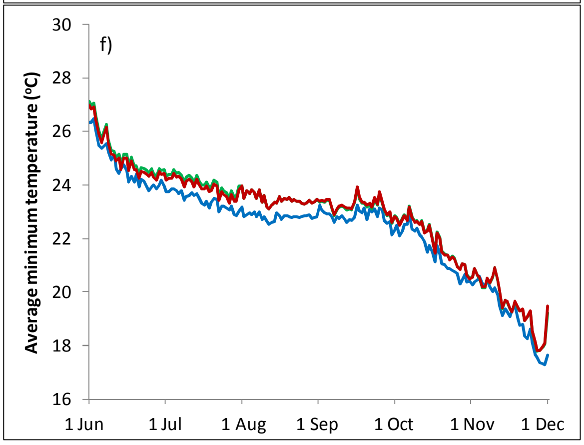
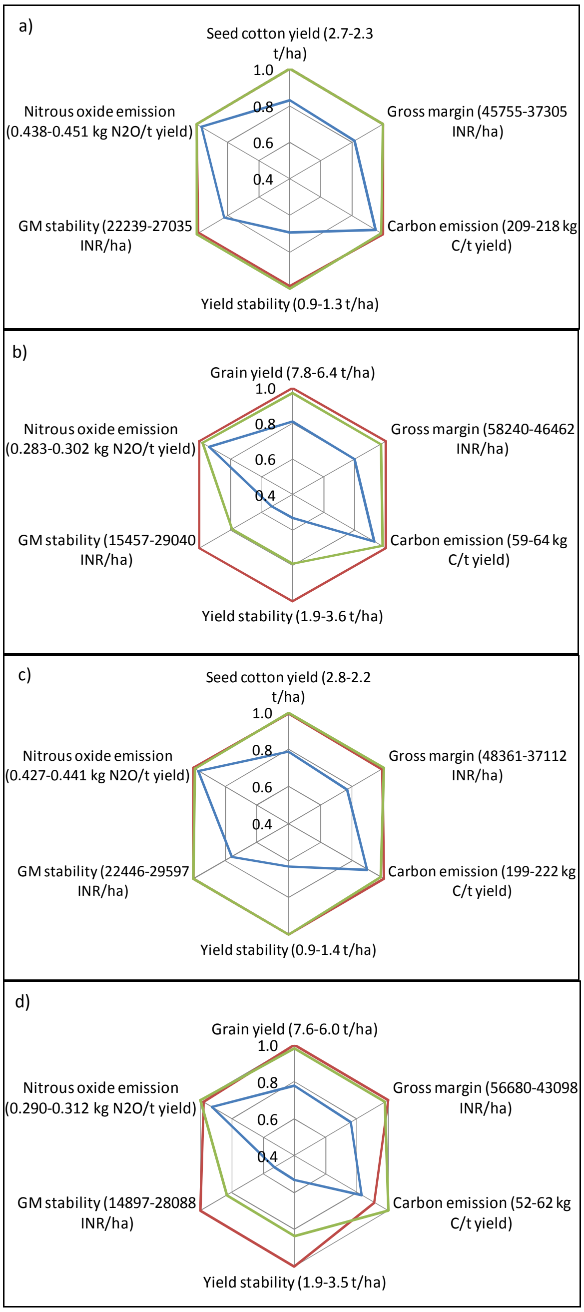
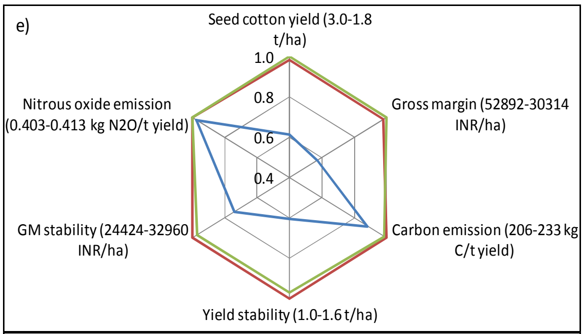

f)
Average minimum temperature (ºC)
30
28
26
24
22
20
18
16
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec

Figure 2.


a)
Seed cotton yield (2.7-2.3 t/ha)
1.0
0.8
0.6
0.4
Gross margin (45755-37305 INR/ha)
Carbon emission (209-218 kg C/t yield)
Yield stability (0.9-1.3 t/ha)
GM stability (22239-27035 INR/ha)
Nitrous oxide emission (0.438-0.451 kg N2O/t yield)
b)
Grain yield (7.8-6.4 t/ha)
1.0
0.8
0.6
0.4
Gross margin (58240-46462 INR/ha)
Carbon emission (59-64 kg C/t yield)
Yield stability (1.9-3.6 t/ha)
GM stability (15457-29040 INR/ha)
Nitrous oxide emission (0.283-0.302 kg N2O/t yield)
c)
Seed cotton yield (2.8-2.2 t/ha)
1.0
0.8
0.6
0.4
Gross margin (48361-37112 INR/ha)
Carbon emission (199-222 kg C/t yield)
Yield stability (0.9-1.4 t/ha)
GM stability (22446-29597 INR/ha)
Nitrous oxide emission (0.427-0.441 kg N2O/t yield)
d)
Grain yield (7.6-6.0 t/ha)
1.0
0.8
0.6
0.4
Gross margin (56680-43098 INR/ha)
Carbon emission (52-62 kg C/t yield)
Yield stability (1.9-3.5 t/ha)
GM stability (14897-28088 INR/ha)
Nitrous oxide emission (0.290-0.312 kg N2O/t yield)


e)
Seed cotton yield (3.0-1.8 t/ha)
1.0
0.8
0.6
0.4
Gross margin (52892-30314 INR/ha)
Carbon emission (206-233 kg C/t yield)
Yield stability (1.0-1.6 t/ha)
GM stability (24424-32960 INR/ha)
Nitrous oxide emission (0.403-0.413 kg N2O/t yield)

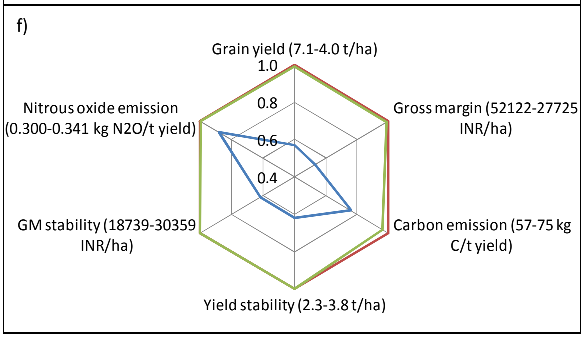
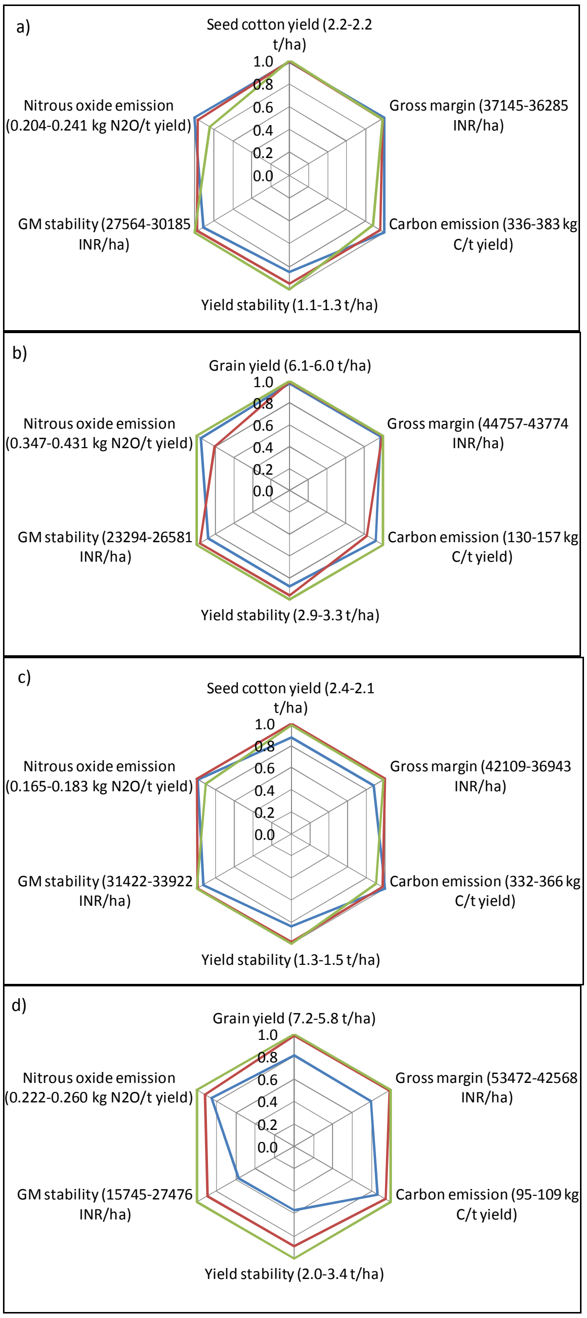
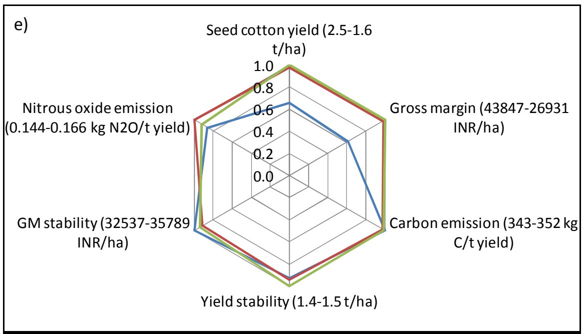

f)
Grain yield (7.1-4.0 t/ha)
1.0
0.8
0.6
0.4
Gross margin (52122-27725 INR/ha)
Carbon emission (57-75 kg C/t yield)
Yield stability (2.3-3.8 t/ha)
GM stability (18739-30359 INR/ha)
Nitrous oxide emission (0.300-0.341 kg N2O/t yield)

Figure 3.


a)
Seed cotton yield (2.2-2.2 t/ha)
1.0
0.8
0.6
0.4
0.2
0.0
Gross margin (37145-36285 INR/ha)
Carbon emission (336-383 kg C/t yield)
Yield stability (1.1-1.3 t/ha)
GM stability (27564-30185 INR/ha)
Nitrous oxide emission (0.204-0.241 kg N2O/t yield)
b)
Grain yield (6.1-6.0 t/ha)
1.0
0.8
0.6
0.4
0.2
0.0
Gross margin (44757-43774 INR/ha)
Carbon emission (130-157 kg C/t yield)
Yield stability (2.9-3.3 t/ha)
GM stability (23294-26581 INR/ha)
Nitrous oxide emission (0.347-0.431 kg N2O/t yield)
c)
Seed cotton yield (2.4-2.1 t/ha)
1.0
0.8
0.6
0.4
0.2
0.0
Gross margin (42109-36943 INR/ha)
Carbon emission (332-366 kg C/t yield)
Yield stability (1.3-1.5 t/ha)
GM stability (31422-33922 INR/ha)
Nitrous oxide emission (0.165-0.183 kg N2O/t yield)
d)
Grain yield (7.2-5.8 t/ha)
1.0
0.8
0.6
0.4
0.2
0.0
Gross margin (53472-42568 INR/ha)
Carbon emission (95-109 kg C/t yield)
Yield stability (2.0-3.4 t/ha)
GM stability (15745-27476 INR/ha)
Nitrous oxide emission (0.222-0.260 kg N2O/t yield)


e)
Seed cotton yield (2.5-1.6 t/ha)
1.0
0.8
0.6
0.4
0.2
0.0
Gross margin (43847-26931 INR/ha)
Carbon emission (343-352 kg C/t yield)
Yield stability (1.4-1.5 t/ha)
GM stability (32537-35789 INR/ha)
Nitrous oxide emission (0.144-0.166 kg N2O/t yield)

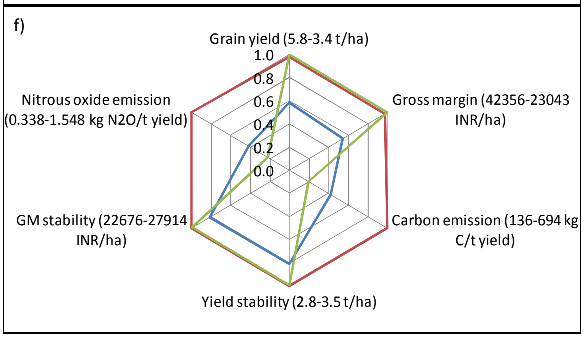
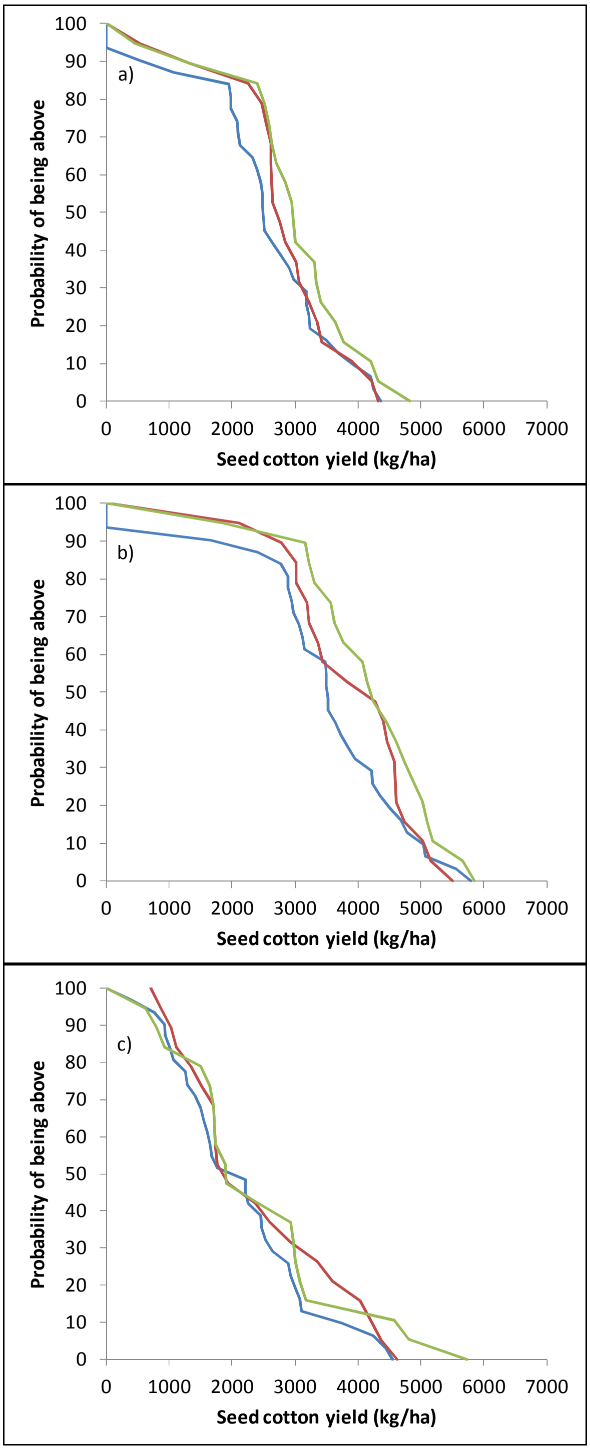
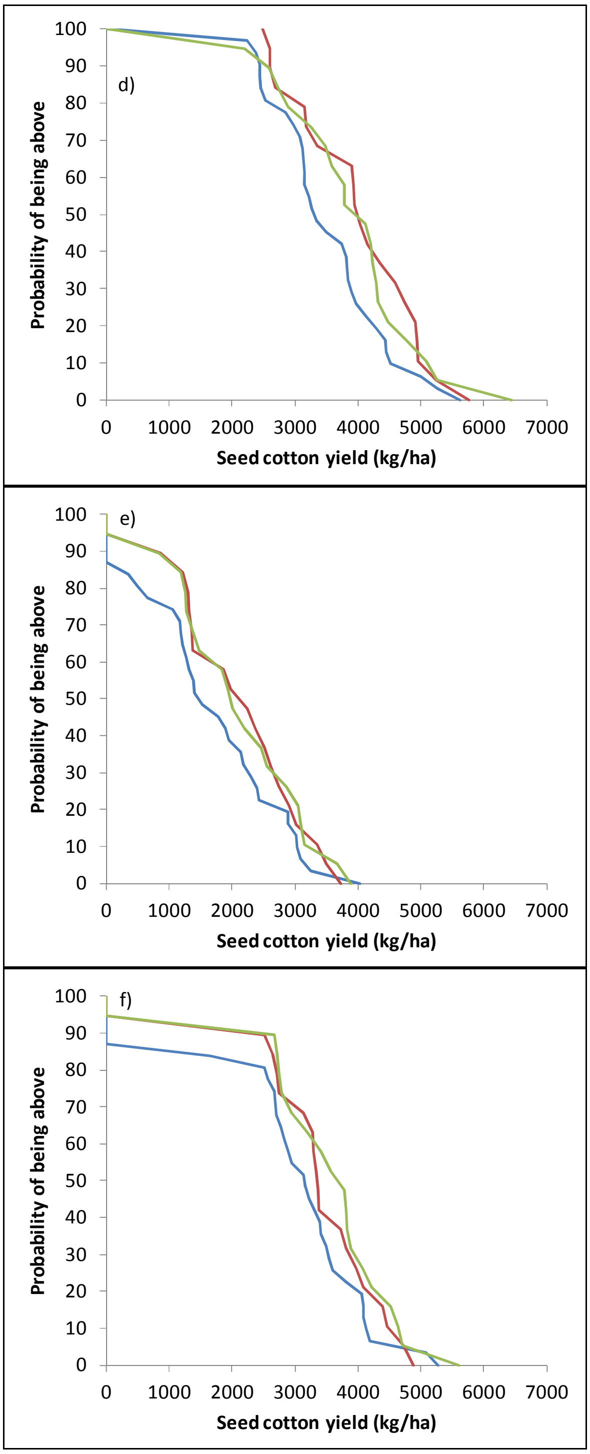

f)
Grain yield (5.8-3.4 t/ha)
1.0
0.8
0.6
0.4
0.2
0.0
Gross margin (42356-23043 INR/ha)
Carbon emission (136-694 kg C/t yield)
Yield stability (2.8-3.5 t/ha)
GM stability (22676-27914 INR/ha)
Nitrous oxide emission (0.338-1.548 kg N2O/t yield)

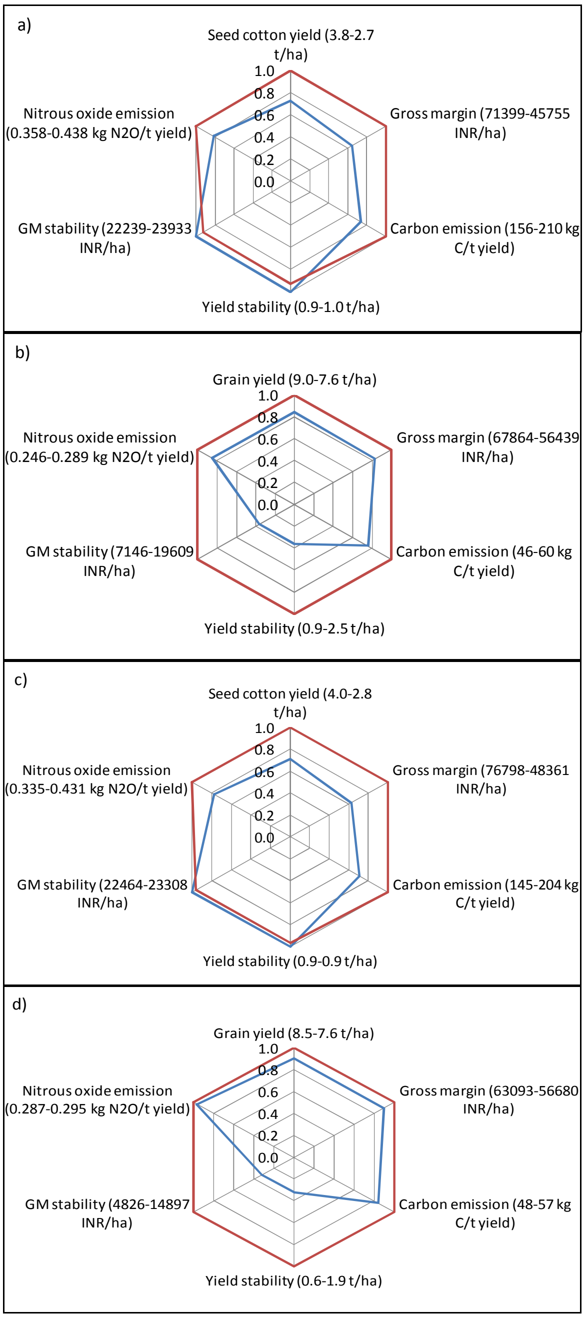
Figure 4.

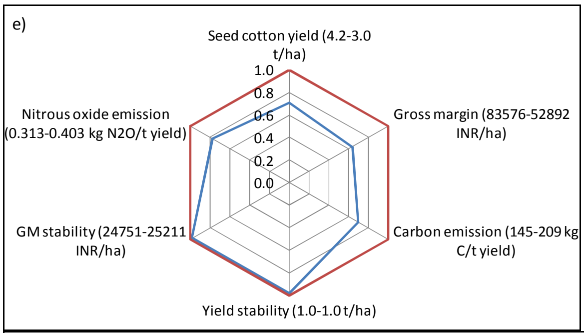

a)
b)
c)
Probability of being above
Seed cotton yield (kg/ha)
100
90
80
70
60
50
40
30
20
10
0
0
1000
2000
3000
4000
5000
6000
7000



d)
e)
f)
Probability of being above
Seed cotton yield (kg/ha)
0
10
20
30
40
50
60
70
80
90
100
0
1000
2000
3000
4000
5000
6000
7000

Figure 5.


a)
Seed cotton yield (3.8-2.7 t/ha)
1.0
0.8
0.6
0.4
0.2
0.0
Gross margin (71399-45755 INR/ha)
Carbon emission (156-210 kg C/t yield)
Yield stability (0.9-1.0 t/ha)
GM stability (22239-23933 INR/ha)
Nitrous oxide emission (0.358-0.438 kg N2O/t yield)
b)
Grain yield (9.0-7.6 t/ha)
1.0
0.8
0.6
0.4
0.2
0.0
Gross margin (67864-56439 INR/ha)
Carbon emission (46-60 kg C/t yield)
Yield stability (0.9-2.5 t/ha)
GM stability (7146-19609 INR/ha)
Nitrous oxide emission (0.246-0.289 kg N2O/t yield)
c)
Seed cotton yield (4.0-2.8 t/ha)
1.0
0.8
0.6
0.4
0.2
0.0
Gross margin (76798-48361 INR/ha)
Carbon emission (145-204 kg C/t yield)
Yield stability (0.9-0.9 t/ha)
GM stability (22464-23308 INR/ha)
Nitrous oxide emission (0.335-0.431 kg N2O/t yield)
d)
Grain yield (8.5-7.6 t/ha)
1.0
0.8
0.6
0.4
0.2
0.0
Gross margin (63093-56680 INR/ha)
Carbon emission (48-57 kg C/t yield)
Yield stability (0.6-1.9 t/ha)
GM stability (4826-14897 INR/ha)
Nitrous oxide emission (0.287-0.295 kg N2O/t yield)


e)
Seed cotton yield (4.2-3.0 t/ha)
1.0
0.8
0.6
0.4
0.2
0.0
Gross margin (83576-52892 INR/ha)
Carbon emission (145-209 kg C/t yield)
Yield stability (1.0-1.0 t/ha)
GM stability (24751-25211 INR/ha)
Nitrous oxide emission (0.313-0.403 kg N2O/t yield)

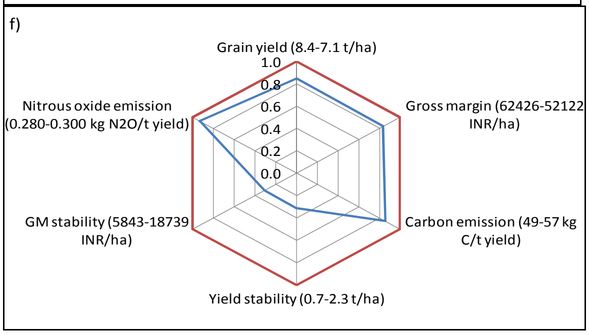
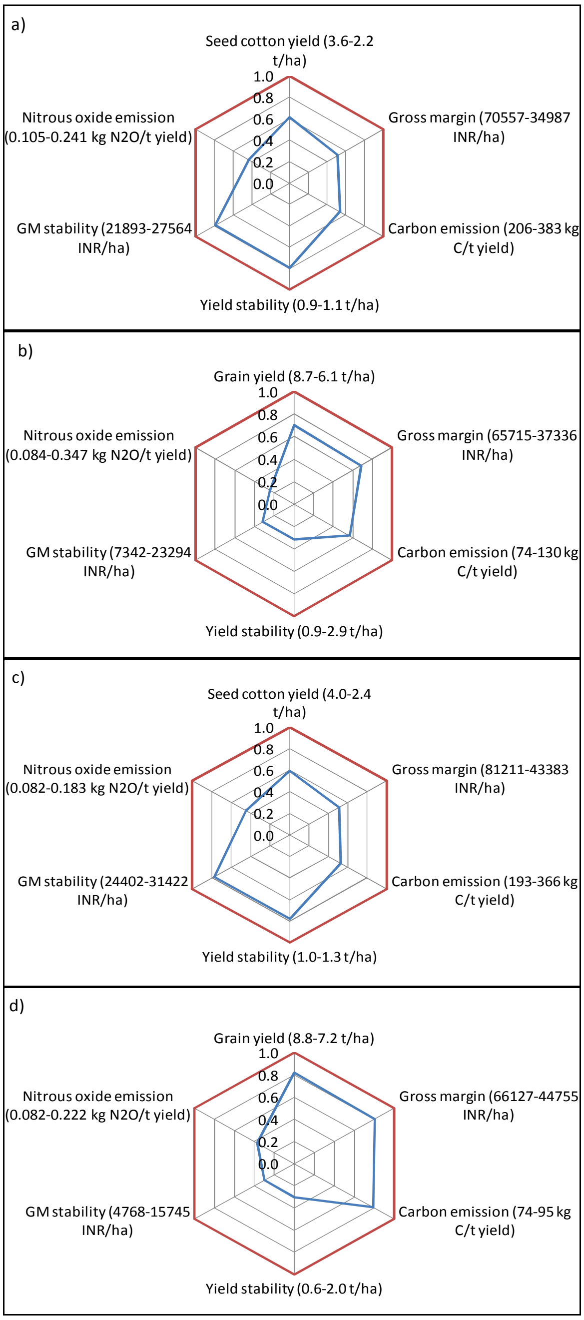
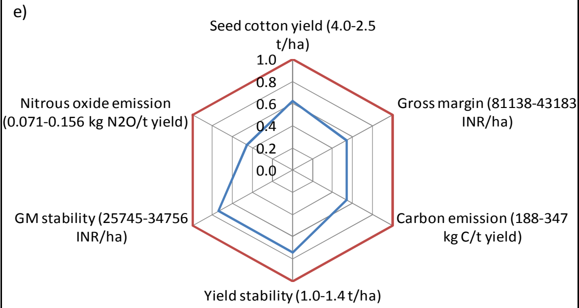

f)
Grain yield (8.4-7.1 t/ha)
1.0
0.8
0.6
0.4
0.2
0.0
Gross margin (62426-52122 INR/ha)
Carbon emission (49-57 kg C/t yield)
Yield stability (0.7-2.3 t/ha)
GM stability (5843-18739 INR/ha)
Nitrous oxide emission (0.280-0.300 kg N2O/t yield)

Figure 6.


a)
Seed cotton yield (3.6-2.2 t/ha)
1.0
0.8
0.6
0.4
0.2
0.0
Gross margin (70557-34987 INR/ha)
Carbon emission (206-383 kg C/t yield)
Yield stability (0.9-1.1 t/ha)
GM stability (21893-27564 INR/ha)
Nitrous oxide emission (0.105-0.241 kg N2O/t yield)
b)
Grain yield (8.7-6.1 t/ha)
Gross margin (65715-37336 INR/ha)
Carbon emission (74-130 kg C/t yield)
Yield stability (0.9-2.9 t/ha)
GM stability (7342-23294 INR/ha)
Nitrous oxide emission (0.084-0.347 kg N2O/t yield)
c)
Seed cotton yield (4.0-2.4 t/ha)
Gross margin (81211-43383 INR/ha)
Carbon emission (193-366 kg C/t yield)
Yield stability (1.0-1.3 t/ha)
GM stability (24402-31422 INR/ha)
Nitrous oxide emission (0.082-0.183 kg N2O/t yield)
d)
Grain yield (8.8-7.2 t/ha)
Gross margin (66127-44755 INR/ha)
Carbon emission (74-95 kg C/t yield)
Yield stability (0.6-2.0 t/ha)
GM stability (4768-15745 INR/ha)
Nitrous oxide emission (0.082-0.222 kg N2O/t yield)

e)


Seed cotton yield (4.0-2.5 t/ha)
1.0
0.8
0.6
0.4
0.2
0.0
Gross margin (81138-43183 INR/ha)
Carbon emission (188-347 kg C/t yield)
Yield stability (1.0-1.4 t/ha)
GM stability (25745-34756 INR/ha)
Nitrous oxide emission (0.071-0.156 kg N2O/t yield)

f)

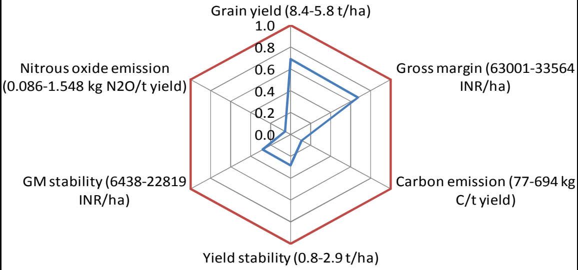
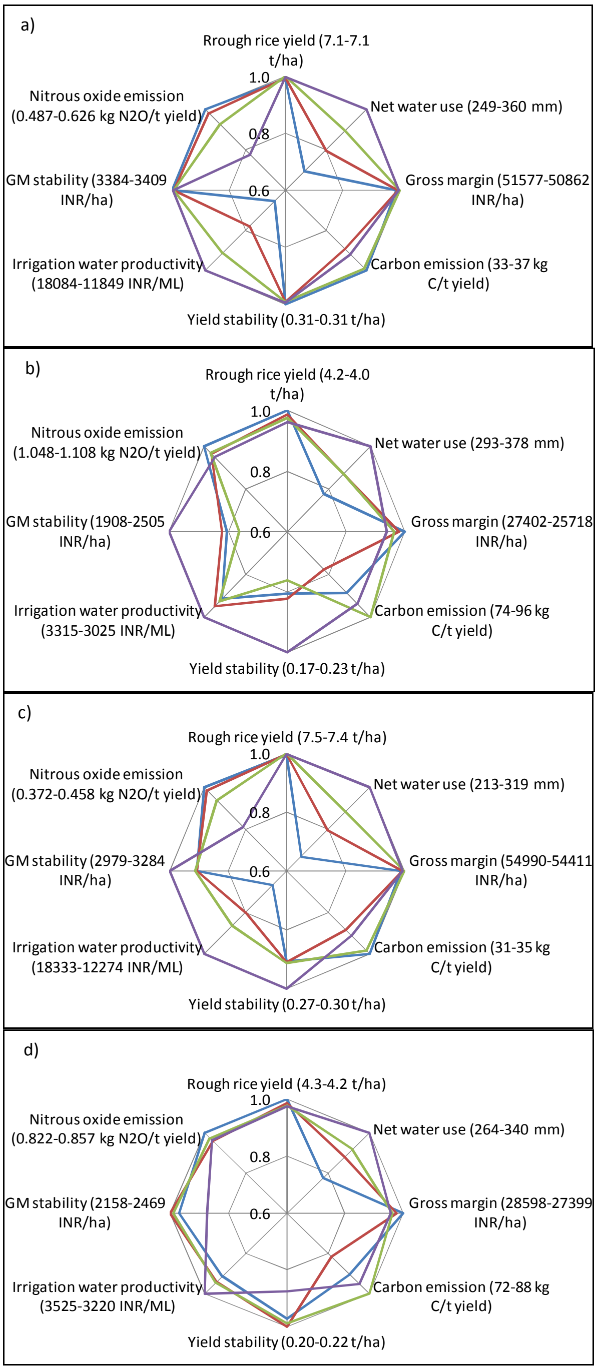
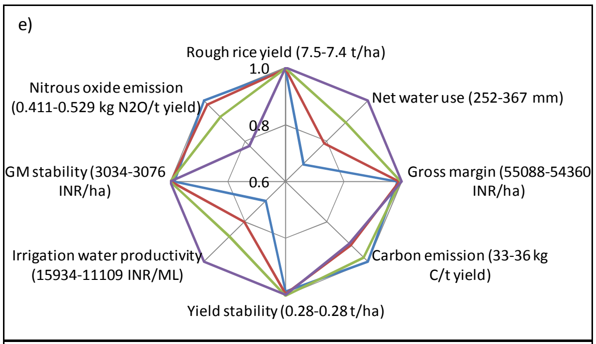

Grain yield (8.4-5.8 t/ha)
1.0
0.8
0.6
0.4
0.2
0.0
Gross margin (63001-33564 INR/ha)
Carbon emission (77-694 kg C/t yield)
Yield stability (0.8-2.9 t/ha)
GM stability (6438-22819 INR/ha)
Nitrous oxide emission (0.086-1.548 kg N2O/t yield)

Figure 7.


a)
Rrough rice yield (7.1-7.1 t/ha)
Net water use (249-360 mm)
Gross margin (51577-50862 INR/ha)
Carbon emission (33-37 kg C/t yield)
Yield stability (0.31-0.31 t/ha)
Irrigation water productivity (18084-11849 INR/ML)
GM stability (3384-3409 INR/ha)
Nitrous oxide emission (0.487-0.626 kg N2O/t yield)
1.0
0.8
0.6
b)
Rough rice yield (4.2-4.0 t/ha)
Net water use (293-378 mm)
Gross margin (27402-25718 INR/ha)
Carbon emission (74-96 kg C/t yield)
Yield stability (0.17-0.23 t/ha)
Irrigation water productivity (3315-3025 INR/ML)
GM stability (1908-2505 INR/ha)
Nitrous oxide emission (1.048-1.108 kg N2O/t yield)
1.0
0.8
0.6
c)
Rough rice yield (7.5-7.4 t/ha)
Net water use (213-319 mm)
Gross margin (54990-54411 INR/ha)
Carbon emission (31-35 kg C/t yield)
Yield stability (0.27-0.30 t/ha)
Irrigation water productivity (18333-12274 INR/ML)
GM stability (2979-3284 INR/ha)
Nitrous oxide emission (0.372-0.458 kg N2O/t yield)
1.0
0.8
0.6
d)
Rough rice yield (4.3-4.2 t/ha)
Net water use (264-340 mm)
Gross margin (28598-27399 INR/ha)
Carbon emission (72-88 kg C/t yield)
Yield stability (0.20-0.22 t/ha)
Irrigation water productivity (3525-3220 INR/ML)
GM stability (2158-2469 INR/ha)
Nitrous oxide emission (0.822-0.857 kg N2O/t yield)
1.0
0.8
0.6


e)
Rough rice yield (7.5-7.4 t/ha)
1.0
0.8
0.6
Net water use (252-367 mm)
Gross margin (55088-54360 INR/ha)
Carbon emission (33-36 kg C/t yield)
Yield stability (0.28-0.28 t/ha)
Irrigation water productivity (15934-11109 INR/ML)
GM stability (3034-3076 INR/ha)
Nitrous oxide emission (0.411-0.529 kg N2O/t yield)

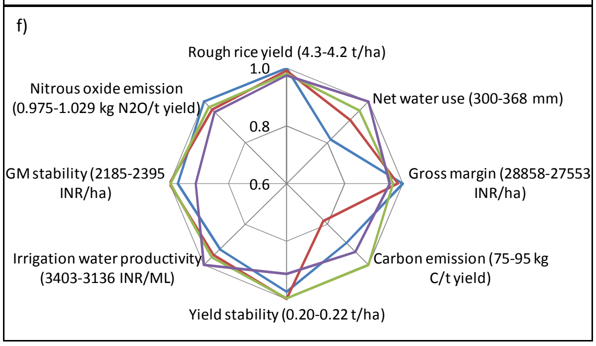
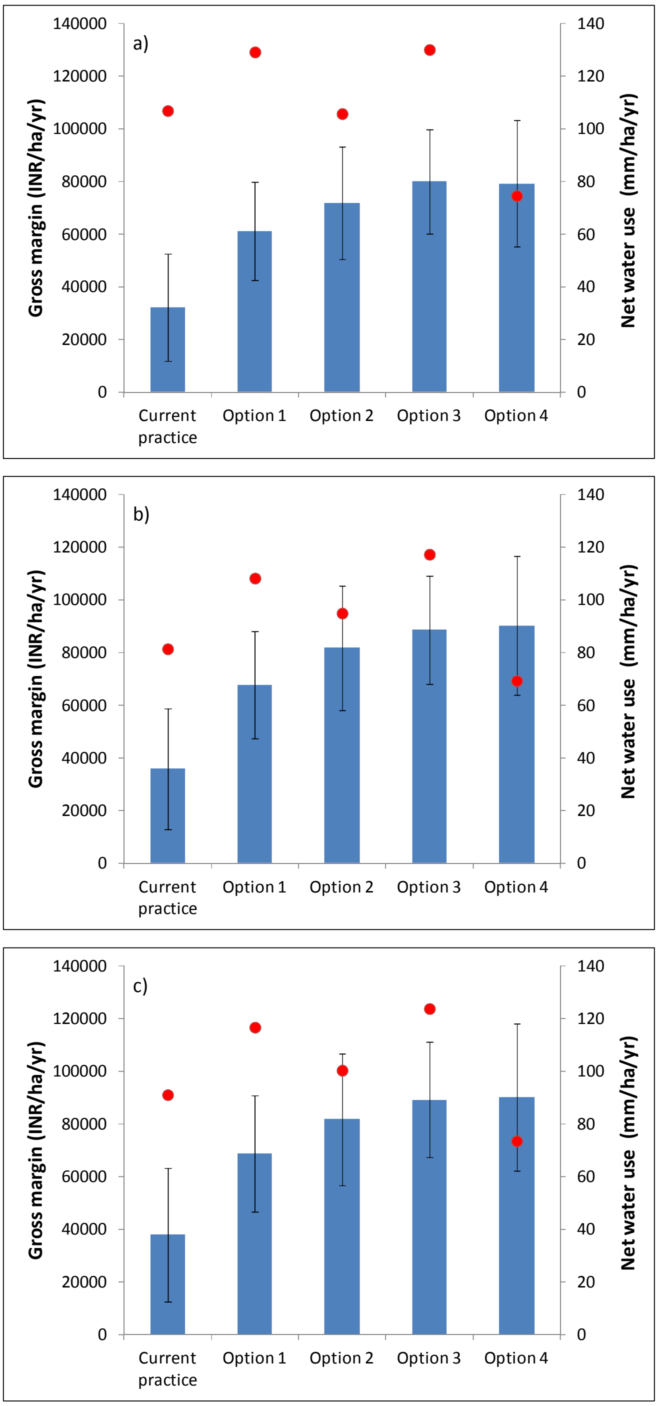

f)
Rough rice yield (4.3-4.2 t/ha)
1.0
0.8
0.6
Net water use (300-368 mm)
Gross margin (28858-27553 INR/ha)
Carbon emission (75-95 kg C/t yield)
Yield stability (0.20-0.22 t/ha)
Irrigation water productivity (3403-3136 INR/ML)
GM stability (2185-2395 INR/ha)
Nitrous oxide emission (0.975-1.029 kg N2O/t yield)

Figure 8.



a)
b)
c)
Gross margin (INR/ha/yr)
Net water use (mm/ha/yr)
140000
120000
100000
80000
60000
40000
20000
0
140
120
100
80
60
40
20
0
Current practice
Option 1
Option 2
Option 3
Option 4

Figure 9.

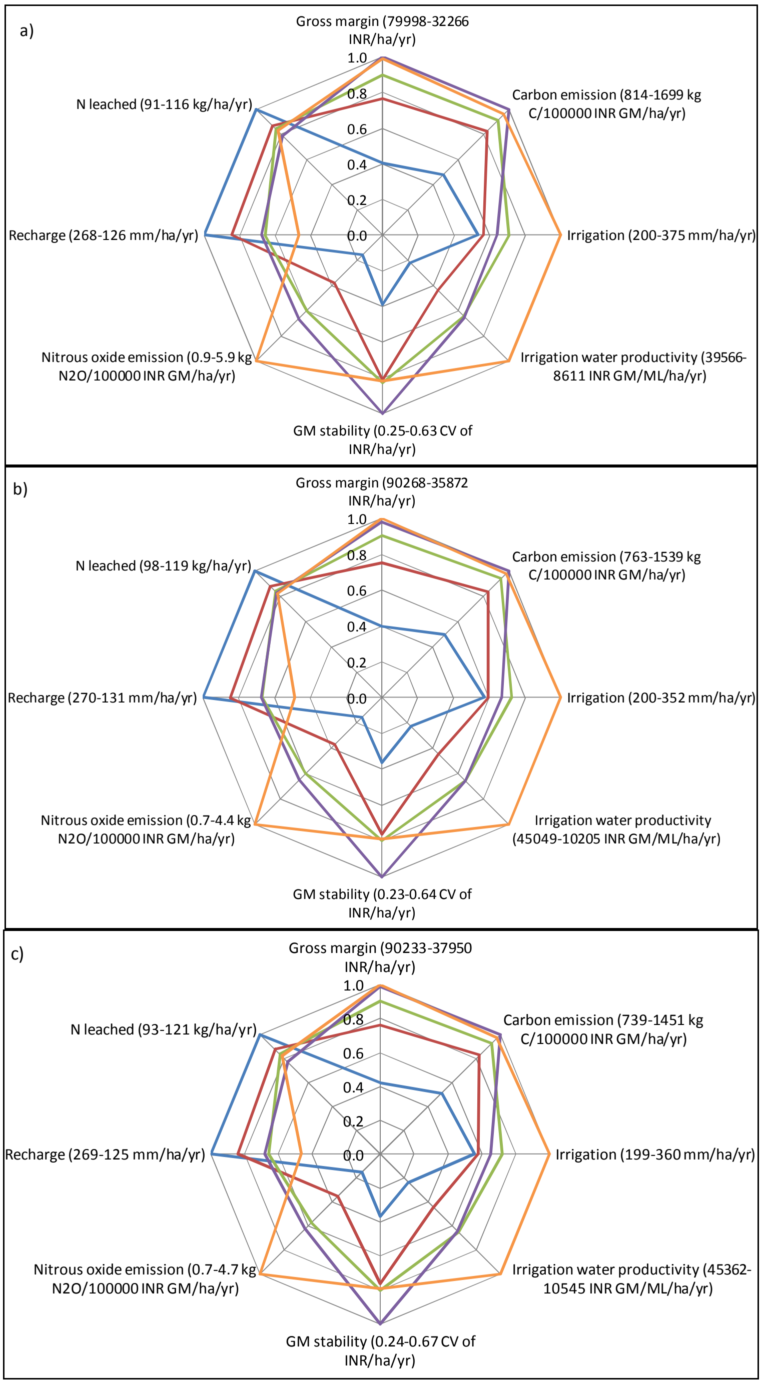

a)
Gross margin (79998-32266 INR/ha/yr)
Carbon emission (814-1699 kg C/100000 INR GM/ha/yr)
Irrigation (200-375 mm/ha/yr)
Irrigation water productivity (39566-8611 INR GM/ML/ha/yr)
GM stability (0.25-0.63 CV of INR/ha/yr)
Nitrous oxide emission (0.9-5.9 kg N2O/100000 INR GM/ha/yr)
Recharge (268-126 mm/ha/yr)
N leached (91-116 kg/ha/yr)
1.0
0.8
0.6
0.4
0.2
0.0
b)
Gross margin (90268-35872 INR/ha/yr)
Carbon emission (763-1539 kg C/100000 INR GM/ha/yr)
Irrigation (200-352 mm/ha/yr)
Irrigation water productivity (45049-10205 INR GM/ML/ha/yr)
GM stability (0.23-0.64 CV of INR/ha/yr)
Nitrous oxide emission (0.7-4.4 kg N2O/100000 INR GM/ha/yr)
Recharge (270-131 mm/ha/yr)
N leached (98-119 kg/ha/yr)
c)
Gross margin (90233-37950 INR/ha/yr)
Carbon emission (739-1451 kg C/100000 INR GM/ha/yr)
Irrigation (199-360 mm/ha/yr)
Irrigation water productivity (45362-10545 INR GM/ML/ha/yr)
GM stability (0.24-0.67 CV of INR/ha/yr)
Nitrous oxide emission (0.7-4.7 kg N2O/100000 INR GM/ha/yr)
Recharge (269-125 mm/ha/yr)
N leached (93-121 kg/ha/yr)

Figure 10.

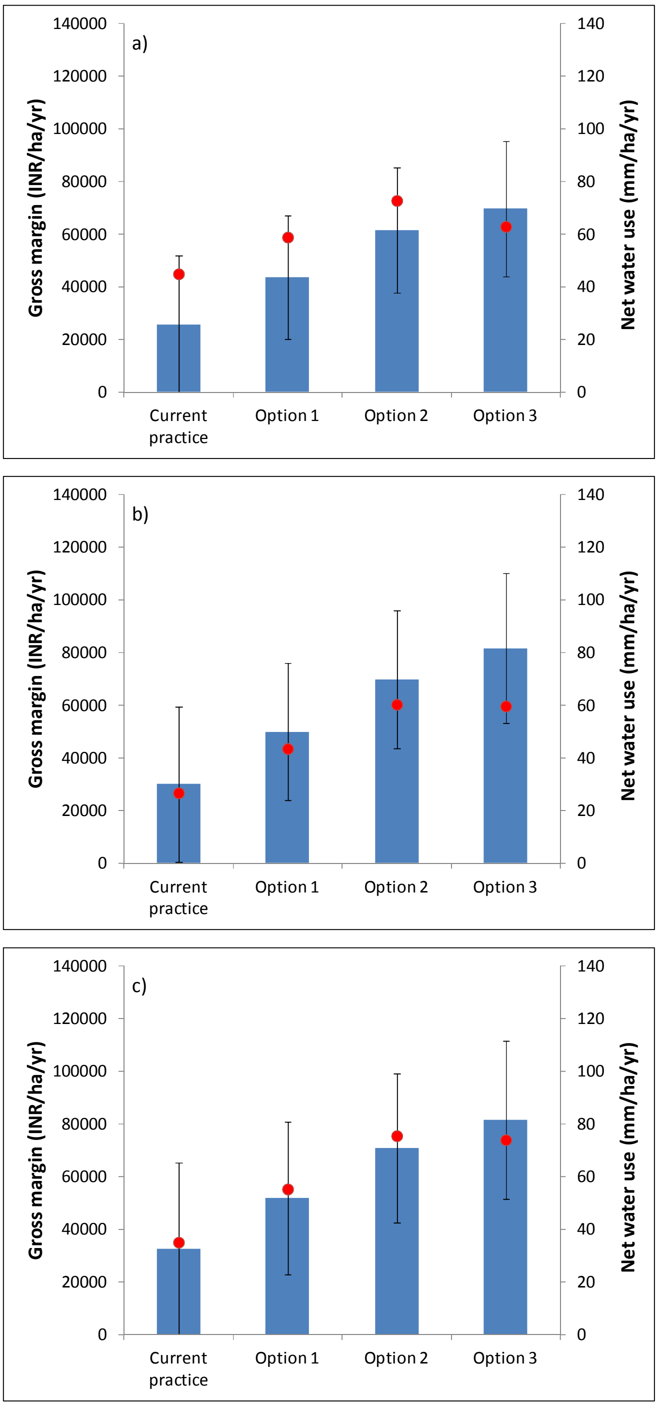

a)
b)
c)
Gross margin (INR/ha/yr)
Net water use (mm/ha/yr)
0
20000
40000
60000
80000
100000
120000
140000
0
20
40
60
80
100
120
140
Current practice
Option 1
Option 2
Option 3

Figure 11.

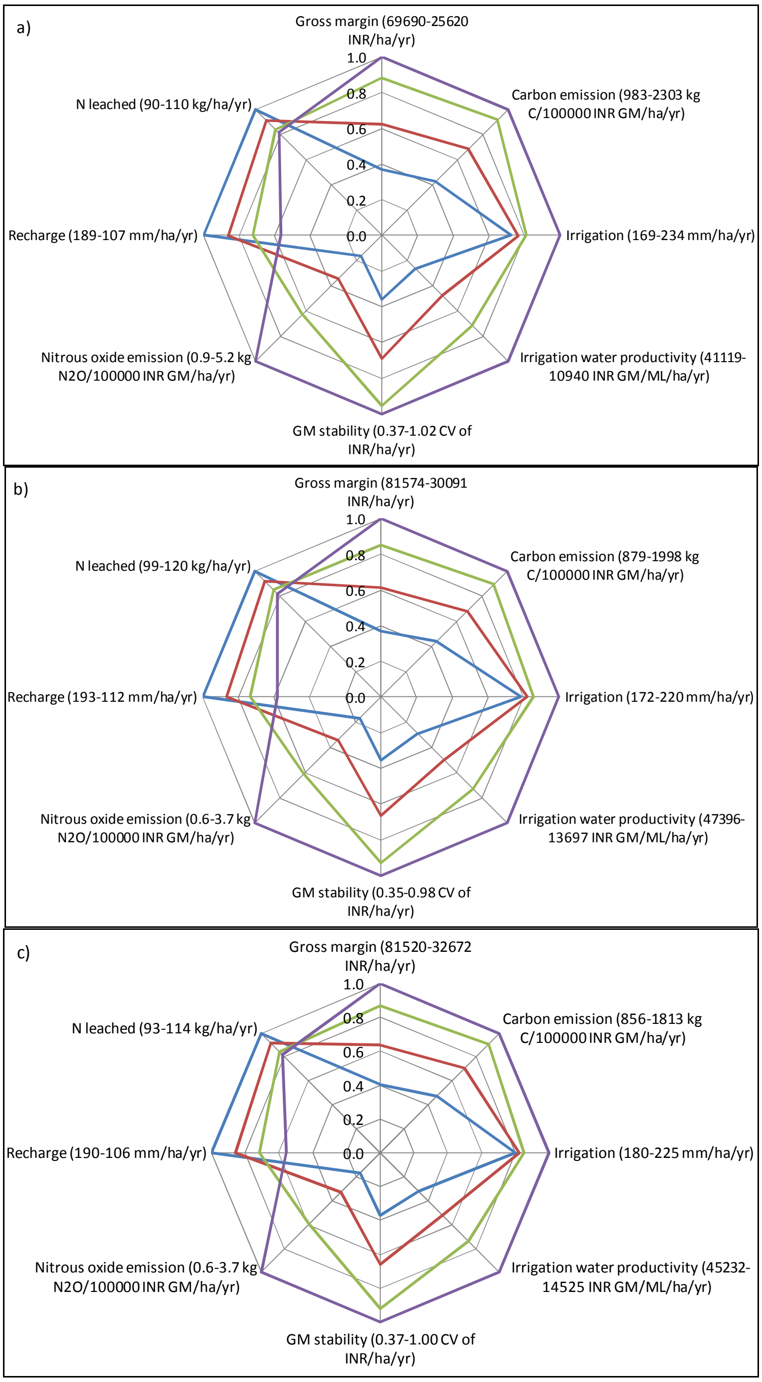
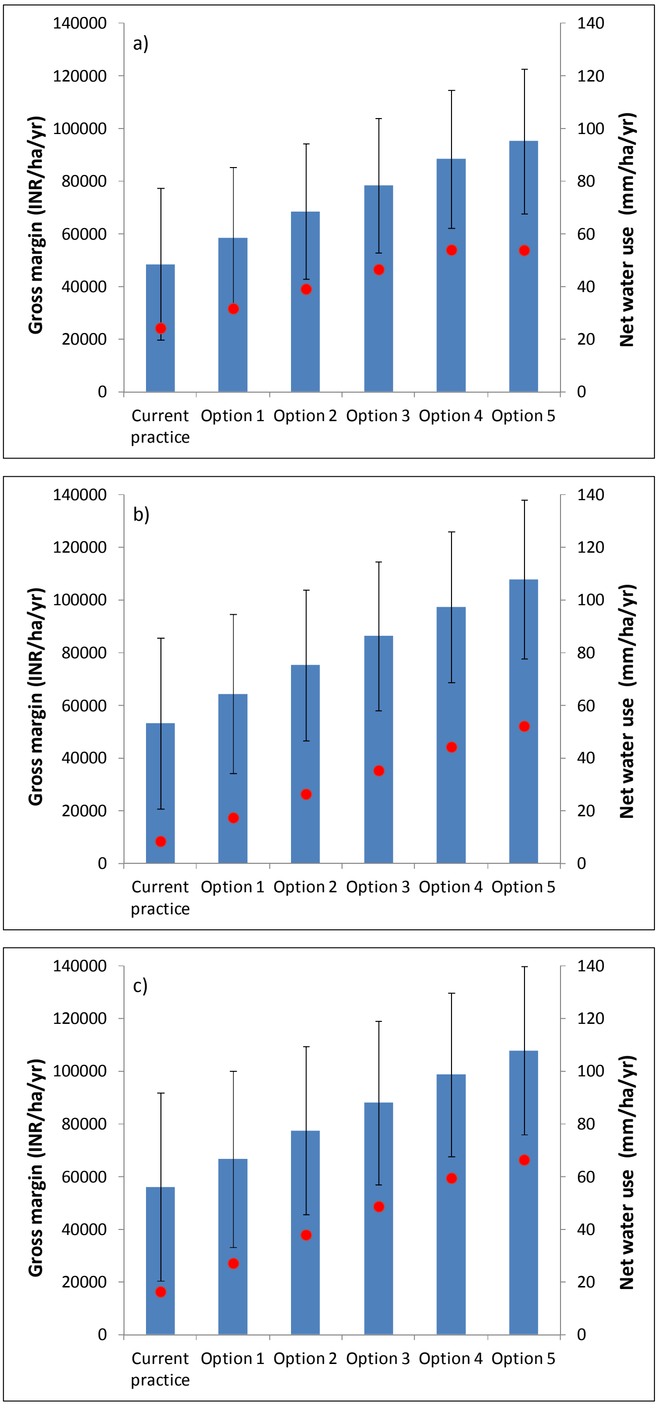
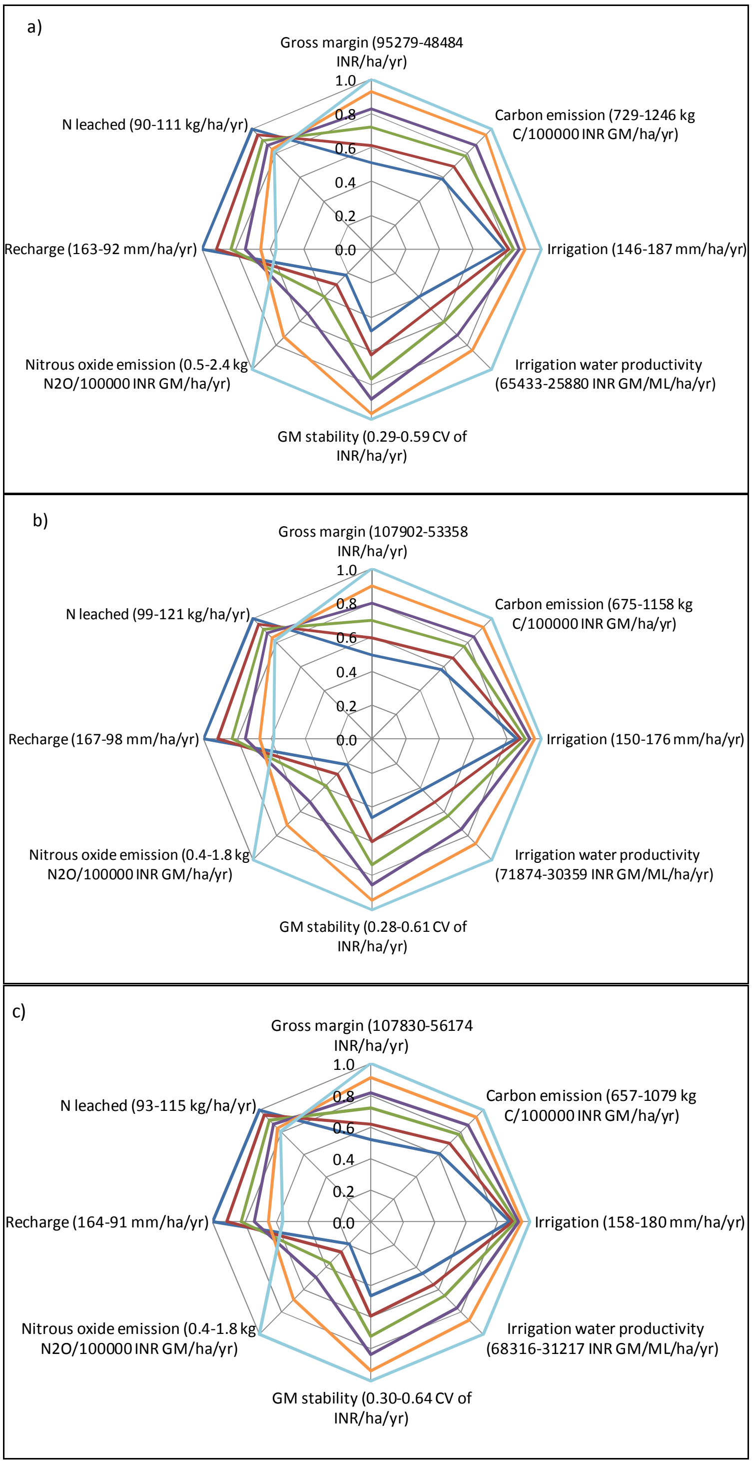

a)
Gross margin (69690-25620 INR/ha/yr)
Carbon emission (983-2303 kg C/100000 INR GM/ha/yr)
Irrigation (169-234 mm/ha/yr)
Irrigation water productivity (41119-10940 INR GM/ML/ha/yr)
GM stability (0.37-1.02 CV of INR/ha/yr)
Nitrous oxide emission (0.9-5.2 kg N2O/100000 INR GM/ha/yr)
Recharge (189-107 mm/ha/yr)
N leached (90-110 kg/ha/yr)
1.0
0.8
0.6
0.4
0.2
0.0
b)
Gross margin (81574-30091 INR/ha/yr)
Carbon emission (879-1998 kg C/100000 INR GM/ha/yr)
Irrigation (172-220 mm/ha/yr)
Irrigation water productivity (47396-13697 INR GM/ML/ha/yr)
GM stability (0.35-0.98 CV of INR/ha/yr)
Nitrous oxide emission (0.6-3.7 kg N2O/100000 INR GM/ha/yr)
Recharge (193-112 mm/ha/yr)
N leached (99-120 kg/ha/yr)
c)
Gross margin (81520-32672 INR/ha/yr)
Carbon emission (856-1813 kg C/100000 INR GM/ha/yr)
Irrigation (180-225 mm/ha/yr)
Irrigation water productivity (45232-14525 INR GM/ML/ha/yr)
GM stability (0.37-1.00 CV of INR/ha/yr)
Nitrous oxide emission (0.6-3.7 kg N2O/100000 INR GM/ha/yr)
Recharge (190-106 mm/ha/yr)
N leached (93-114 kg/ha/yr)

Figure 12.



a)
b)
c)
Gross margin (INR/ha/yr)
Net water use (mm/ha/yr)
0
20000
40000
60000
80000
100000
120000
140000
0
20
40
60
80
100
120
140
Current practice
Option 1
Option 2
Option 3
Option 4
Option 5

Figure 13.


a)
Gross margin (95279-48484 INR/ha/yr)
1.0
0.8
0.6
0.4
0.2
0.0
Carbon emission (729-1246 kg C/100000 INR GM/ha/yr)
Irrigation (146-187 mm/ha/yr)
Irrigation water productivity (65433-25880 INR GM/ML/ha/yr)
GM stability (0.29-0.59 CV of INR/ha/yr)
Nitrous oxide emission (0.5-2.4 kg N2O/100000 INR GM/ha/yr)
Recharge (163-92 mm/ha/yr)
N leached (90-111 kg/ha/yr)
b)
Gross margin (107902-53358 INR/ha/yr)
1.0
0.8
0.6
0.4
0.2
0.0
Carbon emission (675-1158 kg C/100000 INR GM/ha/yr)
Irrigation (150-176 mm/ha/yr)
Irrigation water productivity (71874-30359 INR GM/ML/ha/yr)
GM stability (0.28-0.61 CV of INR/ha/yr)
Nitrous oxide emission (0.4-1.8 kg N2O/100000 INR GM/ha/yr)
Recharge (167-98 mm/ha/yr)
N leached (99-121 kg/ha/yr)
c)
Gross margin (107830-56174 INR/ha/yr)
1.0
0.8
0.6
0.4
0.2
0.0
Carbon emission (657-1079 kg C/100000 INR GM/ha/yr)
Irrigation (158-180 mm/ha/yr)
Irrigation water productivity (68316-31217 INR GM/ML/ha/yr)
GM stability (0.30-0.64 CV of INR/ha/yr)
Nitrous oxide emission (0.4-1.8 kg N2O/100000 INR GM/ha/yr)
Recharge (164-91 mm/ha/yr)
N leached (93-115 kg/ha/yr)

Appendix 7 – Poulton et al: Resilience of Cambodian lowland rice farming systems

Resilience of Cambodian lowland rice farming systems to future climate uncertainty.

P. L. Poulton, N. P. Dalgliesh, S. Vang, T. Veasna, P. Charlesworth, P. Kokic, C.H. Roth

Abstract

Rice production is the major source of food security in Cambodia where 85% of the total arable land is cultivated to rice with traditional transplanted medium and later maturing varieties accounting for > 70% of the plantings during the monsoon period. Climate change poses risks and opportunities to the sustained productivity of rice based farming systems in Cambodia. The objective of this study is to evaluate adaptation strategies that support the replacement of traditional low input systems with a 'response farming' approach for better temporal utilisation of available labour, land and water resources. Options include replacing a traditional transplanted crop with short duration varieties, more efficient crop establishment methods and better agronomic and fertiliser management that responds to timing, intensity and longevity of the monsoon has potential to mitigate effects of current and future climate variability. To achieve this, we apply the APSIM farming systems model to evaluate how adaptation options for smallholder farmers can increase or maintain overall productivity within present day climate variability and future climates, using downscaled GCM baseline and 2030 climate scenarios. To extend beyond the 2030 climate change scenarios, we also assess production risk from an increase in ambient air temperature of 1.4 – 4.3 °C, atmospheric CO_2 concentration of 545 – 885 ppm and variation in rainfall, for rainfed and irrigated systems to 2090. Modelled scenarios indicate a yield response to elevated CO_2 of 17.5% at a concentration of 680 ppm for current temperature and rainfall and are consistent with established physiological effects of CO_2 on crop yields. Simulated rice yields increase at the rate of 6.11% (380-480 ppm) and 4.13% (630-730 ppm) per 100 μmol mol^{-1} and decreased by 4% per degree increase from 0 to 6°C above baseline temperatures. Adaptation strategies involving deployment of short duration rice varieties, in conjunction with direct seeding and better N management indicate comparable and improved production can be achieved to 2030 under current climate projections. However, beyond 2030, the distribution and timing of rainfall will have a significant influence on rainfed lowland rice in Cambodia. In this case a more transformational approach involving widespread provision of irrigation water will be required to offset climate change impacts.

Key Words

APSIM-Oryza, climate change, response farming

Australian Government

Australian Centre for International Agricultural Research

Final Report – Volume 3 Appendices – Reports

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project number	LWR-2008-019
date published	November 2015
prepared by	Monica van Wensveen, Liana Williams and Christian Roth (CSIRO)
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Contents

1 Appendices

This is Volume 3 of the Final Report of the ACCA project (LWR/2008/019). The appendices included in this report are referred to in Volume 1 of the Final Report, and are intended to provide copies of key outputs.

Appendix 1 – van Wensveen 2015: Stakeholder engagement report

Stakeholder engagement for Adapting to Climate Change in Asia project: Planning, process and outcomes

Monica van Wensveen

Unpublished report

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Stakeholder engagement for Adapting to Climate Change in Asia project: Planning, process and outcomes

Monica van Wensveen CSIRO, October 2015

The intent of this report is to provide an overview of the principles, approach and outcomes of stakeholder engagement activities undertaken as part of the Adapting to Climate Change in Asia project between 2010 and 2015.

The main body of the report comprises a description of the principles and tools employed by the project teams for stakeholder engagement, an overview of temporal and relative investment across stakeholder groups for each country, and a summary of engagement outcomes for each country, with a particular focus on dissemination of project practices and influence on policy and planning.

While the report gives the framework and a summary of activities across four countries during the project's life, a wellspring of detail and depth can be found in the project trip reports, annual reports and the Mid-Term and Final Review Notes.

Table of Contents

1. Project premise

Adapting to Climate Change in Asia (ACCA) is a collaborative project creating and testing options with farming communities to enhance their ability to adapt to a changing climate. Researchers and rural communities – in Laos, Cambodia, India and Bangladesh - designed farming practices to help smallholders reduce the impact of an increasingly variable climate.

Locally promising practices that met the needs and capacity of different types of households were tested and evaluated on-farm and by modelling. Project results are being used to support the design and delivery of existing and future climate adaptation programs at broader scales, using information on current and future scenarios.

Country teams had a common research approach and goal, but worked at multiple scales, with multiple partners, multiple stakeholders, diverse social and political contexts and with varying capacity. The diversity of goals added to the complexity - these include science quality, policy influence, community and organisational adoption and timely contribution to international research for development agenda.

2. Stakeholder engagement principles

To address (and embrace) complexity in the project's context and content, it was imperative that ACCA's approach to both research activities and stakeholder engagement activities was well structured, and also flexible and adaptive. To this end, the project adopted five key principles for stakeholder engagement:

Strategic approach

With the aim of attributable impact at multiple scales, a strategic and structured approach to engagement was necessary. This approach considered not only potential stakeholders, but reasons and means for engagement with these stakeholders, as well as anticipated behaviours as a result of engagement. It allowed the project team to prioritise engagement activities, supported team members with consistent and tailored information and provided a framework for critical reflection and reporting.

Adapts to research process

As the nature of the research changed, so did the nature of engagement. Table 1 illustrates the general flow of research and engagement emphases as the project evolved. Note that as research outputs were achieved, both the prioritisation and content of interactions changed.

Stakeholder focus

Different stakeholders have different information needs and different preferences for receiving information. As much as possible, project information was tailored to meet the needs of the stakeholder, taking into account format, level of technical detail, language and cultural sensitivities, literacy levels, existing knowledge etc.

Integrated into project design

Engagement was not an ‘add-on’ to project research - it was explicitly planned and resourced in the project design and workplans. It was consistently implemented through the life of the project and was subject to regular review alongside research progress.

Reciprocal interactions

In many cases, interactions by project staff with stakeholders both imparted and yielded information. Critical information around context and relevance was used iteratively in project planning. Refined knowledge of policy and other drivers allowed us to structure our activities and ‘products’ for greatest uptake and impact.

3. Stakeholder engagement process and tools

A simple set of engagement tools and processes was developed around these principles and implemented in each country to guide interactions with key stakeholder groups and individuals.

Stakeholder matrix

A stakeholder matrix for each country was created at the start of the project, to define key stakeholder groups, reasons for engaging with them and their preferred methods of engagement. The matrix used information collated in the scoping study and the experience and networks of project partners and project leader.

The matrix developed for India in 2011 appears as Appendix A as an example. On the vertical axis are stakeholder groups; along the top of the matrix are anticipated reasons for engagement, followed by preferred mechanisms. Shading in the body of the matrix indicates which mechanisms the team felt might be most effective to interact with each stakeholder group. Whilst some of the emphases and preferred mechanisms changed as the project team learned more about the project and its stakeholders, the underpinning strategy remains valid.

General engagement plan

The initial stakeholder matrix was augmented by a detailed engagement plan, featuring key institutes, groups and individuals within each stakeholder engagement group, the intended means and timing of engagement and any supporting material that may have been required. The engagement plan developed for Laos in 2011 appears as Appendix B as an example.

Annual review

In general, stakeholder engagement outcomes and issues were reviewed by project teams at annual review and planning sessions in each country. Priorities, emphases and communication needs were discussed and agreed for the coming year. These decisions were captured in Trip Reports for annual review and planning meetings and Annual Reports.

Reflection and evaluation

Critical reflection sessions were held with project teams at the end of the project to review the stakeholder engagement process and to distil lessons learned from the ACCA process. A summary of these insights appears as Appendix C.

Table 1. Summary of ACCA research emphases and corresponding engagement focus across project years

Year	Research emphasis	Engagement emphasis
(2009)	(Scoping for ACCA rationale and relevance)	(Scoping for potential partners and relevant stakeholders)
2010	Project planning Developing protocols and methods Assessing and building team capacity	• Building relationships between partners • Sharing information and skills • Raising awareness of project to broad range of stakeholder groups
2011	Project planning Building team capacity Piloting research methods Primary data collection to understand social, biophysical and policy context	• Building relationships between partners • Sharing information and skills • Building relationships with farming communities and district agencies as partners for data generation • Raising awareness of project approach and scope to a broad range of government agencies, for relevance and resonance • Raising awareness of project approach and scope to a broad range of research and planning agencies, for synergies and network opportunities
2012	Identifying and testing locally feasible options using modelling and on farm trials Establishing social research framework	• Exchange of ideas and priorities with farming communities and district agencies as partners for data generation and research direction • Continued exchange with a refined list of policy and planning stakeholders to build potential partnerships for impact • Sharing results and ideas within disciplines, for project planning and implementation
2013	Integrating results across disciplines First round scenario analysis Validation of results with farm community * Review	• Exchange of ideas and priorities with farming communities and district agencies as partners for data generation and research direction • Working with selected policy and planning stakeholders to 'package' relevant results for ease of adoption • Sharing results and ideas between disciplines, for project planning and implementation
2014	Second round scenario analysis Developing knowledge 'products'/ toolkits Generalising results across countries Geographical and institutional scaling Formalising results in publications, conferences * Review	• Sharing results and ideas between disciplines, for development of relevant knowledge products • Partnering with relevant district and national agencies on options to disseminate project practices beyond project sites • Partnering with policy and planning agencies to integrate project principles into existing initiatives or program planning • Engaging with research community
2015	Institutional scaling Finalising publications	• Partnering with relevant district and national agencies on options to disseminate project practices beyond project sites • Partnering with policy and planning agencies to integrate project principles into existing initiatives or program planning • Engaging with research community

4. Investment in engagement

A summary of the evolution of stakeholder investment appears in Table 2 (Cambodia), Table 3 (Laos), Table 4 (India) and Table 5 (Bangladesh). These provide an overview of the relative emphasis for engagement over the course of the project in each country. A detailed example of engagement activities for Cambodia appears as Appendix D (note that this information is collated from CSIRO trip reports and so does not give a full account of project engagement).

Cambodia

Project team

The Cambodian project team comprised representatives from the Cambodian Agricultural Research and Development Institute, the Department of Agricultural Extension, the NGO International Development Enterprises, the Provincial Department of Agriculture in Svay Rieng and CSIRO. An initial focus on building project specific capacity and joint planning and implementation led to more complementary and mutually beneficial collaboration.

Farming community

Initial focus on understanding farming and social systems of our farmer groups in Svay Rieng, moved to joint planning, implementation and review of field trials between farmers and researchers. Towards the end of the project, engagement with farmers in other communes and in other provinces was undertaken by project team members and an ancillary organisation of the project partner, iDE.

Research community

Throughout the project, we had opportunistic interactions with other ACIAR projects working in Cambodia with overlapping areas of interest eg rice breeding and intensification, irrigation and agricultural policy. There were also several opportunities to share progress in formal workshops.

Engagement with CIRAD became less of a priority for the project as CIRAD's geographical focus was upland farming, whilst ACCA's was lowland farming.

Engagement with Royal University of Agriculture faltered initially as an important interest for them was livestock, and this was out of ACCA's scope. Collaboration in later stages of the project focused on delivery of training seminars to post graduate students and researchers on climate adaptation.

Provincial and local government agencies

The Provincial Department of Agriculture in Svay Rieng were both a project partner and key stakeholder for implementation and outscaling across the province. Commune Investment Plans are the result of biennial planning exercises undertaken by heads of village communes, with input from relevant provincial agencies. ACCA had initial plans to mainstream adaptation planning into commune level planning processes, but this became a lower priority given the limited resources attached to the commune investment process, and the difficulties of matching timeframes.

National government agencies

The engagement objectives for national government stakeholders were to provide relevance and operational support for project activities in the earlier stages of the project, and ideally to provide a platform for embedding project principles and beneficial approaches in the latter stages of the project.

ACCA's focal agency was the General Directorate of Agriculture (GDA), which is responsible for agricultural extension, research and implementation. GDA were the conduit to the Ministry of Agriculture, Fisheries and Forestry, through DAE colleagues and other relevant Departments, eg Department of Rice Crops.

The Climate Change Office in the Ministry of Environment has carriage of climate change initiatives for the Prime Minister. Connection with this office was through GDA's input into MAFF's Climate Change Technical Team. The Technical Team reports to MAFF's Secretary of State for Climate Change, who then reports to the Minster of Environment. In response to a request in early 2015 by the Secretary General of the newly established National Council for Green Growth, the Minister for Environment was briefed on ACCA results and other climate adaptation initiatives.

There were two departments within the Ministry of Water Resources that initially seemed aligned with ACCA: the Department of Meteorology (not functional during the project's duration) and the Department of Technical Services that has oversight over creation of new irrigation schemes, which we thought might be an important adaptation strategy. However, the Department was concerned with primary and secondary irrigation during the project, not tertiary, which was the granularity needed for farmer action. During the scoping study, the Ministry of Rural Development were advocates for constructing tertiary irrigation channels. New channels were constructed during the project in two study sites, resulting to key farming practice recommendations. However, close engagement around infrastructure changes was not pursued.

Regional agencies

CAVAC was originally considered as key scaling mechanism by ACCA. The CAVAC focus on pest management and mismatched geographical investment led to interactions for information only. Towards the end of the ACCA project, CAVAC were also developing and planning for their second phase and engagement changed to the potential for collaboration.

Engagement with IFAD and FAO became more important as their investment in large adaptation programs became apparent. These include the existing PADEE (a potential dissemination platform for ACCA techniques and knowledge products) and the forming ASPIRE (a potential avenue for dissemination of ACCA design principles). IDE and DAE are partners.

Interaction with SNV began in 2013, with the principal intent of including ACCA information in PADEE communication and dissemination initiatives, particularly ePADEE. Subsequent engagement has broadened to opportunities to partner with SNV in knowledge management and training initiatives and to explore new mechanisms for connecting with farmers.

Engagement with UNDP was initially targeted towards connecting with their Pilot Program for Climate Resilience and their role in coordinating other climate change donors. High turnover of staff weakened relationships but these were rebuilt in latter stages of the project. Connection points were through inclusion of ACCA as a case study on regional examples of climate adaptation for the

Human Development Report, requests for review of program designs, participation at relevant ACCA and related workshops and through partnerships with IDE, DAE and formerly CARDI in the UNDP Resilient Livelihoods program.

ACCA provided briefings to AusAID/DFAT where possible, due to their role in the Australian aid program, as possible future funders and as a representative in donor climate change fora.

The World Bank and Asian Development Bank are funders of large adaptation programs in the region. Good connectivity with World Bank was not achieved during the project, but there was an ongoing and active relationship with ADB, with requests made to ACCA for information and regular attendance and engagement at ACCA stakeholder meetings.

Selection of other NGOs was through: a) aligned or relevant approaches or objectives; and b) potential for scaling ACCA findings. The project team initially engaged with Oxfam, CARE and World Vision, but although there was a common purpose, no collaborative catalyst was identified.

Engagement with the Mekong River Commission for climate adaptation in both Laos and Cambodia was undertaken with representatives at MRC headquarters in Vientiane.

Laos

Project team[1]

The Lao project team comprised representatives from the National Agriculture and Forestry Research Institute, the National University of Laos' Department of Agriculture, the National Agriculture and Forestry Extension Services (which became the Department of Agricultural Extension and Cooperatives in 2013), the Department of Meteorology and Hydrology, the Provincial Agriculture and Forestry Office of Savannakhet and CSIRO. The District Agriculture and Forestry Offices of Champhone and Outhoumphone districts were also partners, through their connection with the NAFRI and PAFO teams.

Building cohesion between institutes was a focus for the first years of the project, as the project teams had rarely collaborated before or taken an inclusive, interdisciplinary approach to project work. At the close of the project, most teams were open to future collaboration and acknowledged the benefit of working across disciplines. In addition, significant investment was directed towards capacity building to achieve project objectives.

Farming community

Over the course of the project, the initial focus on better understanding and describing the farming and social systems developed into joint testing and review of improved practices and technologies between researchers and farmers in Outhoumphone and Champhone districts. 2012 was the final

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[1] The Small Research Activity LWR-2012-110 *Regional co-learning in simple mechanised tools for rice planting* began in 2013, with a focus on direct seeding as a response to climate variability. The SRA evolved from ACCA research and the SRA project leader was also CSIRO's country coordinator for ACCA in Laos. Consequently, attribution of engagement and outcomes can be unclear, although the distinction for stakeholders is often unnecessary.

year of working closely with participating farmers; subsequently, field trials were conducted as part of the ACCA-SRA project.

In later years, project teams invested in disseminating beneficial approaches to other farmers in Savannakhet Province – through demonstrations, field testing and training – and in Khammouane Province - through collaboration with an existing Climate Smart Agriculture initiative, run by SNV.

Research community

The primary impetus for engaging with research institutes was to explore potential synergies with groups with similar research remits in climate adaptation and natural resource management. In addition, ACCA aimed to gauge the relevance of the research in the study region, to access data and expertise and to look for possible repositories for research outcomes.

Initially, the project team focused on connecting with the large ACIAR project CSE/2009/004, *Developing improved farming and marketing systems in rainfed regions of southern Lao PDR* (the 'South Lao Project'), that was located in a similar region, had common Lao institutional partners and international partners with whom ACCA shared research agendas. When connecting with SLP managers proved unfruitful, the team refocused on connecting with individual research institutes, particularly IRRI, CIAT and IWMI. Except for IWMI, who provided climate analyses and expertise under contract, ACCA was unable to engage in an ongoing and effective manner.

Connections with Savannakhet and Khon Kaen Universities and World Vision Thailand centred on provision of expertise and infrastructure for direct seeding – this is covered in the ACCA-SRA final report.

There was no additional significant engagement with the Lao research community. In retrospect, this is unsurprising, as Lao researchers with an interest in the ACCA approach and outputs are mostly employed in NAFRI or NUOL. In NAFRI at least, research outputs and insights from ACCA have been transferred into new projects in which team members are now involved.

Provincial and district government agencies

The primary agencies in this stakeholder group were PAFO in Savannakhet and DAFO for Outhoumphone and Champhone districts. Each agency was an implementation partner and significant investment was made in building capacity to meet project goals (particularly in participatory methods) and in creating an environment for cross-institutional collaboration.

Because there are few relevant NGOs in Savannakhet, these two agencies were also the key agents for outscaling project results and engaging with farming communities.

In later years, engagement increased with Provincial and District Governors in the five southern provinces– generally through institutional mechanisms and more specifically through targeted demonstrations and field events. Whilst national agencies are responsible for policy, Provincial Governments are semi-autonomous and therefore play an important role in implementation and resourcing new approaches and technologies.

National government agencies

ACCA's initial focus for national policy influence and support were the Ministry of Agriculture and Forestry (MAF) and the Ministry of Water Resources and Mining, which was responsible at the time for climate change and adaptation initiatives, including the coordination of donor activities.

Within MAF, the ACCA team had hoped to connect with the Department of Agriculture, the Department of Planning (who make investment decisions) and the Department of Irrigation (to explore an important adaptation pathway by increasing access to irrigation).

With the exception of the Department of Agriculture, national government engagement was largely unsuccessful. Policy engagement at the highest level by external agencies was either premature or unwarranted by Lao project partners. In deference to the reservations of the project partners, ACCA focused investment into practical demonstration and testing, dissemination of information and training, and embedding the project's research approach and outcomes into relevant national institutes, such as NAFRI.

Ongoing engagement with the Director General of the Department of Agriculture served to raise awareness of project progress and to gauge relevance of activities – particularly agro-advisory delivery and direct seeding of rice - to national drivers for agriculture.

Regional agencies

The Mekong River Commission was initially seen as a key regional agency for adopting ACCA's design principles and as an interface for scaling in the region. A high level of interaction was maintained for the first half of the project, through regular meetings, response to requests for information and engagement, participation on the Science Panel and in strategic planning workshops. Despite enthusiasm to connect through the Climate Change Adaptation Initiative, MRC's funding was cut in 2014, following a reduction in Australia's foreign aid to Laos and efforts to maintain engagement were largely unsuccessful.

ACCA's interaction with AusAID/DFAT was through provision of opportunistic briefings. Whilst these were received with interest, reduction in ODA left little opportunity for funding or expansion.

A major avenue for outscaling project outputs and gaining a better understanding of adoption drivers was AusAID/DFAT's Lao Australia Development and Learning Facility (LADLF), which commenced in early 2014. Proposals to the fund were led by Lao research institutions across a range of thematic areas, including climate change and agriculture. By late 2014, a proposal for adoption of the dry seeded rice was being developed by NAFRI. Unfortunately, reduction in Australian ODA closed this avenue in early 2015.

IFAD's goal in Laos is to enable rural people to overcome poverty, to support improvements to rice production in areas where rice has a comparative advantage, and to free other areas to undertake higher value agricultural production. ACCA's interaction with IFAD began in 2014 through an interest in the project's direct seeder research and was nurtured through provision of technical information for training manuals and extension materials that have been produced as part of IFAD's Sustainable Natural Resource Management Productivity Enhancement Project.

SNV is one of the few development agencies active in the southern provinces. ACCA's collaboration with SNV began in 2013, with a common interest in incorporating direct seeded rice into their rice production supply chain model, as part of SNV's Climate Smart Agriculture program. This expanded to include the use of cropping calendars, rainfall visualisers and climate monitoring and forecasting.

India

Project team

The Indian project team comprised representatives from the Professor Jayashankar Telangana State Agricultural University, PJTSAU (who were formerly with the Acharya NG Ranga Agricultural University, ANGRAU), the NGO Watershed Support Services and Activities Network (WASSAN), the Livelihoods and Natural Resources Management Institute (LNRMI) and CSIRO. The Indian Meteorology Department (IMD) were non-financial collaborators in the project. Local NGOs were critical to successful operations in the three study villages.

As most of the teams had not worked together before, significant early investment was in building cohesion between teams and in establishing processes for collaboration and joint planning. Investment was also made in capacity building of junior collaborators in PJTSAU.

Farming community

In the initial years of the project, the project focus was on understanding and describing the farming system and the social systems and institutions that govern agriculture in the study districts of Warangal, Nalgonda and Mahbubnagar in central and southern Telangana State. On-farm trials and demonstrations, with participatory planning and review built trust and transferred skills between researchers, local NGO partners, participating farmers and their communities.

The advent in 2013 of the Climate Information Centres (CLICs) and their component parts (formation of farmer climate clubs, delivery of agromet advisories, recording and acting on village level meteorology data, and development of seasonal rainfall visualisation tool) created further, diverse mechanisms for engagement.

Research community

Throughout the project, opportunities arose for interactions with other ACIAR projects working on climate and water initiatives. These interactions were both formal (eg through the Water Cluster network and the Climate Water Forum) or informal (eg through key staff working on multiple projects), providing platforms for exploring synergies and for planning efficient engagement with common stakeholders.

Contact was maintained with both national and international research groups, to inform and influence, to explore complementary approaches and to source data and expertise. Key national stakeholders included: the Central Research Institute for Dryland Agriculture (coordinate climate adaptation research; maintained links through stakeholder meetings); National Centre for Medium Range Weather Forecasting (originally a key stakeholder, but change in direction resulted in reduced synergy with ACCA); Indian Institute of Tropical Meteorology (originally targeted as a data source; greater focus on downscaling at the time of the project).

International groups of interest to ACCA included: the International Water Management Institute (links maintained with ACCA although much greater emphasis on water research) and the International Crops Research Institute for the Semi-Arid Tropics (original connections for sourcing data; now interest in the CLICs model for delivering tailored climate information).

District and local government agencies

The Gram Panchayat, headed by an elected Sarpanch is the cornerstone of local government administration. While initiatives and programs are decided at State level, they are conducted at village and district level. It is also at this level that government extension services function.

From 2012 onward, project teams established and strengthened their working relationships with Gram Panchayats in the project study villages to ensure support for and relevance of project activities. This was predominantly through personal briefings, village discussions and by interactions at field activities.

Later links were made with District Collectors for the study districts. This office is appointed by the State for administration at district levels.

State government agencies

Agricultural policy is enacted at State level, with funds and policy direction from the central government. For reasons of relevance, support and scale, interactions with relevant State Government agencies was crucial to project success.

Initially, the Department of Agriculture, with its government administered agricultural extension services, seemed an obvious connection for ACCA activities. While supportive of the project (particularly the agro-advisory approach), the Department at the time did not work in irrigation, but administered smaller programs such as input subsidies and census collation.

The Department of Rural Development used its Watershed Development Program as a key mechanism for poverty alleviation, coordinated and trained a parallel extension service, recognised ACCA's capacity to develop relevant 'knowledge products' and had the funding and capacity to disseminate them as part of DRD activities. DRD's mandate also included climate change, which was formerly the responsibility of the Department of Environment.

As the importance of the Gram Panchayats became apparent to the project teams, connecting with the state agency responsible for local governance, the Department of Panchayati Raj also became apparent, as a means of broader support and impact and through their mandate for development of infrastructure at village level.

Other state agencies stakeholders include: Water and Land Management Training and Research Institute (for potential training opportunities and as a nexus for relevant research); the Department of Irrigation and the Irrigation Command Area Development (although these became less relevant to ACCA's rainfed study areas).

Engagement with state government stakeholders was delayed in 2013-2014 because of the division of the state of Andhra Pradesh. Establishment of administrative structures and processes for Telangana State commenced in late 2014, and preliminary budget decisions commenced in early-mid 2015.

National government agencies

ACCA's initial focus for national policy support and influence were the Indian Meteorology Department (IMD), the Indian Council of Agricultural Research (ICAR) and its network project on National Innovations on Climate Resilient Agriculture) and the National Rainfed Area Authority.

IMD were research partners in the project, as well as key users of PJTSAU-ACCA products such agro-advisories. Strong links have been maintained throughout the project, through targeted briefings, participation in workshops and joint planning for expansion and improvement of seasonal climate forecasts and delivery of climate-oriented agricultural information.

ICAR is the apex body for agricultural research in India. ICAR also funds agricultural institutes and universities and the Deputy Director General of Natural Resource Management has oversight of climate adaptation initiatives in these institutes. Again, strong links were established and maintained with this group, such that the DDG became a member of the external review team for the project's Final Review in July 2014.

Links with NRAA diminished as the project proceeded. Initially it was the role of the NRAA to reconcile relevant policies across ministries, but this changed as authority and responsibility was ceded to other departments.

In the last year of the project, interactions increased with the National Bank for Agriculture and Rural Development who were interested in funding outscaling of CLICs.

Regional agencies and NGOs

Engagement with a range of NGOs was primarily planned as a means to outscale and multiply beneficial ACCA outputs and approaches. Initially, connections with BIRDS and PRADAN were sought, but these organisations were not found to be active in the study region.

After proof of concept, project partner WASSAN has successfully created a conduit to both farmers (eg through their existing Watershed Program activities) and other NGOs, principally through existing NGO networks (eg the Revitalising Rainfed Agriculture Network). Their networks extend beyond Telangana, with at least 100 partners across the country.

Bangladesh

Project team

The Bangladesh project team comprised representatives from the Bangladesh Agricultural Research Institute (BARI), the Bangladesh Rice Research Institute (BRRI), the Bangladesh office of the International Rice Research Institute (IRRI) and modelling researchers from the Philippines headquarters, the Social and Economic Research and Development Institute (SERDI) and CSIRO. The Bangladesh Agricultural Research Council (BARC) were a non-financial collaborator.

Most of the team members had not worked together before – not even BARI and BRRI who are co-located in Gazipur. Early emphasis in team building, joint planning and establishing ways to collaborate and integrate was a positive and beneficial investment.

The departure from Bangladesh of SERDI's director in 2012 led to the eventual disbandment of the group, although intellectual connections have been maintained.

The sister project LWR-2010-033 *Developing capacity in cropping systems modelling to promote food security and the sustainable use of water resources in South Asia* (the SAARC-Australia Project) strengthened links between teams (particularly BARI, BRRI and CSIRO), built institutional capacity in modelling and supported engagement with common stakeholders.

Farming community

In the early stages of the project, there was considerable engagement with farming communities in the Satkhira and Dacope regions of Khulna Division. This engagement comprised key informant interviews, farmer group discussions and village meetings, to inform development of household typologies and to gain a better understanding of farm management decision making for crop modelling and scenario analyses.

A review in 2012 shifted the project's emphasis in Bangladesh to further refinement of the APSIM cropping model, development of a saline systems component, and institutional capacity building through ACCA and the SAARC-Australia project. Subsequently, farmer engagement and explicit scaling activities ceased in 2012.

Research community

At the start of the project, there was significant engagement with a network of Bangladeshi research and development institutes. This was both formal and informal, with an intent of awareness, influence, adoption and dissemination. Both the change in project focus (towards model development) and the departure of key team members from IRRI and SERDI led to reduced capacity for engagement and changed emphases.

An important research stakeholder for ACCA was the Bangladesh Agricultural Research Council (BARC), in the Ministry of Agriculture is the umbrella organisation for the national agricultural research system. It has the mandate for strengthening research capacity, coordinating research effort and creating the national agricultural research plan. Opportunistic contact was maintained with key staff throughout the project, although the focus of engagement shifted from climate adaptation to modelling capacity.

The Cereal Systems Initiative for South Asia (CSISA) Bangladesh aims to increase dissemination and adoption of crop (and aquaculture) management technologies in Bangladesh. Their focus is capacity building for extensionists, research and evaluation of emerging technologies. CSISA is led by IRRI has four geographical hubs, one of which is Khulna. A key mechanism for influence was through the appointment to CSISA of ACCA team members.

Bangladesh Centre for Advanced Studies (BCAS) is a non profit institute working on policy, research and implementation of sustainable development initiatives at multiple levels. BIDS Bangladesh Institute of Development Studies (BIDS) is an autonomous public organisation that conducts policy oriented research on development issues facing Bangladesh. Engagement with these groups was originally sought for policy influence and dissemination, but did not continue beyond 2012.

The Bangladesh Rural Advancement Committee (BRAC) is the world's largest non government development organisation, with a mandate of empowerment and poverty alleviation, and is present in all 64 districts in Bangladesh. Until 2012, ACCA made regular briefings to BRAC; thereafter interactions were through informal networks.

Support to Agricultural Research for Climate Change Adaptation (SARCCAB) in Bangladesh was an IFAD funded, IRRI implemented project in coastal zones affected by the 2007 cyclone. The project aimed to develop and disseminate farming technologies to develop the capacity of affected communities to adapt to climate change. SARCCAB funded ACCA to conduct field work in one of its three focus regions - Dacope in Khulna – and ACCA provided input to SARRCAB until it concluded in 2012.

Throughout the project, there were many opportunities to interact with other ACIAR projects working in similar regions or on related agriculture, climate or water issues. Examples include LWR-2012-079, *Improving dry season agriculture for marginal and tenant farmers in the Eastern Gangetic Plains through conjunctive use of pond and groundwater resources* and LWR-2010-080 *Overcoming agronomic and mechanisation constraints to development and adoption of conservation agriculture in diversified rice-based cropping in Bangladesh.*

Relationships with some research groups were maintained through common research staff eg connections with CIMMYT (International Maize and Wheat Improvement Center) have been maintained through ACIAR project CSE-2011-077, *Sustainable and resilient farming systems intensification in the Eastern Gangetic Plains (SRFSI),* in which ACCA-CSIRO staff are partners. More recently, capacity to model salinity in rice-based cropping systems that was developed in ACCA is being applied in the new ACIAR project LWR-2014-073 on intensification of agriculture in coastal Bangladesh.

Government agencies

Relationships with a variety of government agencies were sought to gauge relevance in ACCA's approach, to identify possible users and disseminators of ACCA outputs and to understand synergies and overlaps with existing government initiatives.

Key amongst these agencies were: the Bangladesh Water Development Board (in the Ministry of Water Resources) at national and polder levels; the Department of Agricultural Extension (in the Ministry of Agriculture) at national and upazila levels, and the Comprehensive Disaster Management Program (CDMP) in the Ministry of Food and Disaster Management. Note that engagement with BARC has already been discussed in the research section.

Ultimately unsuccessful connections were sought also with the Ministry of Environment's Climate Change Cell and the Department of Defence's Department of Meteorology, due to changes in organisational structure and lack of alignment of initiatives.

Regional agencies

Groups working at a regional scale that were initially of interest to ACCA were the CGIAR's Challenge Program for Water and Food (CPWF), UNDP, IFAD and AusAID-DFAT. Primary engagement objectives were outscaling beneficial ACCA outputs, adoption of ACCA approaches and general awareness of project activities. Please note that connections with CSISA have already been discussed in the research section.

Again, changes in project focus changed engagement from formal and regular to opportunistic and through existing research networks (eg connections with CPWF were maintained through research networks in IRRI and the CGIAR's Research Program on Water, Land and Ecosystems).

Table 2. Relative investment in stakeholder engagement in Cambodia

Stakeholder group	2010	2011	2012	2013	2014	2015
Project team	CARDI DAE IDE CSIRO PDA-SR	CARDI DAE IDE CSIRO PDA-SR	CARDI DAE IDE CSIRO PDA-SR	CARDI DAE IDE CSIRO PDA-SR	CARDI DAE IDE CSIRO PDA-SR	CARDI DAE IDE CSIRO PDA-SR
Farming community	Potential farmers	Participating farmers	Participating farmers	Participating farmers Other farmers (SR)	Participating farmers Other farmers (SR + PV)	Participating farmers Other farmers (SR, PV and further)
Research community	RUA CDRI IRD/CIRAD Other ACIAR projects General	RUA Other ACIAR projects General	Other ACIAR projects General	RUA Other ACIAR projects General	RUA Other ACIAR projects General	General
Provincial/local govt	PDA Svay Rieng Heads of Village Communes	PDA Svay Rieng Heads of Village Communes	PDA Svay Rieng	PDA Svay Rieng	PDA Svay Rieng	PDA Svay Rieng
National govt	GDA Min Ag Fish Forestry Min of Environment Min Water Resources Min Rural Devt	GDA (MAFF)	GDA (MAFF)	GDA (MAFF)	GDA (MAFF)	GDA (MAFF)
Regional agencies	CAVAC UNDP ADB Oxfam AusAID MRC	CAVAC UNDP ADB Oxfam AusAID MRC	UNDP ADB AusAID FAO IFAD	CAVAC UNDP ADB FAO IFAD SNV	CAVAC UNDP IFAD SNV	CAVAC ADB UNDP IFAD SNV

Note: Darkest shading denotes high priority; lighter shading demotes medium priority; no shading denotes lower priority. Stakeholder groups that have been omitted are funders (constant high priority) and general public (constant lower priority).

Table 3. Relative investment in stakeholder engagement in Laos

Stakeholder group	2010	2011	2012	2013	2014	2015
Project team	NAFRI, NUOL, PAFO, NAFES, DMH, CSIRO	NAFRI, NUOL, PAFO, NAFES, DMH, CSIRO	NAFRI, NUOL, PAFO, NAFES, DMH, CSIRO	NAFRI, NUOL, PAFO, DEAC, DMH, CSIRO	NAFRI, NUOL, PAFO, DAEC, DMH, CSIRO	NAFRI, NUOL, PAFO, DAEC, DMH, CSIRO
Farming community	Potential farmers	Participating farmers	Participating farmers	Participating farmers* Other farmers (Savannakhet)	Participating farmers Other farmers (Savannakhet)*	Other farmers (Savannakhet + Khammuone)*
Research community	ACIAR South Lao Proj IWMI General	ACIAR South Lao Proj IWMI CIAT IRRI Savannakhet Univ CCARA General	ACIAR South Lao Proj IWMI IRRI Other ACIAR projects Khon Kaen Univ World Vision Thailand General	IWMI* IRRI* Khon Kaen Univ* World Vision Thail* General	IWMI ACIAR Mech Project General	General ACIAR Mech Project
Provincial/district govt	PAFO DAFO	PAFO DAFO	PAFO DAFO	PAFO DAFO Prov Governors	PAFO DAFO Prov Governors	PAFO DAFO
National govt	Min Agric & Forestry Min Nat Res & Environ	Dept Agriculture (MAF)	Dept Agriculture (MAF)	Dept Agriculture (MAF)	Dept Agriculture (MAF)	Dept Agriculture (MAF)
Regional agencies	MRC AusAID	MRC AusAID	MRC UNDP	MRC DFAT IFAD* SNV*	DFAT LADLF* IFAD* SNV*	LADLF* IFAD* SNV*

Note: The Small Research Activity LWR-2012-110 *Regional co-learning in simple mechanised tools for rice planting* began in 2013. As the SRA evolved from ACCA research and the SRA project leader is also the ACCA country coordinator for Laos, it is often not possible to separate SRA engagement from ACCA engagement – certainly many stakeholders did not note or need a distinction. Where multiple objectives for engagement are known, these are noted with an asterisk.

Table 4. Relative investment in stakeholder engagement in India

Stakeholder group	2010	2011	2012	2013	2014	2015
Project team	ANGRAU LNRMI WASSAN CSIRO IMD	ANGRAU LNRMI WASSAN CSIRO IMD	ANGRAU LNRMI WASSAN CSIRO IMD	ANGRAU LNRMI WASSAN CSIRO IMD	ANGRAU LNRMI WASSAN CSIRO IMD	PJTSAU LNRMI WASSAN CSIRO IMD
Farming community	Potential farmers	Participating farmers	Participating farmers	Participating villages; CLICs villages; other farmers	ACCA villages; CLICS villages; other farmers	Other farmers
Research community	CRIDA NCMWRF IWMI ICRISAT IITM Other ACIAR projects General	CRIDA NCMWRF Other ACIAR projects	CRIDA NCMWRF Other ACIAR projects	CRIDA NCMWRF Other ACIAR projects General	CRIDA ICRISAT Other ACIAR projects General	CRIDA ICRISAT Other ACIAR projects General
District/local govt	Village Gram Panchayats District Collectors	Village Gram Panchayats	Village Gram Panchayats	Village Gram Panchayats	Village Gram Panchayats District Collectors	Village Gram Panchayats District Collectors
State govt	Dept Agriculture Dept Environment Dept Rural Devt Irr Command Area Devt Dept Panchayati Raj WALAMTARI	Dept Agriculture Dept Environment Dept Rural Devt Irr Command Area Devt WALAMTARI	Dept Rural Devt WALAMTARI	Dept Rural Devt Dept Panchayati Raj	Dept Rural Devt Dept Agriculture Dept Panchayati Raj NABARD	Dept Rural Devt Dept Agriculture Dept Panchayati Raj NABARD
National govt	Ind Meteorology Dept Ind Council Ag Res Nat Rainfed Area Auth	IMD ICAR	IMD ICAR	IMD ICAR	IMD ICAR (NICRA)	IMD ICAR (NICRA)
Regional agencies; NGOs	BIRDS PRADAN				CCAFS RRA Network NGOs	CCAFS RRA Network NGOs

Note: Engagement with state government stakeholders was delayed in 2013-2014 because of the bifurcation of the state of Andhra Pradesh. Establishment of administrative structures and processes for Telangana State commenced in late 2014, and preliminary budget decisions commenced in early-mid 2015.

Table 5. Relative investment in stakeholder engagement in Bangladesh

Stakeholder group	2010	2011	2012	2013	2014	2015
Project team	BARI: BRRI; SERDI; IRRI; CSIRO	BARI: BRRI; SERDI; IRRI; CSIRO	BARI: BRRI; SERDI; IRRI; CSIRO	BARI: BRRI; SERDI; IRRI; CSIRO	BARI: BRRI; SERDI; IRRI; CSIRO	BARI: BRRI; SERDI; IRRI; CSIRO
Farming community	Participating farmers in Dacope and Shatkira	Participating farmers in Dacope and Shatkira				
Research community	BARC; BRAC; BIDS; BCAS; CIMMYT; CSISA; SARCCAB project; other ACIAR projects; general	BARC; BRAC CIMMYT; CSISA Other ACIAR projects General	BARC CIMMYT; CSISA Other ACIAR projects General	BARC Other ACIAR projects General	BARC Other ACIAR projects General	BARC Other ACIAR projects General
Upazila govt agencies	Bgd Water Devt Board Dept Agric Extension	Bgd Water Devt Board Dept Agric Extension				
National govt agencies	CDMP Dept Agric Extension Climate Change Cell Dept Meteorology Bgd Water Devt Board	CDMP Dept Agric Extension Climate Change Cell Bgd Water Devt Board	CDMP Dept Agric Extension Bgd Water Devt Board	CDMP Dept Agric Extension Bgd Water Devt Board		
Regional agencies	CPWF; UNDP; IFAD; DFAT	CPWF; DFAT	CPWF; DFAT			

Note: A review in 2012 shifted the emphasis in Bangladesh from farmer engagement and explicit scaling activities to further refinement of the APSIM cropping model and subsequent institutional capacity building through ACCA and the sister project LWR/2010/033 *Developing capacity in cropping systems modelling to promote food security and the sustainable use of water resources in South Asia.*

5. Engagement outcomes

This section summarises the results of ACCA’s investment in engagement at the close of the project. For ease of comparison, results are presented for each of the key outcomes articulated at the start of the project: reporting, general awareness and promotion, cohesion and capacity of research partners, science exchange, adoption and dissemination of project practices and policy and program influence (see India’s stakeholder matrix in Appendix A for reference).

The last two outcomes are covered in more detail as they form the foundation of the project’s sustainability and impact in the region.

The mechanism for dissemination is outlined, with an estimate of the current and anticipated size of impact where this is applicable and available. Where primary responsibility for dissemination has passed from the project to another entity, this is noted.

The intention in this report is not to provide details of what information was disseminated – this appears elsewhere in the Final Report. The intention is to report on the outcomes of our strategic engagement with key stakeholder groups.

a. Reporting

Project reporting provided the basis of engagement with ACIAR, and was also a key mechanism for inter-discipline and inter-country update and review. The project team conducted two successful external reviews: a Mid Term Review in Cambodia in February 2013 and a Final Review in Laos in July 2014. Two multi-volume review reports were produced, as well as three Annual Reports and one Semi-annual Report. Over 80 trip reports were created by the CSIRO team and submitted to ACIAR in the course of the project. An example of engagement activities from these reports (from Cambodia) is summarised in Appendix D.

b. General awareness and promotion

Awareness and promotion of the project to the general public in Australia was not a high engagement priority for the ACCA team, as there was no behavioural change from that stakeholder group that the project aspired to achieve.

In the course of the project, the project team participated in production of an ACIAR promotion video in Cambodia (November 2013) and hosted two Crawford Fund journalists in India (February 2011). A project website was established and maintained by CSIRO.

Project teams in countries outside Australia used print media, radio and TV opportunistically as vehicles to promote or impart information about project activities to an audience that was wider than the focal farming communities of the project.

The Indian team (through ANGRAU/ PJTSAU) used print media, radio and TV regularly (twice each week) to deliver agro-advisory information to communities throughout Andhra Pradesh/Telangana. These were predominantly targeted at farmers, but also had a wider reach.

c. Cohesion and capacity of partners (and their respective institutes)

During the first years of the project, significant effort was invested in training activities to achieve project milestones. These activities included both research techniques – eg training soil and crop monitoring methods, systems modelling, seasonal climate forecasting, social research methods and use of project equipment such as dry seeders and agro-meteorological equipment – and approaches to managing a complex project - eg joint planning and implementation, inter-institutional collaboration, strategic stakeholder engagement and internal communication.

Beyond project milestones, the project initiated intensive training courses in APSIM, farming systems, and extension methods with support from the Crawford Fund. Capacity impacts across the ACCA partnership are summarised in Sections 6.2 and 9.2 of the ACCA Final Report.

Enhanced capacity and experience gained from involvement in ACCA are now being widely used outside the scope of the project. Details of how these are being embedded into new country initiatives are summarised in Sections 5e and 5f of this report and in the country chapters of the Final Report.

d. Science exchange

As noted in Tables 1-5, investment in science exchange with the research community in general was greater in the latter half of the project, as data and contextual information were being collected, synthesised and analysed.

At the completion of the project, the project team has produced 41 manuscripts (21 published; 20 peer-reviewed and in final preparation), 30 conference papers and key presentations and 25 key project reports – see Section 8 of the ACCA Final Report for a detailed listing.

e. Adoption and dissemination of practices

This section refers to the diffusion of project practices and technical knowledge to farming communities beyond our collaborating farmers.

Cambodia

Significant mechanisms for dissemination of ACCA practices to Cambodian farmers are summarised below and in **Table 6**. Note that a degree of overlap exists.

1. *Farm Business Advisor network*

Farm Business Advisors (FBAs) are a network of 'micro-entrepreneurs who help farmers to initiate, intensify, or expand market-oriented agricultural production'. They are recruited and trained by IDE (and latterly, the IDE spin off company, Lors Thmer) on good agricultural practice for main crops in their area, and in business skills. ACCA information – particularly the response farming 'toolkit' – is now embedded into their training. Each FBA services 40-50 farmer clients, who can access advice, inputs and credit.

IDE managed the ACCA on-farm research program in Svay Rieng province from 2011 to 2013 and the expansion into Prey Veng province in 2013. At this time, there were an estimated 50 FBAs in the two provinces who had received training in ACCA research, as part of broader IDE training and IDE estimate that they were engaging with around 2000 farm enterprises.

In 2013, IDE's aim was to increase FBA numbers to 200 in 3-5 years, but this goal has already been exceeded in 2015, with 246 FBAs providing inputs and advice to vegetable and rice producers in villages across five provinces – Svay Rieng, Prey Veng, Takeo, Kandal and Kampot.

The aim in the next 3 years is to have more than 400 FBAs established. With each FBA servicing 40-50 farmer clients, iDE estimate they will be providing some level of service to 16,000 to 20,000 farm enterprises.

2. *DAE training and extension initiatives*

The Department for Agricultural Extension (DAE) is responsible for training a network of provincial and commune extension workers and non-geographically aligned support teams in good agricultural practices and in new technologies, varieties and approaches developed or adopted by the various Departments of the General Directorate of Agriculture.

The mechanism for this is that DAE staff use a Training of Trainer (TOT) approach, with trainers then conducting Farmer Field Schools (FFS) as a starting point for dissemination of information to farmers. The TOT training used the manual developed by DAE as part of ACCA, detailing the response farming decision support charts and associated text describing each action. FFS participants were provided with a less detailed manual describing the same response options, with a set of posters for display in each village or commune.

The TOT approach was piloted in 2013 in Svay Rieng, with training of 29 TOTs (which included PDA extension staff), who then conducted six FFSs, with 16 farmers per group; a total of 96 farmers. This approach was then used in PADEE roll-out activities (see next section).

DAE also hosted climate change extension workshops in 2013 and 2014, with another planned for 2015. Around 100 representatives, from senior government through to key farmers, from ten provinces are invited. ACCA's response farming approach has been included in the program of the last two workshops and it is expected that it will be included again in 2015.

In addition, DAE is developing a web or app-based extension hub (as part of ASPIRE), to service the agricultural information needs of researchers, extension workers and farmers. Information will be available at commune or village level and implementation is likely to begin in 2016.

3. PADEE training and extension initiatives

The Project for Agricultural Development and Economic Empowerment (PADEE) is funded by IFAD, coordinated by GDA's Project Support Unit, implemented by SNV, with IDE and DAE as partners. PADEE began in 2012 and is due to end in 2018. ACCA connected with SNV in 2013.

Training and supply of climate adaptation tools to a network of Community Extension Workers (CEWs) has the potential to reach 40,000 farmers across their five focus provinces – Svay Rieng, Prey Veng, Kampot, Kandal and Takeo.

Initially, ACCA's nexus with PADEE was to be through SNV's e-PADEE platform – a tablet-based diagnostic, monitoring and information system being used by CEWs, PDAs and others. However, a recent project consultancy by CamAg (refer to Volume 3 of the ACCA Final Report) suggests that project outputs are not compatible with the current direction of ePADEE. As a consequence, other options are being explored (in addition to DAE training material), including the development of an alternative electronic application or the development of paper-based decision support tools. These options are likely to be explored through ASPIRE.

As part of the roll-out of the PADEE program, a further 64 TOTs were trained by DAE in Svay Rieng in 2013 and 2014. Each conducted three FFSs, with 50 farmers attending, for a total potential exposure of ACCA outputs to 9,600 farmers.

Also as part of PADEE, 432 Commune Extension Workers were trained by DAE in Kampot (72), Kandal (72), Prey Vang (172), Takeo (116) provinces in 2013 and 2104. Response farming techniques were less prominent in training in these provinces and the number of farmers per CEW is not reported. An external impact assessment of PADEE is scheduled for the end of 2015.

4. ASPIRE plans for training

Agriculture Services Program for Innovation, Resilience and Extension (ASPIRE) is funded by IFAD. The program runs from 2015 to 2021 and aims to increase agricultural production and address vulnerability by providing 120,000 farming households with information, training on improved technologies (including climate-smart techniques) and facilitating their access to markets.

ASPIRE is a national programme that begins this year in five pilot provinces: Battambang, Kampong, Kratie Chhnang, Preah Vihear, and Pursat. For 2015-18, ASPIRE plans to train CEWs in 180 communes in these provinces. Each CEW will be responsible to establishing ‘small learning groups’ of 30 farmers; a total of 5,400 farmers. In its second phase (2018-21) it will be extended to the five current PADEE provinces of Kampot, Kandal, Prey Veng, Svay Rieng and Takeo (but with farmers not currently exposed to PADEE), plus additional villages in the first five provinces.

DAE is responsible for training and response farming research outcomes (as embedded in extension materials developed in ACCA) will form an important component of these training activities.

Table 6. Summary of current and potential dissemination of ACCA practices in Cambodia.

Disseminating group	Current reach	Potential reach (3-5 years)
IDE/Lors Thmer	50 FBAs x 40 clients = 2000 farmers; Svay Rieng and Prey Vang	400 FBAs in 5 provinces x 40 clients = 16,000 farmers
	246 FBAs x 40 clients = 8000 farmers; 3 additional provinces	
PADEE	DAE pilot of 29 TOT x 6 FFS x 16 farmers = 96 farmers; Svay Ring	Stated target of 90,000 farmers by 2018 across 5 provinces
	64 CEWs x 3 FFS x 50 participants = 9600 farmers; Svay Rieng	
	432 CEWs in 4 provinces, with possible 4000-20,000 farmers	
ASPIRE	Program commenced in 2015	180 CEWs in 5 new provinces x 30 farmers = 5400 farmers by 2015 Proposed target of 120,000 households in 10 provinces by 2021

Note that these are estimates of possible exposure to ACCA components, not estimates of adoption. It is unclear the relative importance of ACCA information in training material being developed for ASPIRE and PADEE. Also, not all FBAs had a primary focus on rice production.

Laos

Significant mechanisms for dissemination of ACCA practices to farmers in the southern provinces of Laos are summarised below and in Table 7. Note that there is overlap between the outcomes of the ACCA project and the ACCA-SRA project LWR-2012-110.

1. *PAFO dissemination in Savannakhet*

The Provincial Agriculture and Forestry Office (PAFO) is a strategy and implementation unit for rural production and development. PAFO reports to and is financially supported by its Provincial Governor, and is bound by national policies and directives set by the Ministry of Agriculture and Forestry.

In turn, District Agriculture and Forestry Offices (DAFO) report to their District Governor and are responsible for implementation of production and development initiatives and engagement with district communities.

PAFO Savannakhet collaborators (along with DAFO and NAFRI colleagues) were integral to ACCA's farmer field trials and demonstrations of the direct seeder in the two study districts of Champhone and Outhoumphone.

Once aware of interest from other villages and districts in Savannakhet, PAFO established further demonstration plots and Farmer Field Schools (with provincial and district extension centres), additional on-farm testing and facilitated access for farmers to direct seeding machinery.

In the 2013 and 2014 wet seasons, over 100ha (0.06% of the area available for paddy production) of rice was machine seeded in Savannakhet, using only the three machines available to PAFO staff. In the 2015 wet season, this area expanded to 600ha (0.36% of available paddy land, largely in Champhone and surrounding districts).

The provincial administration of Savannakhet is planning the purchase of 1000 direct seeders to be distributed to farmers in Savannakhet over the next five years. Each machine can service five to ten hectares, so the area that could be potentially direct seeded in that time period is between 5000 to 10,000 hectares (3-6% of available land, or 4000-8000 households).

In addition, a range of Lao language communication material was developed by PAFO Savannakhet and NAFRI to support dissemination of direct seeder technology and benefits in the province and to other rainfed rice producing southern provinces. These include brochures and posters and a proposal to produce a Lao language video has just been approved by ACIAR. A technical report on direct seeded rice (refer to Volume 3 of the ACCA Final Report) produced by the ACCA teams supports policy, dissemination and engagement with relevant stakeholders and prospective partners.

2. *NAFRI training*

In addition to operational links to the national extension services (Department of Agricultural Education and Cooperatives; formerly National Agriculture and Forestry Extension Services), NAFRI has a remit to coordinate training at national, provincial and district levels, to research and extension staff who then provide extension services to farmers and rural communities.

Training focuses on Good Agricultural Practices (GAP), incorporating results of research and trials from projects in which NAFRI is involved. ACCA principles for direct seeding (including land preparation, crop establishment, topography issues and weed management) and use of climate forecast information are now included in standard training workshops and materials.

In addition, DAEC has included dry seeded rice production as part of their provincial level capacity building package (in addition to GAP, soil health, mulching and post-harvest issues). There is an anecdotal indication that interest by farming communities in DAEC training initiatives has increased since the start of the project.

3. *SNV Climate Smart Agriculture initiative in Khammouane*

The objective of SNV's Climate Smart Agriculture program is to increase the income and productivity of farmers while reducing greenhouse gas emissions, using location relevant technologies and practices. In Laos, CSA initiatives are being trialled in SNV’s rice production value chain project in Khammouane Province.

ACCA’s collaboration with SNV began in 2013, with an interest in incorporating dry direct seeded rice into the Khammouane initiative. This evolved into a training package of direct seeding (led by PAFO Savannakhet and NAFRI), Good Agricultural Practices (led by NAFRI) and understanding climate (led by NAFRI and CSIRO). This last component comprised monitoring rainfall, comparing current season to historical seasons using a rainfall visualiser and using agro-advisories and climate forecasting – much of which has been successfully trialled in the ACCA project in India.

A training pilot was held in Xaibangfai District in May 2015, with an aim to hold workshops in at least 10 villages by the end of 2015. Attendance targets are around 50 farmers per workshop, which will result in around 500 farmer champions in SNV’s focus districts.

4. *IFAD training and extension material through SNRMPEP*

The Sustainable Natural Resource Management and Productivity Enhancement Project (SNRMPEP) aims to support the government's efforts to maximise agricultural productivity and efficiency in natural resource management. The project is funded by ADB and administered by IFAD. Its initial target for 2015 was to directly benefit 11,250 farming households constrained by poor market access, insecure land tenure and low productivity.

A key component of the project is to build capacity to manage natural resource-based development and to promote agricultural productivity in the southern part of the country. To achieve this, agency staff at the national, provincial, district and village level will receive and have received capacity enhancing support.

ACCA's interaction with SNRMPEP began in 2013. Technical information from ACCA and the ACCA-SRA's dry direct seeding research in Savannakhet has been incorporated into an extensive SNRMPEP training manual, *Direct Seeding Rice*. One thousand copies will be printed in late 2015 and will be distributed to research, extension and academic staff from PAFO, DAFO and universities in the five southern provinces.

SNRMPEP have also produced a Lao-language extension pamphlet on DSR that incorporates significant ACCA information. Three thousand pamphlets will be printed and distributed to farmers and extension officers in the 2015 wet season, and 2000 in the 2016 wet season.

Table 7. Summary of current and potential dissemination of ACCA and ACCA-SRA practices in the southern provinces of Laos.

Disseminating group	Current reach	Potential reach (3-5 years)
NAFRI	Six workshops in the course of the project, with 40 farmers in each = 240 farmer champions across 6 villages in study districts	Training plans largely dependent on external funding and government policy needs
PAFO	In 2013/14 over 100 ha in Savannakhet (0.06% of land available for paddy) were direct seeded as a result of ACCA activity. In 2015 600 ha were direct seeded (0.36% available land).	5000-10,000ha (4000-8000 households) over 5 years if Savannakhet administration purchases 1000 seeders (and equitable access can be achieved).
SNV	10 training workshops x 50 farmer champions = 500 farmer champions; Khammouane province	Project funding finishes end of 2015. Future scaling dependent on external funding.
IFAD - SNRMPEP	3000 DSR brochures distributed to farmers and extension in 5 provinces; 1000 training manuals distributed to research and extension officers in 5 provinces	2000 DSR brochures to be distributed in 2016

Note that these are estimates of possible exposure to ACCA components, not estimates of adoption. Engagement is supported by both ACCA and ACCA-SRA activities.

India

Significant mechanisms for dissemination of ACCA information and practices to Indian farmers are summarised below and in **Table 8**. Note that some overlap exists.

1. *Dissemination through Climate Information Centres*

The CLICs are a village level information hub for farmers. They were first populated with ACCA and PJTSAU outputs and evolved into an online and offline repository of information (with visuals, videos, narrations and animations) on agriculture and climate-related topics. They are managed by trained facilitators who support equitable access for farmers and seek to make information available to everyone within the Gram Panchayat (geographical village boundary).

Three CLICs were launched by the project in 2013 – one in each study village of Bairanpally, Nemmani and Gorita. The content, delivery and scope were evaluated and refined by the project in late 2013. At the end of the project, 33 CLICs had been established; three original CLICs, 18 CLICs in villages associated with WASSAN's Watershed Program and 12 CLICs through Rashtriya Krishi Vikas Yojana (RKVY), the Federal and State funded National Agriculture Development Scheme to increase growth in the agricultural sector.

The Indian project team estimate that around 8000 farmers now have access to ACCA results and practices across the 33 CLICs villages. Results of a second evaluation are currently being finalised.

Currently, project teams are focussed on maintaining the current suite of information centres beyond the end of the project, rather than on significantly increasing the number of CLICs. The longevity of the CLICs is largely dependent on securing ongoing salary for the CLIC operator, who is critical in facilitating access to information and enhancing farmer understanding and decision making. Progress thus far includes:

- Funding for continuing the WASSAN village CLICs is currently under negotiation with the Departments of Rural Development and Panchayati Raj.
- Six of the WASSAN CLICs have been linked to an Integrated Business Service Centre model, being established by the District Collector of Mahbubnagar and are likely to continue.
- RKVY CLICs are funded to the end of 2016, after which funds will be sought from the village farmer groups. PJTSAU will continue to provide technical support.
- In Warangal district, a Farmer Producer Organisation in interested in funding and running the Bairanpally CLIC, with support from WASSAN.
- Another CLIC has recently been sponsored by a local area member of parliament, with concomitant federal funding for 5 years.
- Interest has been expressed by NABARD in outscaling CLICs beyond the project. A number of funding models have been discussed, including incorporation in NABARD's infrastructure development portfolio

2. *Dissemination through media and community engagement*

In addition to delivering agricultural information through CLICs, ACCA practices and approach (eg sowing rules, strategic irrigation approach, rainfall monitoring and comparison) were incorporated into existing PJTSAU and new dissemination mechanisms. These include:

- PJTSAU uses local television and radio stations to broadcast its agro-advisories once or twice a week during the growing season. Theoretically, this gives 5.5 million farming households access to ACCA information.
- 2500 farmers currently receive PJTSAU's agro-advisories by SMS and/or email. There are plans to develop MMS (audio and video) delivery of pest and disease information to farmers with smart phones.
- Telegu language posters containing ACCA recommendations have been created and delivered by WASSAN to all 8700 villages in Telangana.
- Three WASSAN watershed villages trialled a connection with local schools (500 students each) to deliver ACCA and agro-advisory messages at school assemblies to create awareness in students' families.
- A travelling street theatre show developed around ACCA's strategic farming options was performed in more than 50 villages.
- PJTSAU's local exhibition exposed around 50,000 people to the agro-advisory and ACCA approaches.
- Video shows based on agro-advisories were organised in 12 villages, with around 100 farmers attending each show.

It is expected that at least the PJTSAU mechanisms will continue to be used after the close of the project.

3. Training farmers and agricultural officers

Training packages were delivered throughout the project, particularly in the later years. Some training was project specific and some formed part of broader training initiatives in Telangana. ACCA practices that focus on monitoring weather and tailoring farm management practices accordingly were central to this training.

Significant training outcomes delivered by the PJTSAU team include: 1600 district level agricultural officers; 120 farmers in RKVY project villages; 150 farmers aged 18-35 years, as part of the Young Progressive Farmers program; and 60 farmers from the State Farmers Federation.

As Telangana State is still establishing its administrative and investment plans, it is difficult to predict whether any of these training channels will continue beyond the project, but their success in engaging farmers and agricultural officers makes this likely.

The PJTSAU team also conducted training programs for university staff working in agriculture. So far, there have been 12 training programs with around 25 staff in each. In addition, there are plans to incorporate the CLICs approach into the Agriculture Diploma (a two year course after Year 10 of secondary school) of 20-25 Polytechnic Colleges, which will reach around 1200 students each year.

Table 8. Summary of current and potential dissemination of ACCA practices in Telangana State, India.

Disseminating group	Current reach	Potential reach (3-5 years)
CLICs	CLICs established in 33 villages across Telangana; Indian project team estimate around 8000 farmers now have access to ACCA information.	12 RKVY CLICs have State funds to 2016. 8 CLICs have other funding secured. Funding for 12 WASSAN CLICs under negotiation with DRD, DPR and NABARD.
Media and community engagement	2500 farmers receive weekly SMS Posters distributed to 8700 villages 1200 farmers view video shows 1500 school children informed Possible weekly media exposure of 5.5million households	Likely that SMS, local media and pamphlet mechanisms will continue after project; continuity of other mechanisms unclear.
Training farmers and agric officers	1600 district level agric officers 120 RKVY farmers 150 Young Progressive Farmers 60 Farmers Federation farmers 300 PJTSAU agric researchers	Difficult to predict which training channels will continue beyond the project. Plans to include CLICs in Agriculture Diploma of 20-25 Polytechnic Colleges, reaching 1200 students annually.

Note that these are estimates of possible exposure to ACCA components, not estimates of adoption.

Note on Bangladesh

As noted earlier, the primary focus for ACCA work in Bangladesh was model development and capacity building, which was achieved with ACCA and the SAARC-Australia project.

As project-related engagement with farming communities in the target regions of Khulna ceased in 2012, no explicit dissemination strategy for project practices was initiated. However, some scaling of ACCA practices has occurred (or is projected to occur) by connections with other projects and initiatives working in the same or similar districts. These include:

- The Bangladesh component of CSISA, through connections with IRRI and key staff who were formerly in the ACCA project
- The farm scale components of the CPWF in southwest Bangladesh, through IRRI researchers and the CGIAR Water, Land and Ecosystems program
- Co-investment with IRRI's SARCCAB project for on-farm trials near Khulna using ACCA adaptation practice options
- The new ACIAR project on cropping systems intensification in salt-affected areas of coastal southern Bangladesh (LWR-2014-073)

f. Policy and program influence

This section refers to progress towards embedding project principles into policy frameworks and program planning.

Cambodia

At the close of the project, ACCA can report influencing a range of policy and design initiatives in Cambodia. Significant amongst these are:

1. *Informing Cambodian climate policy*

In final interviews, senior government officials in MAFF confirmed that ACCA contributed to the clarification of climate change issues in Cambodia and provided a pathway for action on climate adaptation.

ACCA influence has been noted on the National Action Plan on Climate Adaptation (2013-2023), the sector document on Climate Adaptation for Agriculture, Forestry and Fisheries (2013-18) and the sub-sector agriculture policy document that sits below this document have all been influenced by the ACCA approach to climate change understanding and mitigation.

In particular, Dr Mak Soeun, the Deputy Director General of MAFF was unequivocal when stating that 'until ACCA involvement in Cambodian climate change research, it had been difficult to develop a clear understanding of the topic. The combination of ACCA training and communication, biophysical research, systems analysis and potential systems solutions had provided a way forward, allowing the government to develop appropriate responses.'

2. *Mainstreaming research results into extension practice*

A technical report on response farming developed by the ACCA project team was peer reviewed and approved by a technical panel of Cambodian sector experts in July 2014. It was endorsed by GDA management and then used to support the climate policy initiatives previously described by providing a framework for extension and training in response to climate variability and change.

The response farming approach and extension materials are now used in mainstream DAE and IDE extension activities, and are likely to be widespread in PADEE and ASPIRE initiatives around the country.

3. *Informing the design of the ASPIRE program*

An IDE-SNV consultancy used ACCA research and principles as a case study on climate resilient agriculture. This report was used in IFAD's annual strategic planning process as a Cambodia-specific opportunity, which culminated in the development of the ASPIRE program.

Synergies between ACCA research outputs and the proposed climate adaptation research and training outlined in the 2014 ASPIRE project document were highlighted in a commissioned report on the development of ICT tools using ACCA research outcomes (refer to Volume 3 of the ACCA Final Report).

MAFF officials indicate that Sections 2 (Improving Extension Quality and Knowledge Management), 4 (Infrastructure Supporting Climate Resilient Agriculture) and particularly 3.2 (Innovations for climate resilient agriculture[2]) and 4 of the ASPIRE project document had been explicitly influenced by ACCA research, while ASPIRE project consultants suggest that ACCA type research was influential in project design.

Laos

As a result of ACCA and ACCA-SRA activities, a number of significant policy or program influences can be noted.

1. *Expanding NAFRI response strategy for climate adaptation*

Among NAFRI's strategic aims are the use of integrated research for development to improve efficiency in land use, including agricultural production, and provision of advice to policy makers on the impacts and opportunities for rapid rural change.

Recent changes to NAFRI's organisational structure support this expansion of focus from commodity based research to policy feedback, information provision and methodological development.

ACCA has supported NAFRI's strategic aims through: a) provision of tools and approaches to monitor and advise according to forecasted climate events; b) provision of policy-specific information on changing circumstances of rural communities in rainfed southern provinces; and c) testing and disseminating promising labour-saving technologies and practices for climate resilient rice production.

This knowledge has been used in a variety of fora, including national level climate change working groups, briefings for the Department of Agriculture and Provincial and District Governors and in new international projects on climate resilience.

2. *Changing content and delivery of climate-related extension*

Results from direct seeded rice research have been included in Good Agricultural Practice training activities undertaken by NAFRI, DAEC and PAFO. Importantly, this technological training has been delivered with overarching practical training in monitoring and understanding changes in climate.

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[2] **ASPIRE sub-component 3.2: Innovations for Climate Resilient Agriculture** will support demonstration and testing of promising innovations under smallholder farm conditions. Suitable technologies may include, but will not necessarily be limited to, improved on-farm water management, adjustments to the cropping calendar particularly including introduction of early wet season rice or other crops, introduction of climate resilient varieties, introduction of new crops with a potential to improve climate resilience.

Climate training includes monitoring daily rainfall, comparing current season to historical seasons using a rainfall visualiser and understanding and using agro-advisories and climate forecasting – a training package that has been successfully trialled in the ACCA project in India. This approach is currently used in the ACCA collaboration with SNV's Climate Smart Agriculture initiative and in two ACCA villages in our study districts.

In addition, household categorisation undertaken by NUOL and CSIRO as part of the project has recently been used by DAEC and NAFRI to better match extension needs to extension content.

3. *Responding to policy interest in direct seeding*

The Laos-Australia Development Learning Facility (LADLF), funded by DFAT and administered by Adam Smith International, was intended as an innovative approach to link research and policy, by generating information to support decision making by key policy stakeholders across a range of thematic areas, including climate change and agriculture.

In late 2014, a proposal for understanding the benefits and drivers for adopting dry direct seeding for rice production was drafted by NAFRI, as the lead Lao research agency. A major stakeholder meeting was convened in November 2014, generating significant interest in the initiative by policy makers and potential donors.

Although a reduction in Australian ODA closed this part of the Facility in early 2015, the exercise demonstrated interest at a policy level in ACCA's research outputs. Subsequently a NAFRI-initiated workshop is planned for late 2015 to garner support and funding for future expansion of the work.

India

Despite major political upheaval in the last two years of the project, ACCA can report influence in several important areas:

1. *Mainstreaming CLICs*

The adaptive and integrated approach taken by the project has resulted in the CLIC's reputation as a replicable and locally beneficial agricultural development entity. In 2013, there were three pilot CLICs; by mid 2015, there were 30 more active CLICs. Although the software, hardware, content and training have now been tested and distilled, the system allows for adjustments to be made to meet local information and delivery needs.

Despite alignment with departmental initiatives and opportunities to expand the CLICs network, the project teams have not yet found an ongoing institutional home for CLICs in state departments such as particularly Departments of Rural Development and Panchayati Raj. Dialogue and political support is ongoing.

Consequently, the Indian teams have refocussed efforts on embedding the CLICs concept in non-governmental initiatives and have also been successful in attracting funding from diverse sources who see their value – from farmer organisations to the national agricultural bank (see the previous section on dissemination of practices for details).

In addition, discussions are underway to incorporate the CLICs concept into the Climate Change, Agriculture and Food Security program's Climate Smart Villages initiative and the MS Swaminathan Research Foundation's Village Knowledge Centres initiative.

2. *IMD support for agro-advisories*

The ACCA project has directly supported IMD's mandate for the preparation and delivery of short term weather forecasts (3-5 days) nationally, and the production and dissemination of agro-met advisories at district level, in collaboration with relevant state agencies (eg PJTSAU).

ACCA has provided a trial of agro-advisories that marry IMD forecasts with management recommendations that encompass variation in farm enterprise across multiple districts. In addition, new methods of delivery (eg via SMS, CLICs and email) and presentation (eg pictorial rather than textual, to account for literacy) were tested based on user evaluation.

IMD have endorsed ACCA's integrated approach and adaptive improvement and is supportive of IMD information and forecasts being disseminated through agro-advisories and the CLICs network. PJTSAU is working with IMD on documentation, development of training material and options for replication beyond Telangana.

Note on Bangladesh

The nature of engagement with decision makers in policy and regional programs changed significantly during the project. After 2012, discussions shifted from climate variability and community adaptation to building institutional capability in farm systems modelling. ACCA's target stakeholders changed from departments and programs with carriage for climate change and adaptation to those charged with research capacity and planning.

Despite these disruptions, ACCA can report influence in a number of agencies.

Briefings with the Comprehensive Disaster Management Program (CDMP) yielded early policy influence through discussions on how ACCA outputs could underpin the CDMP's work in climate adaptation. The recognised entry point was upazila level preparation of Disaster Management Plans, that explicitly address disaster risk reduction, preparedness, recovery and adaptation. CDMP's recommendation was for collaboration on a pilot study, formalised by a Memorandum of Understanding with IRRI.

One of the most significant legacies of ACCA and SAARC Australia is the enhanced capacity in systems analysis and modelling in Bangladesh (and other SAARC country) agricultural research institutes. There is now a critical mass of active modellers, working across institutional boundaries, training and mentoring new researchers.

Engagement through direct and sustained interactions and awareness workshops has led to enhanced institutional support for modelling from NARS chiefs and the aspiration of the BARC Chairman to establish greater modelling capacity within BARI and BRRI.

Another projected policy outcome is the intent that modelling will be increasingly be used to inform policy making – particularly around trade-offs and evaluation of options to adapt to changes in climate - in the agricultural research institutes of Bangladesh. This will lead to more balanced decision making and targeted use of research funds.

6. Concluding comments

ACCA was a complex and ambitious research for development project. It succeeded in working at multiple scales, with multiple partners, diverse social and political contexts, with five country teams with different backgrounds, strengths and capacities.

Its research outcomes emanate from diverse fields that include systems analysis, modelling, social science, climate analysis and participatory action research. These were achieved through sound planning and experimental design, investing in capacity and consistent analysis, and have contributed to ongoing science and development discourse.

ACCA also has strong indicators for community impact, policy influence and sustainability, particularly for its size and scope. This suggests that the significant investment in connecting with stakeholders has been productive, in terms of relevance, utility and benefit at multiple scales.

Of particular interest are the extent of dissemination of project practices to the farming community and the indicators of influence in policy and program initiatives. For the project's size and scope, these are significant in all countries but Bangladesh (for reasons discussed in the body of the report), and have followed different pathways and emphases in each.

At least part of this success can be attributed to the principles established at the start of the project – that engagement is strategic, resourced and incorporated into the project design; that the dynamic nature of the research is mirrored in stakeholder activities; and that engagement is participatory, tailored and structured towards stakeholder interest and perceived (and future) need.

From an operational perspective, those involved in engagement have reflected positively on the approach and process for external stakeholders, the quality and inclusivity of internal communication and the efficient communication and delivery of outcomes.

In particular, the project teams highlighted the importance of: explicitly incorporating stakeholder engagement in project design; early planning for scaling beneficial results; prioritising stakeholder activities and adjusting these to the research process; investment in team building and integration; partnering with like-minded NGOs; planning and structuring interactions with decision makers, from farmers to policy.

List of appendices

Appendix A Example of stakeholder engagement matrix: India 2011

	Contractual, reporting			Support, access, networks, relevance			Promotion, general awareness			Policy influence			Adoption			Capacity building, cohesion			Future funding opportunities			Science exchange		
	Ann report	Trip reports	ACIAR pubs	Institute briefings	Institute updates	Institute pubs	Media	Website	Fact sheet	Govt briefings	Policy briefs	Contribute to plan	Demonstrations	Discussions	TBA tools	Training	Workshops	Protocols, guides	Visits	Briefings	Forums, work gps	Publications	Conferences	Seminars
Funders	■	■	■	▒																				
Project team																■	■	■				■	■	■
Partner institutes	▒			■	■	▒																▒	▒	▒
Farming community							▒						■	■	■	■								
NGO community				▒			▒	▒	▒				■	▒	▒			■				▒	▒	▒
Research community				▒	▒	▒																■	■	■
Local govt agencies				■	■					▒	▒	▒												
State govt agencies				■	■					■	■	▒												
National govt agencies				■	■					■	■	▒												
General public							■	■	■															

NOTE: Dark grey = most effective ways to engage; light grey = secondary vehicles for engagement

Appendix B Example of general stakeholder engagement plan: Laos 2011

Stakeholder group	Reasons to engage	Ways to engage	Timing	Coordinator
Funders				
ACIAR Australia ACIAR Cambodia, Thailand Burma and Laos Office	Contractual, reporting General awareness Support, access to networks	• Annual report • Trip reports • Briefings • ACIAR pubs	• May • Each trip • Quarterly • As requested	Christian, Clemens, Monica Thavone, Vanthong
Supporting material	Reporting templates; project website; Lao translation on website			
Partner institutes				
CSIRO NAFRI NAFES NUoL DMH	Support for project activities Access to skills and data Access to networks Reporting	• Personal briefings • Written updates • Attendance at meetings • Invitation to field visits	• Twice a year • Twice a year • Annual meetings in Feb/Mar	Christian, Vanthong, Thavone, Alison Laos & Australian teams
Supporting material	Project flyer (English and Lao); project website; template for updates; connect to NAFRI website			
Farming community				
Participating farmers Non-participating farmers	Adoption of research Capacity building General awareness	• Demonstrations • Village discussions • Farmer training • General media • Agro-advisories • Field days	To be determined in years 2 and 3	Monica, Alison, Clemens John Schiller Thavone, Sipaseuth Khammone, Sysavanh Mixay, Pouthone
Supporting material	Extension materials; flyers; posters, training manuals			

Research community				
Research community in general South Laos Project team IRRI CIAT IWMI NAFRI Climate Change Project (GEF)	Science exchange Access to networks, data Relevance of research	• Publications • Conferences • Seminars • Personal briefings • Institute updates • Workshops	• Ongoing	Whole team for general engagement For specific groups, Christian, Thavone, Silinthone, Pheng, Alison
Supporting material	Briefing templates; project flyer			
District/ provincial government agencies				
Head PAFO Savannakhet District Governor	Support for project activities Relevance of research Adoption of outcomes Access to data and skills	• Personal briefings • Briefing notes/ updates • Training • Invitation to annual meeting • Invitation to field days	Aim for once a year to start, then more frequently	Thavone, Vanthong; Khammone Alison, Christian
Supporting material	Project flyer (Lao); generic project powerpoint			
National government agencies				
Dept Agriculture (MAF) Dept Planning (MAF) Dept Irrigation (MAF) Min Agriculture & Forestry Dept Environment – Office of Climate Change (WREA)	Support for project activities Incorporate into policy Relevance of research Access to data and skills	• Personal briefings • Briefing notes/ updates • Reports • Contribution to plans	Aim for every six months	Christian, Vanthong, Thavone, Silinthone, Alison
Supporting material	Project flyer; generic project powerpoint (context, broad objectives of project and expected benefits); briefing note template			

Regional bodies, donors				
MRC AusAID/DFAT UNDP ADB SDC	Access to networks Support for project activities Incorporate into policy Possible future funding	• Personal briefings • Briefing notes, updates • Contribution to plans	Aim for every six months	Christian, Thavone, Vanthong, Alison
Supporting material	Project flyer; briefing note template			
NGO community				
CARE	Access to networks Relevance of research Adoption of outcomes Support for project activities	• Extension materials • Village discussions • Demonstrations • Briefings	TBA	Alison, Christian, Thavone
Supporting material	TBA (extension materials; flyers; displays, other communication tools)			
Project team				
Cambodian and Australian teams	Team cohesion Science exchange Capacity building	• Meetings • Two monthly updates • Training • Publications, reports	• As possible • Every two months • As funding allows • TBA	All
Supporting material	Sharepoint; two-monthly update template; Skype connection			
General public				
General public – Laos General public - Australia	• Promotion of project • General awareness • Adoption of practices	• General media (radio, articles, TV) • Website • Social media • MAF agricultural media	Not fixed	Monica, Christian, Alison Thavone, Vanthong, Khammone
Supporting material	Website; flyer; media talking points			

Appendix C Project team reflections on stakeholder process

As detailed in the main body of this report, a strategic and structured approach to engagement was employed in the ACCA project. This approach considered not only potential stakeholders, but reasons and means for engagement with these stakeholders, as well as anticipated behaviours as a result of engagement. It allowed the project team to prioritise engagement activities, supported team members with consistent and tailored information and provided a framework for critical reflection and reporting.

Feedback and reflections on the stakeholder engagement process was collected during annual meetings and at the end of the project, with the aim of distilling insights and identifying possible recommendations for future initiatives.

In general, project partners from all countries indicated satisfaction with the approach to engaging with external stakeholders, the quality and inclusivity of internal communication and the efficient communication and delivery of outcomes. Four recurring themes from team discussions are summarised below.

1. *Planning and design*

All teams agree that the ACCA project design was outstanding and that the intent for joint ownership of planning and implementation of project activities was largely achieved.

It was suggested that the project was very ambitious in terms of scope and complexity, and that the project design and integration framework allowed teams and individuals to understand how their work (and the work of others) contributed to larger objectives.

It was also suggested that this clarity in design made communication of the project and its components easy to communicate to others, and to articulate its complexity without over simplifying context or content.

Several teams proposed that their experience with ACCA's integration approach enhanced their capacity to work with stakeholders and increased their confidence to lead integration projects. Others indicated that skills gained in communicating science to stakeholders have been used in planning and communication for new projects.

Articulating and embedding stakeholder engagement objectives in the project workplan was perceived as a beneficial approach, as was planning for outscaling and upscaling from the start of the project, rather than at the conclusion of research activities.

There were some retrospective recommendations made about the stakeholder lists. However, there was overall agreement with the breadth and emphasis of country stakeholders, even if methods and frequency of interactions could have been improved.

2. *Internal communication*

At the start of the project, very few of the project teams had worked together previously and it was critical to build relationships and connections between both country teams (eg India teams, Lao teams) and discipline teams (eg social science teams, modelling teams across the countries).

The integration framework, explicit investment in cohesion and consistent communication supported this process. At the end of the project, project teams expressed changed perceptions in the importance of collaboration, inclusivity and complementarity.

It was believed that the scoping study, incorporating input from all countries, helped to identify common ground and synergies between teams, but that significant effort was needed to build trust and links.

Project teams felt that they would have benefited from more opportunities to work together (eg annual reviews to bring teams together from across countries). Unfortunately, the project was not adequately resourced to do this.

3. Partnering with NGOs

Partnering with NGOs was seen as a very positive aspect of the project, from managing the on farm activities in Cambodia and institutional networks in Bangladesh, to innovative approaches to agricultural extension in India.

It was seen as important to identify NGO partners with similar aspirations – again, ACCA's scoping study informed these decisions.

With the right partnering, it was felt that agriculturally focused NGOs added context to academic research outputs, and that NGOs benefited from engaging with ACCA scientists (particularly modellers) and felt that they were in a better position to engage with other science and education institutes in the future.

Adoption and dissemination of practices by NGOs was seen as a positive indication of the relevance of research outputs and of the potential influence of the project.

In addition, it was suggested that to engage the private sector or business-oriented NGOs, there must be scope for enterprise development. This is likely to be related to profit (eg connection with famers who see agriculture as a business), supporting the group to further develop its business and supporting farmers to improve decision-making and profitability.

4. Connecting with policy stakeholders

There were many insights expressed by the project teams on policy influence.

It was proposed by one team that there is little opportunity to influence existing policy structures, with limited funding, a short timeframe and little appetite for science in policy development. It was felt that ACCA could claim significant achievements for its profile, climate change mandate and funding.

There was consensus that while communicating with national agencies was often challenging, project teams had gained valuable experience in making complex concepts accessible to policy makers and in using research results as examples to influence and inform.

Operationally, there is a tension when engaging with policy stakeholders. On one hand, it is preferable for stakeholders to have a single contact point within (and beyond) the project; on the other hand, there is a tendency for over reliance on a few key people. Much of ACCA's policy influence can be attributed to the project leader (and his country counterparts). Initially, it was difficult for others to represent the complexity of the project; later, working relationships had already been established.

In future projects, perhaps a shared approach is an alternative. In India, engagement with policy makers was divided according to networks and relationships; PJSTAU primarily engaged with the Department of Agriculture and IMD, while WASSAN and LNRMI interacted with the Department of Rural Development.

Appendix D Summary of stakeholder engagement activities for Cambodia from 2010 to 2015.

2010

Date	Stakeholder group	Stakeholder	Topic	Trip report reference
April 2010	Partners	DAE, CARDI, IDE, CSIRO	Project planning	Roth; Laos & Cambodia, April 2010
	Regional org	CAVAC	Possible links between CAVAC and ACCA	
	National org	Infinity Insurance	Possible ACCA climate risk research input into crop insurance initiative	
	National agency	RUA	Possible informal links eg student placement, invited lectures	
May 2010	Partners	DAE, CARDI, IDE, CSIRO	Project planning; inception meeting	Roth, Van & Dalgliesh; Cambodia, May 2010
	Provincial govt	PDA SR	Awareness; verify relevance	
	Regional org	UNDP	Potential links with existing and planned programs	
	Regional org	ADB	Awareness and possible future links	
July 2010	Partners	IDE, CARDI, PDA SR	Training in soil, agronomy and systems data collection and management	Dalgliesh; Cambodia, July 2010
	Partners	IDE, CARDI, DAE, CSIRO	Project review and planning	
	Provincial govt	PDA SR	Relevance and alignment	
	Regional org	Oxfam	Awareness of project approach and synergies	
	Farmers	Koul, Kbal Damrey farmers	Project approach; farm systems understanding	
Aug 2010	Regional org	ADB consultant	Possible inclusion of ACCA as example in ADB Environment Program; scaling possibilities discussed	Brown & Pitkin; Cambodia, August 2010
	Partners	CARDI socio-economic team	Training for adaptive capacity workshops	
Aug 2010	Partners	DAE, IDE, CARDI, CSIRO	Project planning	Grunbuhel & Williams; Cambodia & Laos, August-September 2010
	Provincial govt	PDA SR	Update on progress; test relevance	
	Farmers	Kbal Damray, Koul farmers	Farm systems discussion	
Oct 2010	Partners	IDE, DAE, CARDI, CSIRO	Review, planning, analysis	Dalgliesh; Cambodia, October 2010
	Provincial govt	PDA SR	Update on progress and plans	

	Farmers	Kbal Damray, Koul , Chea Ressey farmers	Farmer interviews – farm systems	
Nov 2010	Partners	CARDI, IDE, DAE, CSIRO	Adaptive capacity workshops; review, planning and analysis	Pitkin; Cambodia, Oct-Nov 2010
	Provincial govt	PDA SR	Update on preliminary results	
	Farmers	Kbal Damrey, Koul farmers	Adaptive capacity workshops and interviews	

2011

Date	Stakeholder group	Stakeholder	Topic	Trip report reference
Mar 2011	Partners	DAE, CARDI, IDE, CSIRO	Annual project review and planning	Van, Dalgliesh & Grunbuhel; Cambodia, March 2011
	Research community	ACIAR Rice Establishment team	Potential synergies, overlaps and coordination between projects	
	Farmers	Kbal Damray, Koul , Chea Ressey farmers	Review progress and plan for wet season	
	Partner institutes	DG GDA; GDA Dept of Rice Crops; GDA Dept Agricultural Land Resources Management	Awareness; relevance check; institutional support	
	Regional bodies	Oxfam America; AusAID	Awareness; potential synergies between programs; coordination of activities	
	Provincial govt	PDA SR	Report on project progress; relevance check; planning for future activities	
	National govt	Climate Change Alliance, Min Env	Possible contribution to national climate change policy (under development)	
May 2011	Partners	IDE, CARDI, DAE, PDA, CSIRO	Review, planning and analysis	Dalgliesh, Poulton; Cambodia, May-June 2011
	Partners	CARDI	Review laboratory processes; develop field procedures; plan for modelling capability	
	National org	RUA	Possible collaboration opportunities, especially student mentoring	
	Farmers	Kbal Damray, Koul , Chea Ressey farmers	Planning meetings for collaborative on-farm research	

	Provincial govt	PDA SR	Report on project progress; relevance check; planning for future activities	
	Funder	ACIAR Country Manager	Update on project progress	
July 2011	Regional bodies	MRC	Meeting of CCAI's CC Adaptation Demonstration Projects to provide platform to exchange practitioner experiences	Grunbuhel; Vietnam & Cambodia, July 2011
	Partners	DAE, CSIRO	Review and planning for social data activities	
Sep 2011	Farmers	Kbal Damray, Koul , Chea Ressey farmers	Review and planning meetings for collaborative on-farm research	Dalgliesh; Cambodia, September 2011
	Partners	IDE, DAE, CARDI, CSIRO	Review, planning and analysis	
Nov 2011	Partners	CARDI, DAE, NUOL (Laos), CSIRO	Meeting to discuss recently completed data collection for adaptive capacity and household typology and plan for next steps	Williams, Brown & Grunbuhel; Cambodia, November 2011
Nov 2011	Provincial govt	PDA-SR	Update and feedback from PDA Director	Poulton; Cambodia, November-December 2012
	Farmers	Koul, Kbal Damrey and Chas Ressey farmers	Present trial results; farmer feedback; review and planning with collaborating farmers	
	Partners	IDE, DAE, CARDI, CSIRO	Review, planning and analysis	

2012

Date	Stakeholder group	Stakeholder	Topic	Trip report reference
Jan 2012	Farmers	Kbal Damray, Koul , Chea Ressey farmers	Meetings to provide feedback to farmers (and other stakeholders) on research outcomes and for farmers to provide feedback on research results and plans	Dalgliesh; Cambodia, January 2012
	Provincial govt	PDA	Update and feedback from PDA Director	
	Partners	IDE, DAE, PDA, CARDI, CSIRO	Review, planning and analysis; prepare for APM and stakeholder briefing	
	Partners	CARDI	Review experiment outcomes to improve the capacity to model rice based farming systems	

Apr 2012	Partners	IDE, DAE, PDA, CARDI, CSIRO	Annual project review and planning	Roth, Dalgliesh & Grunbuhel; Cambodia, April-May 2012
	Farmers	Koul, Kbal Damrey, Chea Ressey farmers	Farmer meetings to present household typologies and relevant household adaptations strategies and practices	
	Provincial govt	PDA-SR	Briefing to present results of 2012 wet season activities and household typologies and relevant household adaptations strategies and practices	
	Regional orgs	UNDP, ADB, AusAID, FAO, IFAD	Workshop to brief key stakeholders on progress and project approach to differentiate adaptation strategies according to household types	
	National agencies	GDA/MAFF, CCD/MEnv	Workshop to brief key stakeholders on progress and project approach to differentiate adaptation strategies according to household types	
Oct 2012	Farmers	Koul, Kbal Damrey and Chas Ressey farmers	Farmer meeting to discuss current on farm research and to plan for future activity	Dalgliesh; Cambodia, October 2012
	Provincial govt	PDA-SR	Brief PDA director of project progress and plans	
	Partners	IDE, DAE, PDA, CARDI, CSIRO	Review, planning and analysis; prepare for mid term review (MTR)	

2013

Date	Stakeholder group	Stakeholder	Topic	Trip report reference
Feb 2013	Partners	Representatives from partner institutes in all countries	Mid term review workshop to reflect and present 2.5 years research achievements and plan for remaining 1.5 years.	Roth, Laing, Williams, Gaydon & Hochman; Cambodia, February 2013
	Funder	ACIAR RPM & review team	Formal review process	
	Regional orgs	ADB, FAO, IFAD, UNDP, SNV, CAVAC	Brief organizations on progress and results of ACCA to date and explore potential pathways for ACCA to contribute to policy/ donor impact. PADEE (IFAD/UNDP funded; SNV implemented) is most likely opportunity	

	National govt	CCD/MEnv	Meeting to brief CCD on progress and results of ACCA to date and to explore potential pathways for ACCA to contribute to policy impact. Most likely opportunity is Cambodia Climate Change Alliance, managed by CCD.	
Mar 2013	Partners	IDE, DAE, CARDI, CSIRO	Review and planning meeting, particularly for policy and farmer engagement activities*	Roth; Cambodia & Bangladesh, March 2013
	Donor	IFAD	Further discussion about operationalising link to PADEE as key pathway to scale out ACCA results	
	National agency	RUA	Opportunities for future research collaboration under ACCA 2	
May 2013	Partners	IDE, CARDI, DAE, CSIRO	Design farmer engagement process; conduct pilot FGD	Roth & Dalgliesh; Cambodia, May 2013
	Provincial govt	PDA-SR	Interface between ACCA and PADEE at provincial level; ACCA contribution to farmer field schools, guidelines and training materials	
	Farmers	Kbal Damrey	Pilot FGD	
Oct 2013	Farmers	Koul, Kbal Damrey and Chas Ressey farmers plus farmers from two control villages	Key Informant Interviews around how farmers are incorporating project research into rice production	Dalgliesh & Poulton; Cambodia, October 2013
	Regional govt	Director PDA SR	Update of project findings; update of PDA activities	
	Partners	IDE, PDA, CARDI, DAE, CSIRO	Discussion of results of FGDs; identification of key informants according to household type; preparation for KII activities	
Nov 2013	National agencies, regional orgs	Oxfam, SNV, World Vision, GDA, UNDP, IFAD, RUA	Stakeholder workshop to provide update on ACCA results and implications for policy and program design	Roth; Cambodia & Laos, November 2013
	National agencies, regional orgs	DAE, SNV, IDE, GDA, IFAD, FAO	Present ACCA results and approach at PADEE extension workshop hosted by DAE and SNV; focus on mainstreaming climate adaptation into extension training	
	Regional org	FAO	Potential of ACCA to inform design of IFAD’s	

			ASPIRE initiative for ag innovation and extension	
	Regional org	SNV	Potential ongoing collaboration in future projects; immediate plans to convert ACCA results into extension content	

2014

Date	Stakeholder group	Stakeholder	Topic	Trip report reference
May 2014	Partners	DAE, CARDI, IDE, CSIRO	Planning for upcoming review	Roth; Cambodia & Laos, May 2014
	Partners; regional bodies; national orgs	DAE, CARDI, IDE, CSIRO, SNV, UNDP, Rice Crop Dept GDA, DALM GDA	Awareness of project results and recommendations; synergies and integration; opportunities for dissemination of results; plan for formal 'endorsement through technical review panel	
	ACIAR	ACIAR Rice Dialogue workshop	Forum for making research results more relevant to policy; knowledge sharing	
	National agency	RUA	Planning training seminars for post-graduate students and researchers	
	Regional org	UNDP	Update; planning joint workshop with UNDP to develop and test improved design principles for climate adaptation programs	
	National agency	DG GDA	support of the DG GDA to disseminate ACCA results through the PADEE program	
June 2014	Partners; regional bodies; national agency	Technical Review Panel, comprising, GDA, SNV, IDE, PDA	Endorsement of crop calendars and response farming concept; discussion of issues and opportunities around implementation and scaling	Van & Dalgliesh; Cambodia, June 2014
	National govt	GDA – Dir DAE, DRC	Briefing made to Directors of GDA Rice Crops and Agric Extension on behalf of Tech Panel	
	Regional org	SNV/PADEE	Opportunities for partnership in knowledge management and dissemination	
	Regional org	CAVAC	Potential areas of synergy between CAVAC program (existing and future) and areas of possible collaboration	

	Partners	IDE, CARDI, CSIRO	Preparation for final review and reporting	
Oct 2014	Regional org	CAVAC, DFAT	Opportunities to incorporate ACCA principles into design of next phase of CAVAC; synergies between ACCA and CAVAC approach to research and dissemination	Roth; Cambodia, October 2014
	Partners	DAE, CARDI, CSIRO	Update on project activities, particularly connections with PADEE and incorporation of technical information into extension and policy	

2015

Date	Stakeholder group	Stakeholder	Topic	Trip report reference
Feb 2015	Regional bodies;	DNV, Dept CC (MoE), ITC, Dept Public Health, DFAT, World Vision, GDA, CARDI, DAE, IDE, CSIRO	Stakeholder workshop to provide summary of key findings and potential to incorporate into existing and future initiatives	Roth & Williams; Cambodia, February 2015
	Partners	DAE, CARDI, IDE, CSIRO	Team meeting to discuss remaining project activities and reflect on existing and anticipated project impacts	
	Regional org	e-PADEE consultant	Scope feasibility of incorporating ACCA results into e-PADEE platform for use in extension	
	Regional org	IFAD	Discussion around strengthening existing informal links between ACCA and PADEE, particularly scaling through field schools and e-PADEE	
	Regional org	CAVAC	Update of ACCA findings; further discussion on links to CAVAC 2 (still in development)	
	Regional org	SNV	Discussion around strengthening existing informal links between ACCA and SNV; specific discussion around incorporating decision-tree information into extension training	
	Regional org	ADB	Potential to feed ACCA findings into new ADB-IFAD	

			agribusiness initiative	
	Regional org	UNDP	Update on ACCA outputs; possible connections to Resilient Livelihoods program.	
	National govt	Minister of Environment, National Council for Green Growth	Briefing to Minister on ACCA and other CSIRO climate adaptation initiatives	
July 2015	Partners	DAE, CARDI, IDE, CSIRO	Team meetings to collate project outcomes and impacts and capture final reflections and future directions	Dalgliesh; Cambodia, August 2015
	Regional org	Devatar, CamAg, IFAD	Discussion on possible future links and synergies with IFAD's ASPIRE program and Devatar's information sharing platform.	

Note: This information is taken from CSIRO Trip Reports only and so does not give a full account of engagement in each country.

Appendix E List of acronyms and commonly used abbreviations

ACCA	Adaptation to Climate Change in Asia (project acronym)
ACCA-SRA	Shorthand for Small Research Activity LWR-2012-110 (Laos)
ADB	Asian Development Bank
ANGRAU	Acharya NG Ranga Agriculture University, now PJTSAU (India)
ASPIRE	Agriculture Services Program for Innovation, Resilience & Extension (Cambodia)
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BRRI	Bangladesh Rice Research Institute
CARDI	Cambodian Agriculture and Rural Development Institute
CAVAC	Cambodia Agricultural Value Chain Program
CCAFS	CGIAR research program on Climate Change, Agriculture and Food Sustainability
CDMP	Comprehensive Disaster Management Program (Bangladesh)
CEW	PADEE's Community Extension Workers (Cambodia)
CIAT	International Center for Tropical Agriculture
CIP	Commune Investment Plan (Cambodia)
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement (French Agricultural R&D Institute)
CLIC	Climate Information Centres (India)
CRIDA	Central Research Institute for Dryland Agriculture (India)
CSA	Climate Smart Agriculture
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAFO	District Agriculture and Forestry Office (Laos)
CSISA	Cereal Systems Initiative for South Asia (Bangladesh)
DAE	Department of Agricultural Extension (Cambodia)
DAEC	Department of Agricultural Extension and Cooperatives, formerly NAFES (Laos)
DPR	Department of Panchayat Raj (India)
DRD	Department of Rural Development (India)
DSR	Direct Seeded Rice
FAO	Food and Agriculture Organisation
FBA	iDE's network of Farm Business Advisors (Cambodia)
FFS	Farmer Field School
GAP	Good Agricultural Practices
GDA	General Directorate of Agriculture (Cambodia)
ICAD	Irrigation Command Area Development (India)
ICAR	Indian Council for Agricultural Research
ICRISAT	International Crops Research Institute for the Semi-Arid Tropic
iDE	International Development Enterprises (Cambodia)
IFAD	International Fund for Agricultural Development
IITM	Indian Institute of Tropical Meteorology
IMD	Indian Meteorology Department
IRRI	International Rice Research Institute
IPCC	Intergovernmental Panel on Climate Change

IWMI	International Water Management Institute
LADLF	Lao Australia Development and Learning Facility
LNRMI	Livelihoods and Natural Resource Management Institute (India)
MAF	Ministry of Agriculture and Forestry (Laos)
MAFF	Ministry of Agriculture, Fisheries and Forestry (Cambodia)
MRC	Mekong River Commission
NABARD	National Bank for Agriculture and Rural Development (India)
NAFES	National Agriculture and Forestry Extension Service, later DAEC (Laos)
NAFRI	National Agriculture and Forestry Institute (Laos)
NCMWRF	National Centre for Medium Range Weather Forecasting (India)
NICRA	National Innovations on Climate Resilient Agriculture (India)
NRAA	National Rainfed Area Authority (India)
NUOL	National University of Laos
ODA	Official Development Assistance
PADEE	Program for Agricultural Development and Economic Empowerment (Cambodia)
PAFO	Provincial Agriculture and Forestry Office (Savannakhet, Laos)
PDA	Provincial Department of Agriculture (Svay Rieng, Cambodia)
PJTSAU	Prof Jayashankar Telangana State Agricultural University, formerly ANGRAU (India)
RUA	Royal University of Agriculture (Cambodia)
RKVY	Rashtriya Krishi Vikas Yojana - National Agriculture Development Scheme (India)
SAARC	South Asia Association for Regional Collaboration
SARCCAB	Support to Agricultural Research for Climate Change Adaptation in Bangladesh
SERDI	Social and Economic Research and Development Institute (Bangladesh)
SNV	Stichting Nederlandse Vrijwilligers (Netherlands Development Organisation)
SNRMPEP	Sustainable Natural Resource Management & Productivity Enhancement Project
TOT	Training of Trainers
UNDP	United National Development Program
WALAMTARI	Water and Land Management Training and Research Institute (India)
WASSAN	Watershed Support Services and Activities Network (India)
WB	World Bank

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Appendix 2 – Chialue et al. 2014: Results of focus group discussions Lao PDR

Farmer perspectives and experiences with adaptation options, Savannakhet: A summary of farmer engagement processes

Lytoua Chialue, Clemens Grünbühel, Alison Laing, Silinthone Sacklokham, Liana Williams, Feu Yang

Unpublished report

Farmer perspectives and experiences with adaptation options, Savannakhet: A summary of farmer engagement processes.

Lytoua Chilaue, Clemens Grünbühel, Alison Laing, Silinthone Sacklokham, Liana Williams, Feu Yang

Introduction

The Adapting to Climate Change in Asia (ACCA) project is working with local communities and government to develop field-tested options to adapt to current climate variability and predicted future change. The first two years of the project focused on understanding household livelihoods and adaptive capacity and the development of agricultural practices that would support improved rice production given a variable and changing climate. The focus of the work has now shifted to testing these initial findings and ground-truthing adaptation practices directly with farming households. A farmer engagement process involving interviews and focus group discussions was designed to capture farmer perspectives, experiences and opinions on the proposed adaptation options. The aims of the farmer engagement process were to gather information regarding:

- Household decision making processes as they relate to trialling, evaluating and (dis)continuing with new farm practices;
- Farmer perceptions and experiences of practices;
- Broader implications and changes due to new technology/practices;
- Test/ground-truthing prior definition of household types, and explore if/how practices were viewed differently by household types.

Insights provided through this engagement process have informed further development and understanding of the proposed adaptation practices, including future research needs.

Study villages are located in two districts of Savannakhet Province, Lao PDR. Outhoumphone, which has purely rainfed, lowland rice production; and Champhone, which is flood prone, with some access to irrigation. Variable and unpredictable rainfall patterns are a big challenge in these rainfed areas, however increasing migration of young people and resulting labour shortages present a more immediate challenge for many farmers. Options to respond to changes in the system vary depending on the circumstances of different households. To better understand the diversity of households within these areas, households have been grouped based on access to resources and livelihood strategies. Key variables were agro-ecosystem, access to land, irrigation and options for labour/remittances (Table 9).

Table 9 Summary of household types

Type 1.	Lower and upper lowland, small farms with no irrigation using family labour. Households have access to 0.2-1.9ha and aim for self-sufficiency in rice, but most are unable to achieve it. Households rely on remittances from members working permanently off-farm. This type is found in Phin Neua, Nonsavang and Sivilay.
Type 2.	Lower and upper lowland, medium farms with no irrigation using family labour. Households have access to 2-3ha of land, and are more likely to have used some land to dig ponds for water storage/supplementary irrigation. Farmers produce wet season rice for home consumption, dry season vegetables for sale and raise a small number of livestock. This type is found in Phin Neua, Nonsavang and Sivilay.

Type 3.	Lower and upper lowland, large farms with no irrigation using family and hired labour. Households have 3-15ha of land and are market oriented; selling surplus wet season rice and breeding large animals. They have put some land aside for ponds for irrigation. Other surplus land is rented to other households or used for animal grazing. This type is found in Phin Neua, Nonsavang and Sivilay.
Type 4.	Lowland, small and medium farms with irrigation, using family labour. Households have 0.5-2.5ha of land for wet season, and 0.16-1ha of dry season rice. They are self sufficient in rice and produce vegetables for market. Dry season rice production is very expensive and absorbs significant household resources. Agricultural income is supplemented with seasonal wage labour and permanent migration. This type is found in Nanokkien.
Type 5.	Flood affected lowland, small and medium farms with irrigation, using family labour. Households have 1-2.5 ha and are mostly self-sufficient in rice; however production is not enough for a sufficient income. Wet season crops are at risk of loss due to flooding. Households have invested in pumps to grow dry season rice, though it is costly and has high risk. Agriculture is supplemented by wage labour and fishing. Often a family member has permanently migrated and sends back remittances. This type is found in Nanokkien, Sakheun and Taleo.
Type 6.	Flood affected lowland, large farms with irrigation using family and hired labour. Households have 3-5 ha of rice fields and are market oriented. They sell surplus rice and also livestock. There is a risk of wet season flooding, but can usually spread risk over different land parcels at higher elevation. They must hire labour to support agriculture. This type is found in Nanokkien, Sakheun and Taleo.

Development of adaptation practices has focused on reducing exposure to climate risks, while being mindful of the different capacities and resources available to farming households. A number of practices were trialled in the 2011 and 2012 wet seasons (Roth and Laing, 2012). As a result of these trials and farmer interest, use of a direct seeder has become the main adaptation practice explored by the project. In terms of climate risk, use of a direct seeder allows farmers to plant earlier without waiting for standing water – smaller rainfall events in the early wet season are able to trigger germination and crop development[3]. However direct seeders also remove the need for labour for transplanting – a significant attraction for farmers in labour constrained environments. To use direct seeders, farmers need access to hand tractors, and to follow specific land preparation processes to minimise weeds.

Methods

Information about new practices was provided to farmers through 'Good Agricultural Practice' (GAP) training. Follow up interviews were conducted in the days after training; and focus group discussions were held at the end of the season to capture farmers' reflection on adaptation practices (Table 10). Some local support was available to farmers who decided to use the direct seeder, mainly through the co-location of field trials within the village.

Good agricultural practice training

[3] *For a more detailed explanation of the rationale for direct seeding, see Laing et al (2013).*

Training was sessions were held over two days – one day each of theory and practical demonstration (focused on use of direct seeder). Training varied slightly depending on the agricultural condition of the area, but broadly covered:

- Introduction to good agricultural practice and climate change
- Selection rice varieties based on the area/conditions and seed selection
- Soil improvement practices
- Herbicide use
- Direct seeding of rice using mechanical seeder
- Post harvest techniques

Three separate training sessions were held, involving 59 farmers over nine villages involved with the project. Training was provided by the National Agriculture and Forestry Research Institute (NAFRI), Department of Agriculture Extension and Cooperatives (DAEC) and District Agriculture and Forestry Offices (DAFO).

Table 10: Summary of farmer engagement activities, 2013

	Post GAP Training (April 2013, pre-trial/adoption)	End of season (December 2013, after one season)
Aim / broad questions	- Farmer feedback on training and practices - Which (if any) practices are farmers interested in trialling - Why / why not, constraints, expected benefits etc	- Reflection on season, conditions, challenges - Were practices implemented as planned? Why / why not? - Experience with practices, including benefits, costs, challenges/constraints. - Intention to continue with practices? - Other practices farmers are aware of and reflections on those?
Method	Interview (n=30)	Focus group discussion (n≈47) [b]
Villages (no. from that village)	Champhone Sivilay (6) [a] Sakheun (4) Taleo (5) Nanokkien (5) Outhoumphone Phin Neua / Phin Tai (5) Nonsavang (5)	Champhone Sivilay (7) Sakheun (6) Taleo (5) Outhoumphone Phin Neua/Phin Tai (7) Nonsavang (5) Nonvilay (9)[c] Vangkhaen (9) [c]
Participation by Type (%)	T1. 6.7 T2. 23.3 T3. 30 T4. 20 T5. 6.7 T6. 13.3	T1. 2.1 T2. 31.9 T3. 44.7 T4. 0[d] T5. 12.8 T6. 8.5

[a] Lists only the number of interviews/village. GAP training included a greater number of participants and more villages.

[b] Participation in FGDs is an estimate only and is likely to be lower than the actual participation.

[c] These villages were not directly involved in the project and were used as a comparison with / without the intervention of the project.

[d] Type 4 is predominant in Nanokkien, which was not sampled in the focus group discussions.

Interviews

Research teams from the National University of Laos (NUOL) observed the training and conducted follow-up interviews in the days following the training. Interviews focused on understanding farmer perceptions of the training and recommended practices; if they were intending to implement any of the training; and why/why not. Thirty training participants were approached for interview in the days following the training. Participation was sought from a range of farmer types to reflect the diversity of circumstances and understand if and how their perceptions of practices and ability to implement them differed.

Focus group discussions

A team of researchers from NUOL, AIT, CSIRO and UQ returned to a sample of villages in December 2013 to follow up with farmer experience after the season. Participation was voluntary and sought a mix of farmers considering household types, attendance at training and implementation of recommended practices. Two additional focus group discussions in villages with no direct exposure to project activities were also conducted as a way of understanding the broader conditions and current activities of households without the influence of this project. Discussion covered the general conditions with the season; aspects of the GAP training that were implemented and farmer experiences; other practices the farmers were using or aware of, and plans for future seasons (the full FGD guide is included as Appendix A).

Results

Post-GAP training feedback on practices

Farmers were generally positive about the training, although preferred practical demonstration to theory and felt the theory session covered too much information in too short a time. Nonetheless, farmers were interested in the new practices and most felt they could implement with further DAFO support.

Lack of labour for key tasks such as transplanting has been a key constraint for these farmers. They considered the direct seeder had the potential to directly address this constraint and was the practice they were most interested in. Farmers noted its potential in terms of reducing labour costs, and seed use, reducing the production cycle and saving time. Six of the 30 farmers interviewed were already familiar with the direct seeder through other projects.

There was concern relating to potential for direct seeding to increase weed problems and an interest to observe results of the field trial. Those farmers that stated they couldn't try the seeder didn't have access to a hand tractor.

In general, though 90 percent of farmers interviewed were interested in using the direct seeder. However they felt further support and information provision from DAFO was key to their successful adoption. There was no discernible difference in how different household types viewed the practices or their ability to implement.

Feedback after trials

Across all villages, households noted various conditions had affected the season - most commonly poor rainfall distribution and prolonged periods of dry conditions which affected crop establishment and yields. Farmers in Sakheun felt it was hard to implement the training in such a dry season. Drier conditions meant pests like gall midge were less of a problem in some villages (eg. Phin Neua / Phin Tai) but participants in Nonsavang experienced a serious gall midge problem which was unusual given the dry conditions. The main constraints mentioned were water scarcity followed by gall midge and stem borers.

Reflecting on the GAP training, households found it to be complicated, though most tried to implement some of the recommendations – most often use of the direct seeder. Those that decided against using the seeder explained they either didn't feel they knew enough to do so, or didn't have enough land to set aside to experiment with it. Key constraints to implementing practices suggested in the GAP training included access to equipment or inputs (fertiliser), labour, or having suitable land.

Experience using direct seeder

Household experiences with the direct seeder varied significantly depending on factors such as the toposequence of the field used, water availability, land size and labour for weeding. Though many households had some concerns with the seeder, they noted their limited experience in using it, and considered trying again next season with some modification (eg. trying in a different field). Farmers in Sakheun who only had land only in the higher toposequence, with no or limited water access were less interested in continuing with the direct seeder due to weed problems.

Labour

The potential for reduced labour demand in transplanting was a clear advantage for many households. However in many cases, households were uncertain if this was an advantage overall due to the demands of weed management.

The labour need for transplanting is largely predictable (in terms of approximate timing and the overall amount) whereas the labour need for weeding was less predictable and continuous through the season. Many households were managing by hand and some weeded as many as four times. Farmers in Nonsavang also noted the competition for labour created by having both transplanting and direct seeded rice plots. The time when direct seeded fields needed to be weeded was the same time as seedlings needed transplanting this year.

Weed management

In all villages, weeds were a key challenge in using the direct seeder. Households who were able to manage weeds more effectively either a) had planted a smaller area with the direct seeder, and thus had lower labour demands to manage weeds, and/or b) had water available, either through planting in lower toposequences or with supplementary irrigation, so that standing water suppressed the weeds. For households without these conditions, new and improved options for controlling weeds are a necessity if the direct seeder is to be a viable option. Many households felt inter-row cultivators were not effective- in their experience they were not efficient and not appropriate for large areas. There is still very little interest in using herbicides to control weeds due to ecological and health concerns. Farmers in Phin Neua/Phin Tai and Nonsavang were cautiously open to organic herbicides but only with further training and support. In general focus group discussions revealed a preference for alternative measures (ie. standing water) to suppress weeds.

Timing of planting and harvesting
Early planting can be problematic with animals still free to graze in harvested fields. In many cases, farmers felt this was manageable within existing village structures and agreements. In general terms, it seems that if only one or two farmers are planting early, it is their responsibility to fence in their fields. However if many people are planting early, the obligation shifts to the owners to tether their animals.

Reliability of early season rainfall and the timing of direct seeding was also raised during discussions – in all villages a period of prolonged drought had followed after the direct seeder had been used (May). The farmers were concerned that in future seasons planting early with the direct seeder may result in loss of seed if rain did not come soon enough.

Maturation time of rice was an issue in some villages, prompting farmer reflection on choice of rice variety. Many felt later maturing varieties would be more suitable, avoiding damage by birds and the difficulties of harvesting/post-harvest activities before the end of the wet season.

Other
Access to seeders is currently a constraint to further testing and experimentation. This season farmers shared seeders, but since they all need to use them about the same time, there is a limited number that can effectively share the one machine. One or two farmers in Phin Neua had been able to buy seeders. Farmers in Taleo and Sivilay had seen ads on TV and were interested but need an accessible price.

Farmers in Sakheun-Tai had problems with seed distribution caused by a fault with the machine which resulted in sub-optimal plant densities. They expressed a preference for a seeder that could deliver in points, rather than in a continuous row.

Control villages shared many of the reflections on the season as those villages involved with the project. Though they had no direct exposure to the direct seeder or other practices, households in Vangkhaen had heard about it through other villages. They had heard the dry conditions had affected the yields and there were weed control issues. Their initial perception is that transplanting was better due to the ability to control weeds.

Experience with other GAP training recommendations
The content of the training varied slightly from village to village and was generally less of a focus of discussion than the direct seeder.

Selection of varieties for different types of area and rice seed selection
Most farmers were using improved varieties, including Lao varieties Thadohkam (TDK) 5, 8, 11 and 1-1; Thasano (TSN) 5 and 6; Thai varieties RD8 and 10. Farmers noted issues such as selection of varieties based on duration and photosensitivity depending on crop establishment methods and other requirements (eg. wanting shorter varieties so cattle could graze sooner; planning so that harvest could occur simultaneously regardless of timing of transplanting or establishment method; or photo-period sensitive varieties to time harvest with the end of the wet season). While generally

happy with the varieties they were using, there was an overall interest in the development of varieties with better pest and disease resistance. Most farmers were following recommendations to get new seeds every two to three years from the research station.

Fertiliser

While GAP Training recommended three applications of fertiliser (basal, at emergence and after 20 days), most farmers are unable to afford fertiliser for all three applications. Timing of application was prioritised based on what households could afford versus what they perceive gives the best outcome. Some felt that better results were seen from top dressing if they only had a limited amount of fertiliser (as opposed to only basal application). Some were interested in methods to place fertiliser with seed, while others were worried about burning seed.

Organic pest control

Despite receiving training, farmers did not have the confidence or interest to try organic pest control. There was a strong hesitation regarding any form of chemical pesticide in most of the villages, with a few individual exceptions. These individuals had experience in other projects that had incorporated their use (e.g. as part of a conservation agriculture project).

Other practices and adaptations

Other new practices were usually learnt of through exposure by other projects, whether they be working in the same village, or neighbouring villages.

Improving the Resilience of the Agriculture Sector in Lao PDR to Climate Change Impact (IRAS) had been introducing the drum seeder this year, though there had been problems regarding late arrival of machines. Though most of our participants had limited exposure to the drum seeder, many of them seemed to think the direct seeder offered more benefits, including: more reliably planting in rows, lower likelihood of seeds being swept away or dislodged with heavy rain after sowing and less chance of birds eating seed.

Some farmers in Taleo had also been exposed to the system of rice intensification, though they quickly dismissed it due to a) the difficulty in transplanting young seedlings; b) unsuitable over large areas; c) weed competition with young seedlings and d) pests, such as the golden apple snail. One farmer noted that the women (who are responsible for transplanting) were particularly unhappy with the idea of transplanting seedlings that were so young.

With water such a key constraint, many of the discussions on future options or alternatives involved construction of small ponds to enable supplementary irrigation. It is unclear how realistic this is given available resources.

Table 11 Summary of key issues from each focus group discussion

Village	Key constraints (2013)	Direct seeder			Weed management		Improved varieties	Pest Control	Fertiliser
		Advantages	Disadvantages	Other comments	Rotary weeder	Herbicide			
Phin Neua/Tai	-Water	-Labour saving in transplanting	-Weeds -Ongoing labour required for weeding	-Need to time use just before rains	-Hard to use -Needs water -Weeds come back faster	-Reluctant to use	TDK various Exchange at Thasano 2-3yr.	-Dry conditions limited problem	-Can't afford recommend ed practice
Nonsavang	-Water -Gall midge -Stem borer	-Easy to use -Early start to planting -Labour saving	-Weeds grew faster than rice -Labour for weeding at same time as transplanting	-Consider rice variety (duration) -More suited to lower toposequence -Will experiment in other plots	-High labour -Limited effect	-Reluctant to use	TSN 7 TDK 6 8 11 *Nam Pheung* variety Exchange 2-3 yrs Interested in gall midge tolerant variety	-Not confident to use organic pesticide without more training/sup port	-Can't afford recommend ed practice -Not sure if it is worth any topdressing if can't follow precisely
Sivilay	-Dry conditions / late rain -Pests	-Labour saving (transplantin g)	-Significant ongoing labour needed for weeding -Bird attack due to early maturation -Had to fence from livestock -Pests concentrated on DS plots due to timing	-Performed worse at higher toposequence than lower -General perception is positive	-Used (but no specific comment)	-	TSN varieties All medium duration, glutinous Want longer duration to use with direct seeder	-	-
Sakheun	-Dry conditions -Pest damage		-Significant ongoing labour for weeding -Fence off from livestock - Weeds -Seed distribution	-Faulty seed dispersal mechanism -Keen to use early maturing variety to release livestock asap	-Not good for large areas	-No interest, standing water sufficient	RD 8 10 TDK various	-	-

			not good	after harvest					
Taleo	-Water access -Weeds	-Decreases labour costs about 50% cf. transplant	-Weeding (worse on higher toposequence) -Some harvested crop affected by rain	-Tight timeframes sharing the seeder		-	TDK 5 TDK 1-1 TSN 5 RD 10 20	-	-Apply in lowland / where enough water is present
Nonvilay	-Lack of water	-NA	-NA			-	TDK 8 11 TSN 5 6 No traditional varieties used	-	- Depends on family income, usually only small amounts
Vangkhaen	-Lack of water	-NA	-NA	-Heard about it through other village -Aware of weed control issue and dry condition affecting yield		-	TSN 7	-	- Can't afford to buy

Discussion

Direct experience of trying to implement recommended practices has highlighted the challenges of applying practices in real-world situations. In initial interviews after the training, almost all farmers felt they could do direct seeding and would be able to save money while achieving good yields. While the potential for this is still present, there is a lot more caution after the experience of one season. The sense of caution is tied to weed problems, likely exacerbated by the dry season, however given the project's motivation for introducing the practice, the challenges presented by dry conditions are important. The direct seeder, enabling early establishment prior to accumulation of standing water, removed some risk of water stress due to dry conditions later in the season (Laing and Roth 2013). Farmer experimentation with the seeder highlighted this to be the case, with direct seeded fields initially doing better than transplanted, which were established late, often with older seedlings (Laing and Roth 2013). However this advantage was overshadowed by the prevalence of weeds, exacerbated by the dry conditions.

This highlights a difference in perspective and priorities among researchers and farming households, between managing climate risk and reducing labour costs. For researchers, the introduction of the direct seeder is motivated by dealing with climate variability - this link is not seen by many of the farmers we spoke to. Instead, they see the main attraction as the potential for labour saving if weeds can be managed. Indeed, farmers in Nonsavang noted the direct seeder would have been ok in a season with sufficient rain to help manage the weeds.

While direct seeding offers a way to manage labour constraints, transplanting is still preferred to manage climate risk. With transplanting, the farmers have enough experience and the nursery gives time to react based on the season. With the new technology, they don't yet have the experience or skill to adapt with different conditions. There is still a strong interest to persevere and experiment.

Broader system implications and impacts

At this early stage, direct seeding is ancillary to transplanting, and introduction of direct seeding triggers many subtle adjustments in the broader farming system, particularly in regard to the timing of different activities. Timing of key activities between direct seeded and transplanted fields were in competition (weeding at the same time as transplanting) or out of sync (harvesting). As direct seeded crops established and matured earlier, they became a target for pests and farmers had trouble managing post-harvest in wet conditions. Some issues can be addressed with variety choice (crop duration and photosensitivity) while others may require broader shifts in practice or management, such as fencing fields or tethering animals. Implications in terms of animal fodder for tethered animals were not explored.

Key variables / characteristics for use of direct seeder

The most pressing concern for farmers in using the direct seeder relates to weed management, which, for these farmers, is intimately linked with access to water to suppress weeds. Based on the focus group discussions, direct seeding seems most compatible for households with irrigation (types 4, 5 and 6). Indeed, some households were considering experimenting with lower fields where more water was available.

In drier areas / higher toposequences, focus group participants noted it was easier for households with smaller areas planted to direct seeding to manually manage the weeds. Though this suggests it might be more appropriate for smaller households (type 1), this type was under-represented in focus group discussions, and it would be reasonable to suggest that these households are least able to experiment with new practices.

Conclusions

The practice most discussed and implemented was the direct seeder. Most households could not afford the recommended amounts of fertiliser application and were reluctant to use pesticides. Though there is still a lot of interest in the direct seeder, the post-training enthusiasm has been tempered by challenges with weed management and timing with other activities.

Many of the issues that have been a challenge in this season (variety selection, seed distribution, timing of harvesting) are manageable given a good understanding and the ability to plan for different seasons. Weed management is perhaps a slightly more difficult challenge, particularly in dry conditions and in contexts where herbicides are generally not an option. However farmers were willing to experiment with additional land preparations and new fields to overcome this. The focus group discussions highlighted that farmers with land at higher toposequence and without water access to suppress weeds are less interested in continuing with the seeder.

References

Laing AM, Roth CH, Phengvichith V, Phouisombath K, Schiller JM, Sipaseuth, Souliyavongsa X, Thiravong K and Vorlasan S (2013) *Direct seeding of rice in Lao PDR – a discussion paper. Summary of learnings to date from wet season 2013*. CSIRO, Australia.

Roth CH and Laing AM (2013) *Midterm progress report. ACIAR Project LWR-2008-019: Developing multi-scale climate adaptation strategies for farming communities in Cambodia, Laos, Bangladesh and India.* CSIRO Unpublished Report, Brisbane.

Appendix A. Focus group discussion guide

Aims:

- to follow up on farmer implementation of GAP training recommendations;
- to connect the technologies/practices back to relevance to climate adaptation;
- to explore broader implications and changes due to new technology.

Method: Focus group discussions (FGDs)
Broad structure:

A. Villages that have been involved in the project, and received GAP training

(1) Reflection on the past season – weather conditions, yields, any issues etc.
(2) Follow-up regarding implementation of new practices (from GAP training)
Discuss if households were able to implement practices from GAP training as they expected; how they found the practices, changes or adjustments they made, constraints and unexpected opportunities.
(3) Explore other practices or technologies
What are households aware of or are they experimenting with technologies from other sources (eg. private companies; word of mouth); what is the rationale for applying them?
(4) What are the follow-on changes to the farming and social system from implementing these changes?
(5) What are the impacts or changes relating to labour due to the changes in technology; migration and broader changes to livelihoods more generally?
(6) Ranking of challenges in farming
Based on existing information (eg. HH survey; Self Assessment workshops; Post GAP interview or data from other sources) create a list of challenges/constraints in farming (eg. labour, input, drought, flood…)
Get participants to rank in terms of which is the most challenging. Our aim here is to get an idea of how pressing/challenging they see variation in climate compared to other factors.
(7) Discussion of new practices and how they may help address constraints
Discuss the new practices / technology that came up in sessions (1) and (2) and discuss how farmers perceive they address or help manage some of the challenges (if any). eg. use of drought tolerant variety to cope with uncertain rainfall. etc.

NB: All participants need to be related to the typology – therefore, HH size, land size, irrigation, crops (cash/subsistence), and other income sources need to be collected from each participant.

B. Villages that have not been involved in the project

(1) Reflection on the past season – weather conditions, yields, any issues etc.

(2) Gather general information on the village – the population, average farming system, land size etc
(3) What training has the village received, if any?
Discuss if households were able to implement practices from training as they expected; how they found the practices, changes or adjustments they made, constraints and unexpected opportunities.
(4) Explore other practices or technologies
What are households aware of or are they experimenting with technologies from other sources (eg. private companies; word of mouth); what is the rationale for applying them?
(5) Potential of direct seeder and other GAP options
Ask about existing knowledge of direct seeding technology, fertiliser application and variety selection. Explore the participants' impressions of the practices, what benefits or constraints they consider they may offer.

NB: All participants need to be related to the typology – therefore, HH size, land size, irrigation, crops (cash/subsistence), and other income sources need to be collected from each participant.

<u>Implementation:</u>
10/12/13 Outhoumphone: (1) Phin Neua and Phin Thai; (2) Nonsavang
11/12/13 Champhone: (3) Sivilay; (4) Sakheun Tai; (5) Taleo
12/12/13 Outhoumphone: (6) Nonvilay; (7) Vangkhaen (not received GAP training)
12/12/13 (pm) Write up and debrief

<u>Participants:</u>
Ly Toua, Fue Yang, Clemens, John, Liana, Alison, Khammone, DAFO
For FGD we will need to identify a FGD facilitator, a note-taker and observer. Other project participants can be assigned specific roles, such as observing group dynamics and making sure all topics are covered.
FGD participants should amount to approx. 8-10 respondents.

Appendix 3 – Dalgliesh 2014: Response farming in Cambodia technical report

Increasing flexibility in Cambodian monsoonal rice cropping systems

Neal Dalgliesh

Submitted to GDA, Cambodia

INCREASING FLEXIBILITY IN CAMBODIAN MONSOONAL RICE CROPPING SYSTEMS

Neal Dalgliesh, CSIRO Australia

Foreword-the Technical Reference Panel

While the ACIAR Climate Adaptation Project (ACCA) research team thought that there was potential for the suggested wet season rice production interventions to contribute to increased farmer productivity, it was considered important that a peer review of technical content and systems sensibility be conducted before any recommendations were made to modify Cambodian rice production policy. A Technical Reference Panel was established to review the seasonal cropping calendars (Appendix 1) and associated response farming protocols (Appendix 2). The panel, which met in Phnom Penh on the 3rd and 4th June 2014 under the auspices of the ACCA project, consisted of rice and systems specialists from Cambodian Government agencies, locally based NGOs and Australian partners. It included representatives from DAE (Say Tom, Mao Minea), iDE (Lim Naluch, Lam Boramy), CARDI (Ung Sopheap), PDA-Svay Rieng (Sok Channthorn), DRC-GDA (Kong Kea), SNV (Ke Sam Oeurn), Dept of Ag Engineering-GDA (Seng Tuy), Dept Land Resource Management-GDA (Koy Ra) and CSIRO (Monica van Wensveen and Neal Dalgliesh).

The panel recommended that the attached monsoon season rice production interventions be considered for promotion on medium and high lands, in provinces where the soils and environment were similar to those of Svay Rieng and Prey Veng. These included the PADEE focus provinces of Kampot, Kandal and Takeo (as well as Svay Rieng and Prey Vang), the proposed ASPIRE focus provinces of Kampong Chhnang, Pursat, Preah Vihear, Kratie and Battambang, and the provinces of Preah Sihanouk and Kampong Speu. This document aims to summarise the background research on which the systems interventions were based and the outcomes of technical panel deliberations including the specifics of the recommended response farming interventions.

Developing multi-scale adaptation strategies for Cambodian farming communities

In this project researchers and rural communities are designing farming practices to help smallholders reduce the impact of an increasingly variable climate on their livelihoods. Locally promising practices that meet the needs and capacity of different types of households have been tested and evaluated on-farm and through systems modelling. The knowledge gained through this process has then been used in the development of appropriate extension programs and their delivery to the broader farming community grappling with the challenges of producing crops in a highly variable seasonal climate.

Cambodian research focus

In Cambodia, one of 4 Asian countries participating in the project, a transdisciplinary team of social and biophysical researchers are working with the farmers of Svay Rieng and Prey Veng provinces, to investigate opportunities to improve farmer resilience to the challenges they face in growing crops in a highly variable climate. Farmers in the medium and high lands have traditionally met the requirements of family food security by producing one medium duration rice crop during the monsoon season. This differs from provincial lowlands where recession rice predominates- recession rice is not the focus of this document. Yields from the traditional growing of wet season rice have been relatively low, a result of the use of local varieties that are generally genetically inferior to modern varieties as well as low levels of nutrition and poor agronomic practice. While farmers have been able to meet their requirements in most years, research shows that this is becoming more difficult due to the increasingly variable climate, particularly the impacts of drought and floods on production, and social and economic factors including the effect of rural migration on the agricultural labour supply.

A participatory approach has been used to investigate options to increase the flexibility of the cropping system to meet the on-going production challenges, while appreciating that it cannot be a 'one size fits all' solution, due to the differing aspirational goals and livelihood trajectories of individuals. Consequently, on-farm research has focussed on a range of potential opportunities, anticipated to meet the needs of a broad range of livelihood types. These vary from the small subsistence farmer wishing to grow sufficient rain-fed rice to meet food security requirements while utilising surplus family labour in off-farm enterprises, to those who see farming as their main enterprise and are interested in optimising production through the adoption of modern techniques including the use of genetically superior, modern, short and medium duration rice varieties, supplementary irrigation, better crop nutrition and agronomic practice and the use of mechanisation to reduce labour demands.

Increasing flexibility-responding to seasonal climatic conditions

It was theorised that the central focus of Cambodian wet season rice research be that climatic conditions varied both inter- and intra-seasonally and required that farmers have the ability and the tools to respond to seasonal changes, either in 'close to real time' in response to observed climatic conditions, or in the longer term, possibly as a result of improved seasonal climate forecasting. This led to the development of the concept described as 'response' farming.

Data from three years of on-farm research were used to test possible options developed in collaboration with the farming communities. These included the replacement of local medium duration rice with short and medium duration open-pollinated varieties developed by the Cambodian Agricultural Research and Development Institute (CARDI), mechanised establishment of the crop, supplementary irrigation, improved nutrition and better agronomic practice, particularly in regard to weed management.

While on-farm research was essential in testing the logic of particular system changes, it was not possible to undertake field-based research for a period of sufficient length to experience all potential climatic variation. Crop modelling, based on long term regional meteorological records (rainfall, temperature, radiation) and local soil information provided the longer-term link. Simulation of crop production (in this case, rice) provided an assessment of seasonal productivity over the longer-term, and an estimate of associated production risk. Comparison of on-farm data and the simulation output for the same years enabled testing for 'sensibility' of particular interventions at relatively low cost.

Response farming interventions

Response farming assumes that there are a number of ways in which the monsoon period can be used to produce rice, with particular options better suiting particular climatic conditions. For example, whether there is an early, average or late start to the wet season and whether high, medium or low amounts of rainfall are received. The 'response' made by the farmer will depend on these conditions and the strategy they perceive to be the most appropriate to meet their livelihood goals. The image of a 'tool box' which contains seasonal management options is a useful analogy, with appropriate tools taken from the box as the season progresses to meet production and livelihood demands (Figure 1). The types of tools that are stored in the box include crop duration and variety, crop sequencing and timing of establishment, availability of supplementary irrigation, availability of labour and the potential for increased mechanisation, seeding technologies (direct seeding and transplant), fertiliser (both organic and inorganic) and pest management technologies leading to aspirational seasonal production, crop return and gross margin goals.

It should be noted that the advocates of 'response' farming are not suggesting that all, or particular options are more important than others, or that they will be used by every farmer in every season or across an entire farm. Response farming is about having a range of tools which are all likely to contribute to reduced climate risk and to improved yields, and in many cases, will also improve financial returns, but, the final choice on whether to use particular options is the decision of the individual.

Conditions for crop establishment

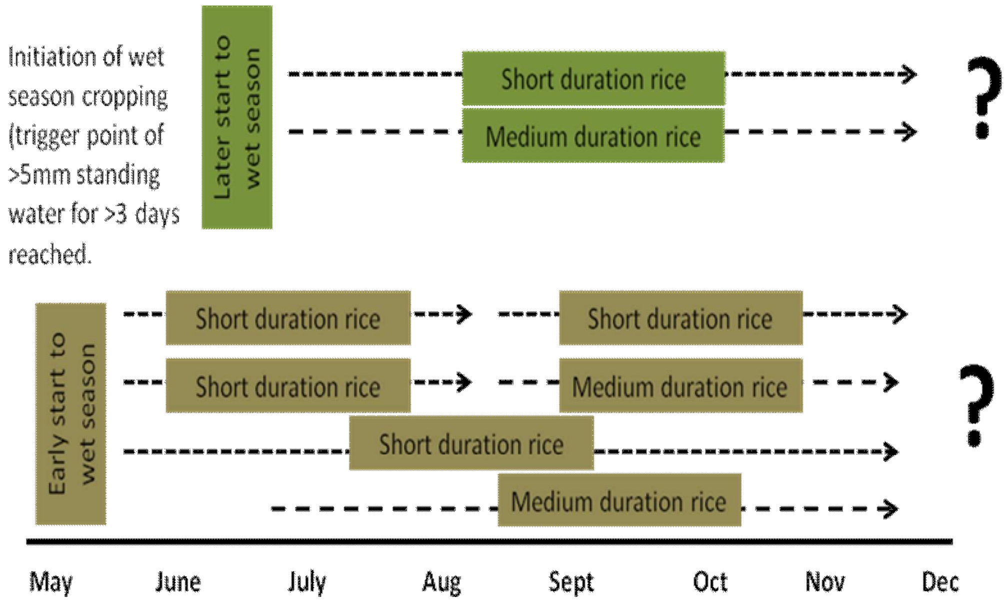

Figure 1: *The way in which the farmer responds to meeting the basic soil water criteria for cropping action (>5mm of standing water in the paddy for >3 consecutive days) and their selection of tools is a personal choice. Available options are dependent on the timing of start of the wet season but are likely to include some of the following: whether to grow 2 short duration crops, a single medium duration crop, or a combination; the availability of supplementary irrigation; the availability of labour and/or mechanisation for land preparation and crop establishment; productivity and economic returns and the individuals attitude to the production and financial risk associated with particular options.*

It is suggested that the initial trigger point for decision making occurs when water in the paddy is >5mm in depth for >3 consecutive days. This assumes that the presence of standing water indicates that the soil has been saturated by recent rainfall and that tillage is now possible in preparation for planting. While theoretically, it would be possible to develop trigger points around the occurrence of seasonal rainfall and its impact on crop production, this is currently impractical due to the lack of regional meteorological infrastructure and expertise to measure and interpret rainfall data at a local level.

Commonly, the trigger point (water >5mm in depth for >3 consecutive days) occurs in early to mid-May, although with a late start to the monsoon, may not occur until late May or June. Its timing will dictate which response is the most logical, but could include, a) the direct seeding of an early, short duration variety as soon as the trigger point has been reached; with the potential to follow-on with a double cropped short or medium duration crop in the second half of the monsoon season, or b) depending on when the trigger point occurs, avoiding the risk of second crop failure by growing only 1 short duration crop, possibly planted a little later in the season to minimise the risk of dry conditions at establishment, or c) opting to wait until the monsoon is fully established and direct seeding or transplanting a medium duration variety in July/ August (Figure 1). Further risk mitigation may be achieved through crop 'drought proofing' by the use of supplementary irrigation with water supplied from a tube well, pond or canal. Irrigation enables a higher degree of seasonal flexibility in terms of timing of crop establishment, selection of crop duration type and the level of investment in fertiliser and other inputs which the farmer is willing to risk. In essence, supplementary irrigation reduces the risk of failure.

Broad details of the cropping options available to the farmer are provided in the following section, however the specifics of crop timing and agronomic management are provided in the appendices (1 and 2). It should be noted that the production and gross margin data presented for recommended treatments in the following section have all received CARDI recommended fertiliser rates of N, P and K applied as per the individual protocols in Appendix 2. 'Farmer Practice' undertaken in 2011 and 2012, with which the above treatments are compared, consists of the growing of a medium duration, local variety with limited amounts of inorganic fertiliser applied.

1. (a) Short duration rice-double cropped-direct seeded-supplementary irrigation
(b) Short duration rice-double cropped-direct seeded-rainfed

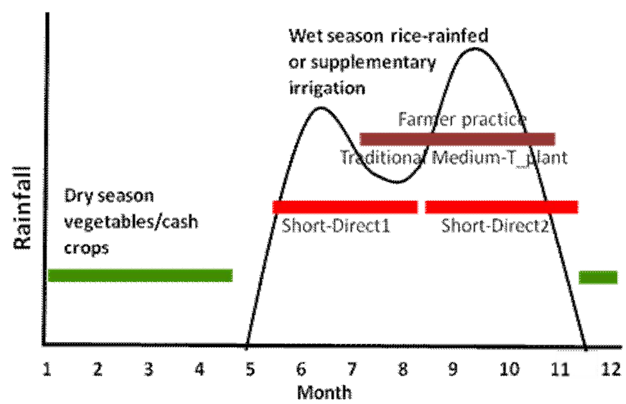

Figure 2: Replacing 'Farmer Practice' with the direct seeding of 2 short duration crops (both grown using CARDI fertiliser rates and good agronomic practice).

The growing of 2 short duration crops (Figure 2) requires a higher level of management than single crop production due to the need to time the establishment of the second crop so that maturity occurs before the end of the wet season. Research shows that there is a high risk of second crop failure when it is established after the first week of September, due to the high incidence of December water deficit. Keys to the success of double cropping are the early establishment of the first crop and a short transition time between the harvest of the first, and the establishment of the second crop. This period should be no longer than 10 days. Having the capacity to apply supplementary irrigation makes this sequence a very viable option. Time lines for the growing of this sequence under rainfed and supplementary irrigated conditions are provided in Appendix 1 and 2 (Options 1(a) and 1(b).

Table 1 shows seasonal production for the growing of 2 short duration crops and the associated gross margins, compared with farmer practice. These data show that the growing of 2 short duration crops in sequence achieved median production between 2 and 3 times higher than farmer practice in 2011 and 2012 (for example 1927 kg/ha compared to 4923 kg/ha in 2012) (Table 1). While it is difficult to apportion this difference to a particular component of the modified system, it is considered that the use of modern varieties, improved nutrition and better agronomic management all contributed. Of particular interest, is that the maximum seasonal production achieved over the 3 years of research, for the double cropping scenario was 2.8 times (7095 kg/ha) that of the traditional medium duration variety (2535 kg/ha). What this infers is that a small number of farmers were highly successful at maximising yield using the modern varieties and associated technologies. This should set the benchmark for farmers who see the maximising of productivity as their ultimate goal.

Table 1: *Seasonal production and gross margin (with and without labour) for a sequence of 2 short duration crops (grown with recommended fertiliser input) compared to farmer practice (1 medium duration traditional variety with limited inputs) in Svay Rieng (2011 to 2013) and Prey Veng (2013) provinces.*

Season	**2011**		**2012**		**2013**	**All seasons**	
Establishment	Direct	Transplant	Direct	Transplant	Direct	Direct	Transplant
Duration	Short	Farmer practice	Short	Farmer practice	Short	Short	Farmer practice
No. of crops in season	2	1	2	1	2	2	1
Time of establishment	Early/Mid	Mid	Early/Mid	Mid	Early/Mid	Early/ Mid	Mid
Plot number	11	35	9	27	4	24	62
Seasonal production (kg/ha at 14% moisture)							
Lowest Yield	1792	1229	3798	1094	5658	1792	1094
Median Yield	4232	1792	4923	1927	6491	4745	1852
Highest Yield	5428	2372	6163	2535	7095	7095	2535
Middle 50% Yield	3518-4669	1621-1973	4678-5716	1621-2104	5804-7064	4015-5687	1621-2023
Gross margin-no labour (US$/ha)							
Lowest	(261)	81	(48)	30	556	(261)	30
Median	512	296	376	283	824	545	288
Highest	805	456	736	428	987	987	456
Middle 50%	304-659	253-354	255-659	174-341	669-926	300-669	236-350
Gross margin-with labour (US$/ha)							
Lowest	(630)	(329)	(234)	(363)	199	(630)	(363)
Median	273	(114)	9	(91)	485	227	(101)

Highest	425	46	331	160	689	689	160
Middle 50%	(39)-314	(157)-(56)	(112)-255	(180)-(9)	330-598	(49)-323	(157)-(39)

As expected, comparisons of gross margin showed that the 3 year median for the 2 short duration crop sequence was almost twice as high as for farmer practice ($545 to $288/ha) (excluding labour costs). This disparity continued to increase when labour was considered, with a median gross margin of $227/ha for the 2 short duration sequence compared to a loss of $101/ha for farmer practice. This difference reflects the higher labour costs associated with transplanting and the differences in yield resulting from the lower crop inputs and management levels used in farmer practice. These data show that at least 75% of the farmers who grew the traditional medium variety did so at an economic loss. However, it should also be noted that around 30% of farmers growing the 2 short duration crops during the 3 seasons also lost financially. This resulted from, a) the inexperience of both the farmers and their advisors in growing 2 crops, b) the increased drought risk associated with the second crop when planted later than optimal, and c) the higher levels of investment required for 2 crop which, when the second crop failed, resulted in higher levels of financial loss.

2. Short duration double cropped rice followed by medium duration photo-period sensitive CARDI variety rice-rainfed, direct seeded (crop1), transplanted (Crop2)

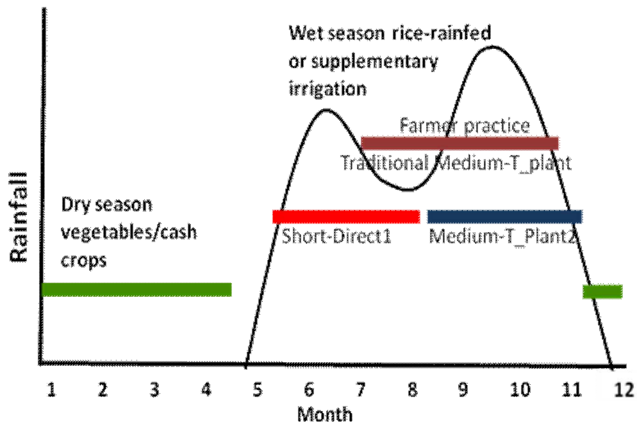

Figure 3: Replacing 'Farmer Practice' with the direct seeding of a modern, single short duration crop which is then followed by a modern, medium duration crop (both grown using CARDI fertiliser rates and good

In this scenario, a short duration variety is established in the early wet season and then followed by a medium duration crop, transplanted in late August (nursery established in late July). The transplanting of a medium duration, photo-period sensitive variety, such as Phka Rumdual, provides the opportunity to produce rice which has a higher market value than short duration varieties such as Chulsa and IR66. As with the growing of 2 sequential short duration varieties, this option is reliant on the early establishment of the first crop and a quick transition between the 2 crops. While this scenario is shown as a rainfed option, supplementary irrigation would reduce the level of risk associated with timing of first crop establishment and ensure an adequate water supply for second crop completion. This option was not subject to on-farm testing but was highly recommended by the Technical Reference Panel with the time line provided in Appendix 1 and 2 (Option 2).

3. (a) Short duration rice-single cropped-direct seeded-rainfed
(b) Short duration rice-single cropped-direct seeded-supplementary irrigation

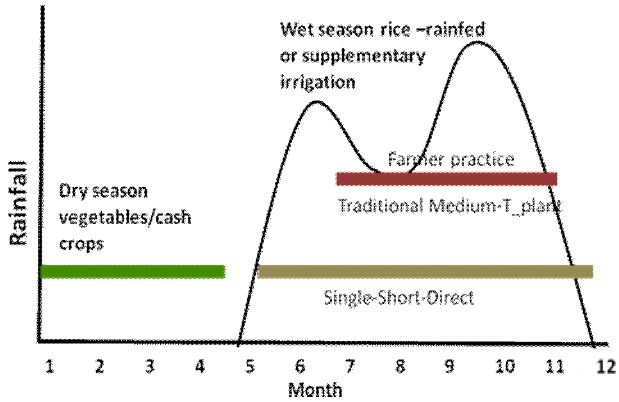

Figure 4: Replacing 'Farmer Practice' with a single, short duration, direct seeded crop grown either under rainfed conditions or with supplementary irrigation (grown using CARDI fertiliser rates and good

The replacement of farmer practice, with a single, direct seeded, short duration variety is logical in terms of seasonal productivity and in ensuring flexibility in response to variable climatic conditions (Figure 4). This could be either rainfed or grown with supplementary irrigation. Therefore, a crop would be able to be established as soon as planting trigger conditions were met (>5mm standing water for >3 consecutive days), starting in early to late May for an average season, or into June for a later break. Those with irrigation access have more flexibility in establishing their crop, while those without this luxury are more likely to opt to minimise their risk by waiting until monsoon conditions are stable before crop establishment. Given that short duration varieties (such as Chulsa and IR66) mature in <100 days, this option is the most flexible of the systems discussed, with the establishment window extending from May through until early September, although a cautious approach should be taken from late August onwards given the risk of an early finish to the monsoon or of inadequate water supply to complete a later maturing crop.

In terms of family livelihood strategies, this option provides marked advantages. An early planted crop, grown to meet family food security requirements, or as part of a broader strategy to spread risk, could be harvested as early as mid-August. This crop would normally meet annual food security requirements and allow family members to become involved in other agricultural enterprises such as vegetable or cash crop production, or allow members to migrate to the city to access available labour markets. Also, the July/August period is often drier than the surrounding months, providing a more seasonally stable period to harvest and process crops.

***Table 2:** Seasonal production and gross margin (with and without labour) for 1 short duration crop (grown with CARDI recommended fertiliser inputs) compared to farmer practice (1 medium duration traditional variety with limited inputs) in Svay Rieng (2011 to 2013) and Prey Veng (2013) provinces.*

Season	**2011**		**2012**		**2013**	**All seasons**	
Establishment	Direct	Transplant	Direct	Transplant	Direct	Direct	Transplant
Duration	Short	Farmer practice	Short	Farmer practice	Short	Short	Farmer practice
No. of crops in season	1	1	1	1	1	1	1
Time of establishment	Early	Mid	Early	Mid	Early/Mid	Early	Mid
Plot number	15	35	19	27	35	69	62
Seasonal production (kg/ha at 14% moisture)							
Low Yield	890	1229	1716	1094	1872	890	1094
Median Yield	2537	1792	2740	1927	3784	3080	1852

Highest Yield	3920	2372	5001	2535	6394	6394	2535
Middle 50%	1912-3062	1621- 1973	2099-3129	1621-2104	3016-4348	2514-3902	1621-2023
Gross margin-no labour (US$/ha)							
Low	(72)	81	(83)	30	5	(83)	30
Median	442	296	193	283	486	411	288
Highest	870	456	923	428	1205	1205	456
Middle 50%	263-651	253-354	114-337	174-341	315-619	230-542	236-350
Gross margin-with labour (US$/ha)							
Low	(279)	(329)	(295)	(363)	(175)	(295)	(363)
Median	215	(114)	(19)	(91)	272	213	(101)
Highest	653	46	711	160	1031	1031	160
Middle 50%	56-444	(157)-(56)	(98)-125	(180)-(9)	124-403	46-376	(157)-(39)

Table 2 shows seasonal production from the growing of 1 short duration crop and the associated gross margins, compared to farmer practice. These data show that with CARDI recommended rates of fertiliser and good agronomic practice, the growing of a single short duration crop achieved a median yield (over the 3 seasons) of 3080 kg/ha compared to farmer practice of 1852 kg/ha).

Comparison of gross margin shows that the median for the single short duration crop was $411/ha compared to $288/ha for farmer practice (without labour costs). When labour was included the median gross margin for the 1 short duration crop was $213 compared to a loss of $101 for farmer practice. Of particular interest in this comparison is that the top farmer growing a single short duration crop achieved a gross margin, with labour of $1031 compared to the best farmer practice of $160, a large disparity, but one that provides optimism for the use of improved management options as farmers are challenged by the vagaries of climate and markets. Time lines for the growing of this option under rainfed and supplementary irrigated conditions are provided in Appendix 1 and 2 (Options 3(a) and 3(b).

4. **(a) Medium duration rice-single crop-direct seeded or transplanted-supplementary irrigation**

   (b) Medium duration rice-single crop-direct seeded or transplanted-rainfed

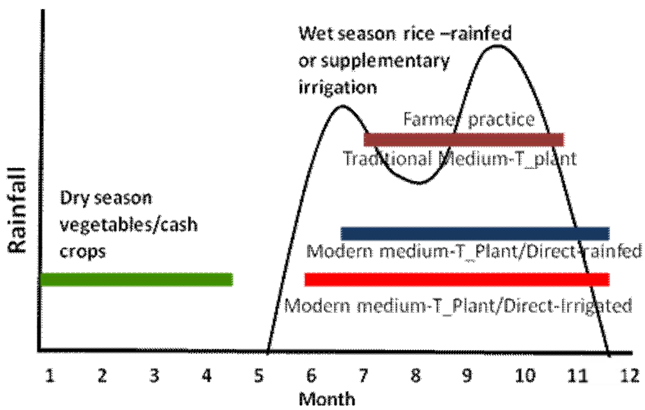

Figure 5: Replacing 'Farmer Practice' with a single, medium duration, direct seeded crop grown either under rainfed conditions or with supplementary irrigation (grown using CARDI fertiliser rates and good

The use of a direct seeded, medium duration, modern variety, is the closest option to current farmer practice (Figure 5) and therefore the least risky of the suggested rainfed options in terms of current Svay Rieng and Prey Veng farmer experience. Typically farmer practice, and this option would be planted at similar times, although, where supplementary irrigation is available, the medium crop could be planted earlier to reduce the risk of late wet season water deficit. The median yield achieved over the 3 seasons from growing a medium, modern variety (typically Phka Rumdoul) was higher than for farmer practice (2461 kg/ha compared to 1852 kg/ha for farmer practice) but was lower than those achieved with the single, short duration modern variety (Table 3). However, gross margins were not dissimilar between these 2 options, as shown in Table 4. Time lines for the growing of this option under rainfed and supplementary irrigated conditions are provided in Appendix 1 and 2 (Options 3(a) and 3(b).

Table 3: *Seasonal production and gross margin (with and without labour) for 1 medium duration crop (grown with recommended fertiliser input) compared to farmer practice (1 medium duration traditional variety with limited inputs) in Svay Rieng (2011 to 2013) and Prey Veng (2013) provinces.*

Season	**2011**		**2012**		**2013**	**All seasons**	
Establishment	Direct	Transplant	Direct	Transplant	Direct	Direct	Transplant
Duration	Medium	Farmer practice	Medium	Farmer practice	Medium	Medium	Farmer practice
No. of crops in season	1	1	1	1	1	1	1
Time of establishment	Mid	Mid	Mid	Mid	Mid	Mid	Mid
Plot number	14	35	15	27	19	48	62
Seasonal production (kg/ha at 14% moisture)							
Low Yield	926	1229	1291	1094	2261	926	1094
Median Yield	2017	1792	1886	1927	3404	2461	1852
Highest Yield	2641	2372	2746	2535	3884	3884	2535
Middle 50%	1754-2533	1621-1973	1633-2389	1621-2104	3091-3524	1863-3232	1621-2023
Gross margin-no labour (US$/ha)							
Low	15	81	184	30	213	15	30
Median	460	296	343	283	469	446	288
Highest	760	456	674	428	647	760	456
Middle 50%	348-647	253-354	301-543	174-341	395-525	328-541	236-350
Gross margin-with labour (US$/ha)							
Low	(45)	(329)	13	(363)	45	(45)	(363)
Median	387	(114)	171	(91)	292	289	(101)
Highest	664	46	502	160	477	664	160
Middle 50%	288-575	(157)-(56)	129-371	(180)-(9)	249-351	165-396	(157)-(39)

Comparing the suggested systems options

To this point, this report has made comparison between the possible system options identified through on-farm research and the typical farmer practice of growing a local, transplanted, medium duration variety, however it is also important to compare the differences between the suggested system options. Table 4 provides an overview of the seasonal productivity and gross margins achieved during 3 seasons of research. As might be expected, when comparing median seasonal production, the growing of 2 short duration crops shows the best returns, however when seasonal gross margin for each system is compared the story is more complex. Where inputs costs are considered, but not labour, the highest median return is still achieved from growing 2 short duration crops, but when labour is included, the modern, medium duration option is ahead of the short duration options ($289/ha, compared to $213/ha and $227/ha for the short duration cropping options). This is a result of the higher costs of pesticides required to control weed and insects in the early wet season, compared to later medium duration crops where weeds are often controlled through flooding and insects tend to be diluted across larger areas of crop.

The data also show that there is more downside financial risk associated with the growing of short duration varieties (lowest gross margin with labour for 1 short crop of -$295 and for 2 short of -$630/ha) than with the modern medium (-$45), although it is suggested that as farmer and agronomist experience increases, these differences are likely to reduce, while at the same time, the number producing higher yields (and achieving higher gross margins) will increase. A very positive indication of this is the high levels of production and subsequent high gross margins being achieved by individual farmers. For example, the best seasonal productivity from a single short duration variety was 6394 kg/ha and for the sequence of 2 short varieties, 7095 kg/ha, while the highest gross margins (including labour) were $1031/ha and $689/ha respectively.

Table 4: *Overall comparison of the 3 tested systems options compared to farmer practice (1 medium duration traditional variety with limited inputs) in Svay Rieng (2011 to 2013) and Prey Veng (2013) provinces showing seasonal production and gross margin (with, and without labour).*

	All seasons			
Establishment	Direct	Direct	Direct	Transplant
Duration	Short	Short	Medium	Farmer practice
No. of crops in season	1	2	1	1
Time establishment	Early to Mid	Early & Mid	Mid	Mid
Seasonal production (kg/ha at 14% moisture)				
Low Yield	890	1792	926	1094
Median Yield	3080	4745	2461	1852
Highest Yield	6394	7095	3884	2535
Middle 50%	2514-3902	4015-5687	1863-3232	1621-2023
Gross margin-no labour (US$/ha)				
Low	(83)	(261)	15	30
Median	411	545	446	288

Highest	1205	987	760	456
Middle 50%	230-542	300-669	328-541	236-350
Gross margin-with labour (US$/ha)				
Low	(295)	(630)	(45)	(363)
Median	213	227	289	(101)
Highest	1031	689	664	160
Middle 50%	46 to 376	(49) to 323	165-396	(157)-(39)

The future

This research has shown that the direct, wet seeding of modern, short and medium duration rice varieties, using either a drum seeder or by hand broadcasting, and grown using higher levels of nutrition and agronomic management will increase the productivity and economics of the monsoonal, rice based cropping systems of Cambodia. However, while examples of possible technologies have been provided, these should not be considered as the only available options, or that new opportunities will not arise that better fit particular farmer preferences or environmental and seasonal conditions. For example, the use of direct seeding into dry conditions using specially developed planters is currently being researched and may provide improvements to systems flexibility and timeliness of operations compared to current options. It should also be remembered that it is very unlikely, at least in the short to medium term, that individual farmers would commit the whole of their production area to a particular cropping system. This is the case for a number of reasons including the need to, a) vary crop production timing to balance labour demand and availability, b) manage seasonal production risk, c) minimise security issues (animal and human) associated with the production of crops that are established or mature outside the accepted norms for the village, and d) meet individual household culinary preferences.

The important research message is that a flexible approach to rice production and being responsive to environmental conditions will pay dividends to the individual farmer and to overall rice productivity. However, the price for being involved in producing rice in a responsive way is the need for the farmer to be more alert to changes in seasonal conditions and to be able to respond quickly. It also requires extension workers to develop a much more dynamic ‘whole of season, hands-on’ approach to farmer engagement and support.

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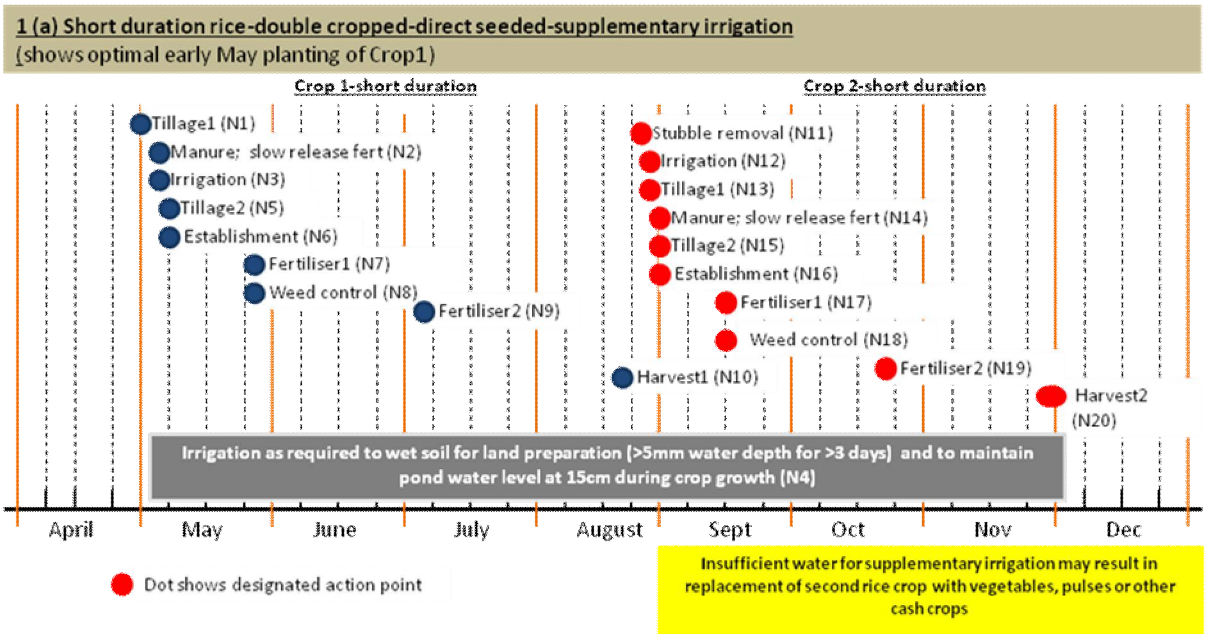
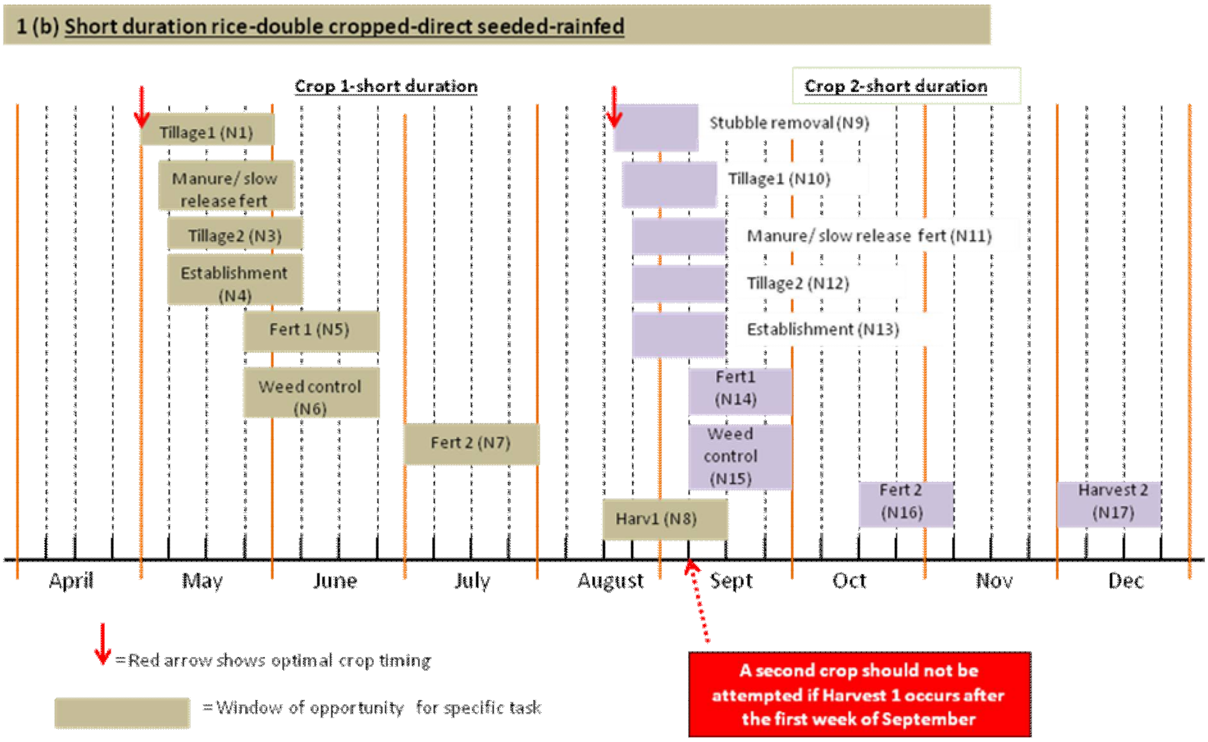
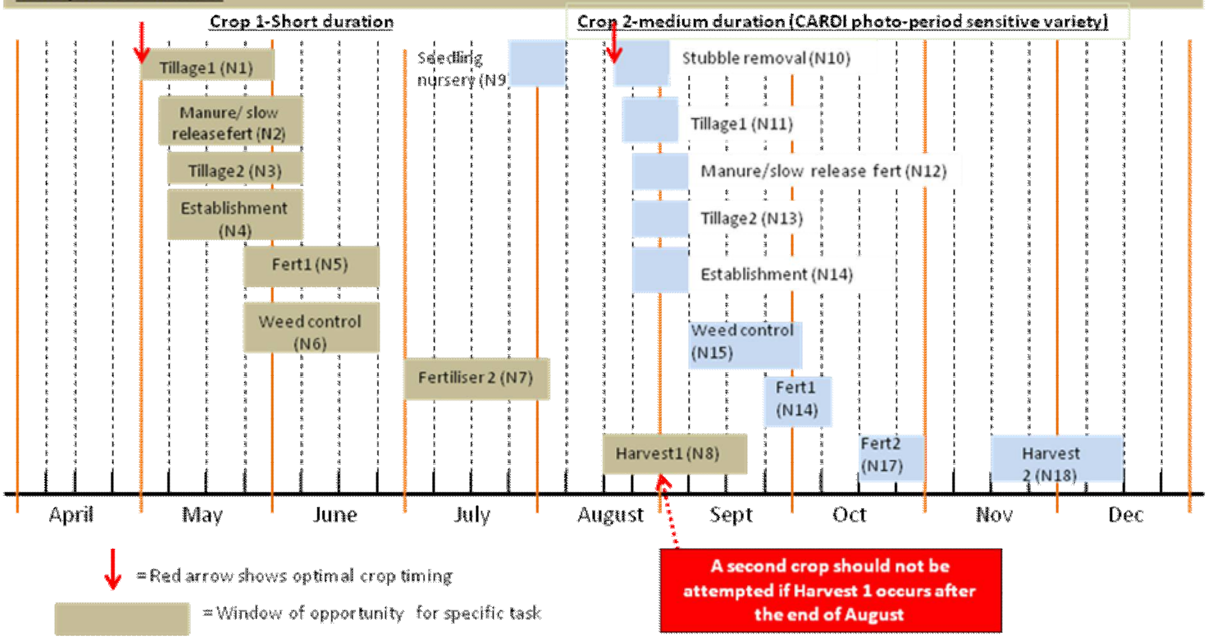
Appendix 1: Seasonal cropping calendars

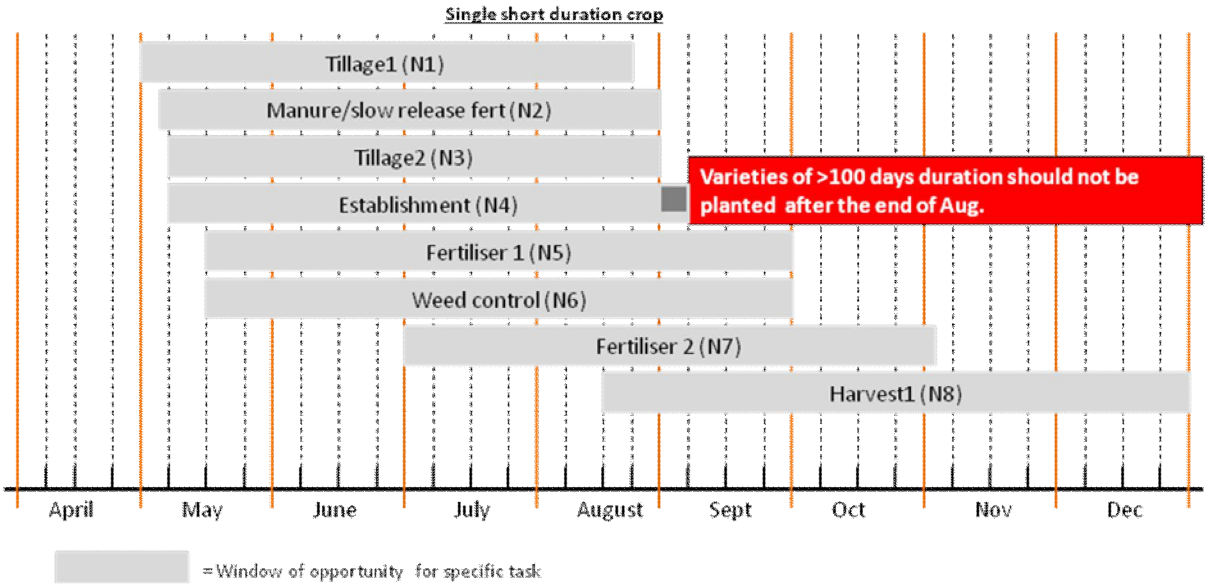




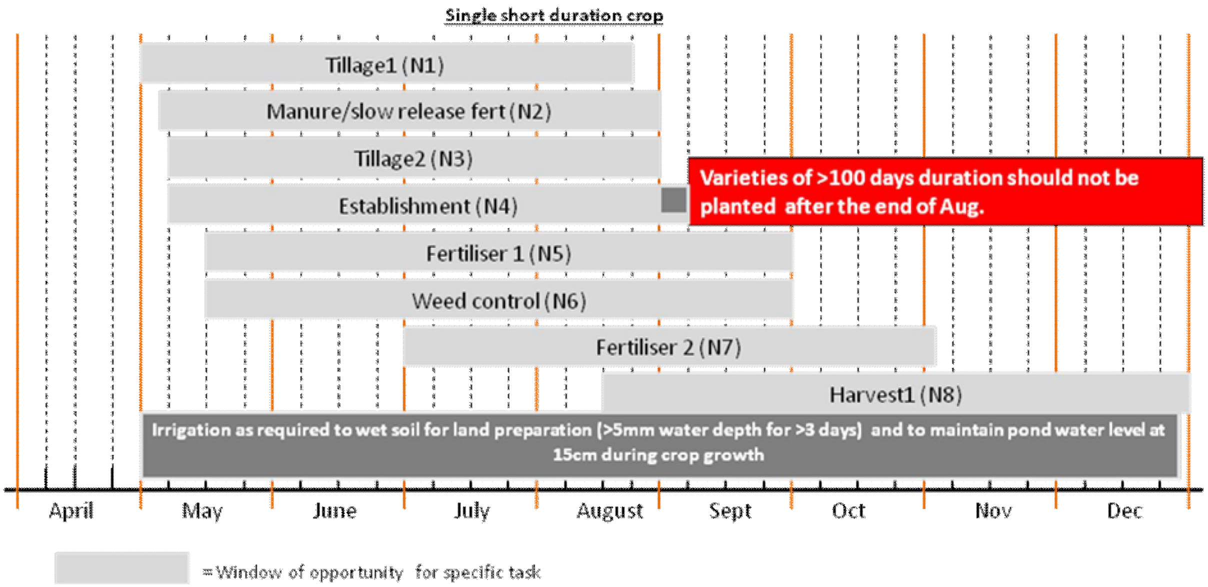
2. Short duration rice-direct seeded-rainfed, double cropped with medium duration rice (CARDI photo-period sensitive)-transplanted–rainfed



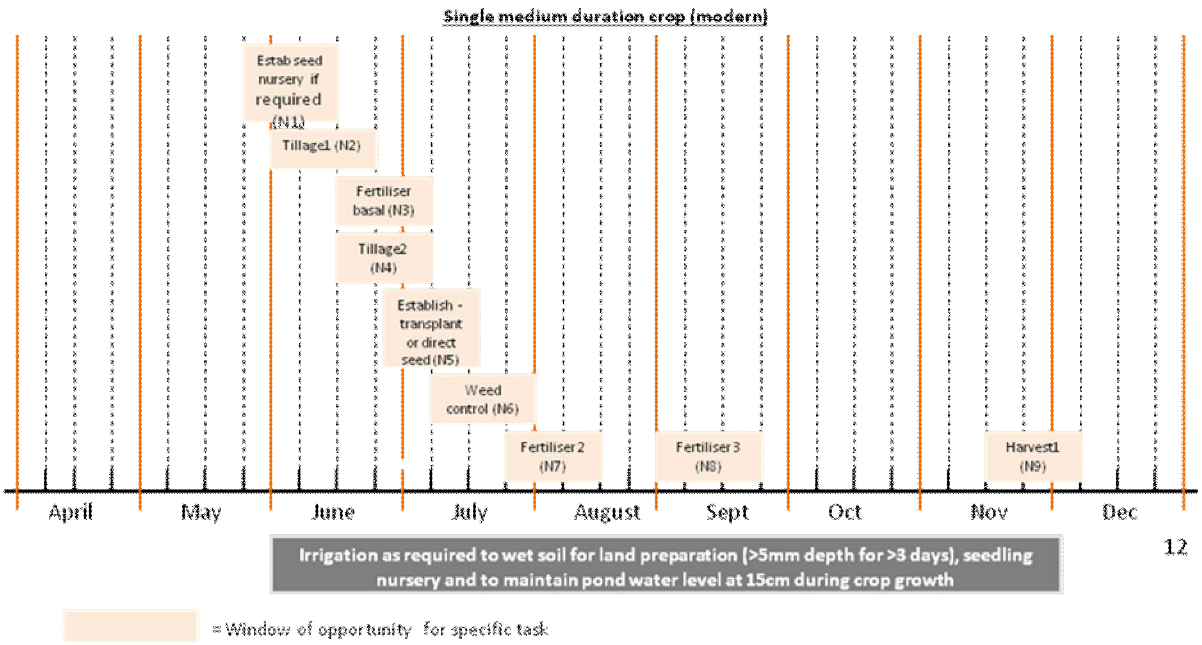
3(a) Short duration rice-single cropped-direct seeded-rainfed



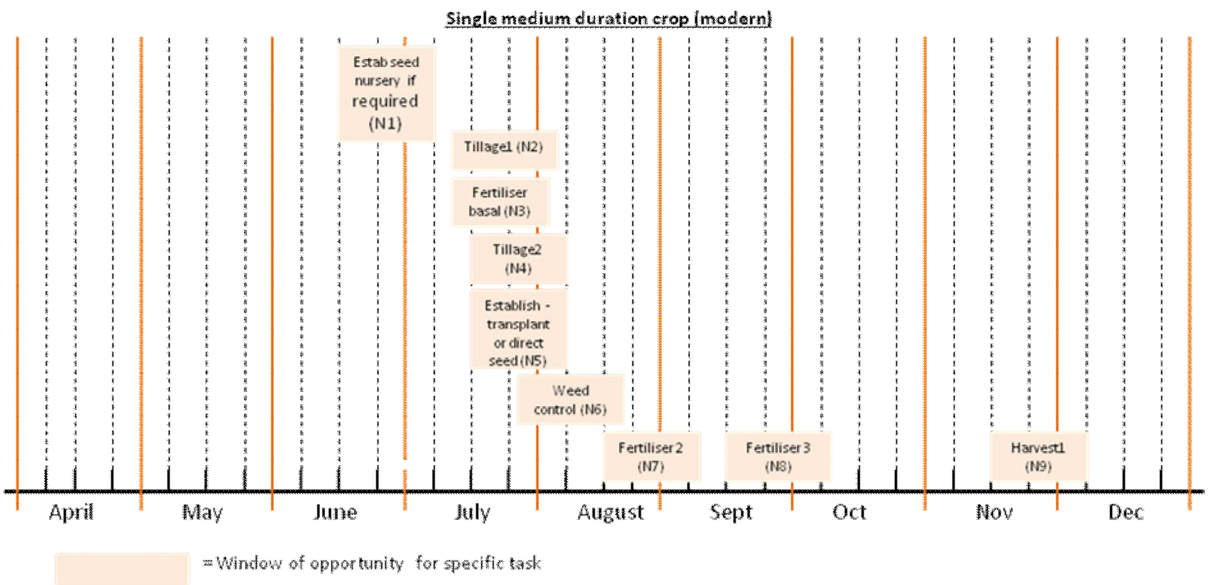
3(b) Short duration rice-single cropped-direct seeded-supplementary irrigation



4a) Medium duration rice-single crop –direct seeded or transplanted-supplementary irrigation



4b). Medium duration rice-single crop-direct seeded or transplanted-rainfed



Appendix 2: Response farming protocols (*Ver 1.11_June 2014)*

1 (a) Short duration rice-double cropped-direct seeded- irrigated

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
Crop 1-short duration					
1	1	Tillage 1 (T1)	1, 2	May-week1	If no rain, add sufficient water to allow tillage to be undertaken. Tillage is assumed to be done with power tiller. Harrowing and levelling (which are the main reasons for the second tillage) may be done as part of T1 if later access to a power tiller is likely to be difficult.
2		Manure and/or slow release fertiliser	1, 2	May-week1 5 days after T1	Manure: it is difficult to be definitive regarding manure application due to the variability in supply. When available, manure is to be applied prior to T2. The recommended rate is 5000kg/ha (dry weight) but a more typical rate is likely to be 300 to 500 kg/ha (dry weight). Apply whatever is available. Slow release compressed block fertiliser (e.g. FDP) (if being used): incorporate at a rate of 180kg/ha prior to tillage 2 (assuming FDP nutrient concentrations). Where a slow release fertiliser is used, no additional fertiliser is applied at 15 DAS (days after sowing) although extra N may be required at Panicle Initiation (PI), depending on crop performance.
3		Irrigation at planting	1, 2	May-week1 6 days after T1	Add water, if required, to ensure soil surface is wet and suitable for drum seeding prior to T2.
4		Irrigation through season	1, 2	As required to maintain pond water level at 15cm.	Irrigations to be applied during the season to maintain water levels at 15cm, timing of this will be dependent on rainfall and availability of irrigation water.
5		Tillage 2 (T2)	1, 2	May-week1 7 days after T1	Tillage undertaken. Assumed to be done with power tiller (see T1 regarding harrowing option)
6		Establishment - drum seeding or hand broadcasting (P1)	1, 2	May-week1 7 days after T1	Drum seeding: Seed soaked for 12 hours and allowed to sit for 12 hours before being sown at a rate of 80 kg/ha (dry seed weight) Hand broadcast: Seed soaked for 24 hours and allowed to sit for 24 hours before being sown at a rate of 150-200 kg/ha (dry seed weight) (rate 15 to 20g/m^2) (dry seed weight)
7		Fertiliser 1	Koktrap	May-week4 15 days after T1 or as indicated in Note 2	Urea (50 kg/ha); DAP (75kg/ha); KCl (50 kg/ha). Timing of application of fertiliser should occur when the depth of water in the paddy is <20cm but when the whole soil surface is covered. KCl application may be split between the 15 DAS application and the PI application. **Note:** Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 15 DAS although N may be required at PI.

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
7			Prateah Lang	May-week4 15 days after T1 or as indicated in Note 2	Urea (35 kg/ha); DAP (50kg/ha); KCl (50 kg/ha). Will be applied as a basal if manure is not available (Note 2). Timing of application of fertiliser should occur when the depth of water in the paddy is <20cm but when the whole soil surface is covered. KCl application may be split between the 15 DAS application and the PI application. KCl application may be split between the 15 DAS application and the PI application. **Note:** Where slow release fertiliser (e.g. FDP) is used, no additional fertiliser is applied in-crop at 15 DAS although N may be required at PI.
8		Weed control	1, 2	May-week3 15 days after T1	Hand weeding or Chemical weed control. Herbicide either applied in a granular form mixed with the fertiliser or as a liquid using a hand sprayer. Granular application is not recommended due to a lower chemical efficiency but is being used by farmers due to the labour savings. **ACTION: List trade names (must be registered with Ministry Ag by active ingredients) and also check what is available in local markets. Suggest including a photo of labels of locally available herbicides. Note: investigate this for fertilisers also, including FDP.** **a) Pre-emergent herbicide in rice** **Pretilachlor** 1. AI : Pretilachlor 300g/L+safener 2. Brand name: Sofit Syngenta 3. Used to control: Grasses, sedges and broadleaves 4. Rate : 1 to 1.5 L / ha 2) spray volume: 160 to 224 L /ha 5. Application: Wet direct seeded 0-3 DAS **Butachlor** 1. Active Chemical: Butaclor 60% 2. Brand name: Taco600EC 3. Company name: Guangzhou Pesticide factory 4. Used to control: Grasses, sedges and broadleaves 5. The usage: 25ml-30ml/1000m2 (Spray volume: 200L water/ha) 6. Application: Wet direct seeded 1-4 DAS **B) Post emergence herbicide in rice at SVR**

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
					Power 1. Active Chemical: Quinchlorac 2. Brand name: Power 3. Company name: Agrotech 4. Used to control: Grasses, sedges and broadleaves 5. The usage: 20g/500m2(Spray volume: 300L/ha) **Master** 1. Active Chemical: Chlorinuron Ethyl+ Metsulfuron Methyl 2. Brand name: Master 3. Company name: Agrotech 4. Used to control: sedges and broadleaves 5. The usage: 10g/ha(Spray volume: 200L/ha)
9		Fertiliser 2 @ Panicle Initiation	Koktrap	July-week1 At panicle initiation	Rates of fertiliser application should be based on crop performance (particularly crop colour), CARDI recommendations are: Urea (80 kg/ha). Application timing may vary with variety as this application is linked to crop phenology. **Note**: Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 15 DAS although 20kg/ha N (44kg/ha) Urea may be applied at PI if crop colour suggests N is required.
9			Prateah Lang	July-week1 At panicle initiation	Rates of fertiliser application should be based on crop performance (particularly crop colour), CARDI recommendations are Urea (55 kg/ha). Application timing may vary with variety as this application is linked to crop phenology. **Note:** Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 15 DAS although 20kg/ha N (44kg/ha) Urea may be applied at PI if crop colour suggests N is required.
10		Crop maturity and harvest (H1)	1, 2	August-week3 85-100 days after P1	Harvest: Timing will depend on the duration of the variety being grown but will be between 85 and 110 days from planting.
Crop 2-short duration					
NOTE: If water for supplementary irrigation of the second crop is unavailable, then the production of vegetables, forages, pulses or other cash crops should be considered as alternative land-use options					
11	2	Stubble removal	1, 2	August-week4 2 days after harvest1	Stubble management: to be cut at 10-15 cm above the soil to minimise the crop transition time (facilitate ploughing, reduce N tie up) and removed from the field (animal feeding?)

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
13		Tillage 1	1, 2	August-week4 6 days after harvest1	Tillage undertaken after sufficient rainfall or irrigation when pond water at a depth of >5mm for >3 days. Tillage is assumed to be done with a power tiller. Harrowing and levelling (which are the main reasons for the second tillage) may be done as part of T1 if later access to a power tiller is likely to be difficult.
14		Manure and/or slow release fertiliser	1, 2	August-week4 7 days after harvest1	Manure: it is difficult to be definitive regarding manure application due to the variability in supply. When available, manure is to be applied prior to T2. The recommended rate is 5000kg/ha (dry weight) but a more typical rate is likely to be 300 to 500 kg/ha (dry weight). Apply whatever is available. Slow release compressed block fertiliser (e.g. FDP) (if being used): incorporate at a rate of 180kg/ha prior to tillage 2 (assuming FDP nutrient concentrations). Where a slow release fertiliser is used, no additional fertiliser is applied at 15 DAS (days after sowing) although extra N may be required at Panicle Initiation (PI), depending on crop performance.
12		Irrigation prior to T2	1, 2	August-week4 7 days after harvest1	If no rain, add water, to ensure soil surface is wet and suitable for drum seeding.
15		Tillage 2	1, 2	August-week4 7 days after harvest 1	Tillage undertaken. Assumed to be done with power tiller (see T1 regarding harrowing option)
16		Establishment - drum seeding or hand broadcasting (P2)	1, 2	August-week4 7 days after harvest1	Drum seeding: Seed soaked for 12 hours and allowed to sit for 12 hours before being sown at a rate of 80 kg/ha (dry seed weight) Hand broadcast: Seed soaked for 24 hours and allowed to sit for 24 hours before being sown at a rate of 150-200 kg/ha (dry seed weight) (rate 15 to 20g/m^2) (dry seed weight)
4		Irrigation through season	1, 2	As required to maintain pond water level at 15cm.	Irrigations to be applied during the season to maintain water levels at 15cm, timing of this will be dependent on rainfall and availability of irrigation water.
17		Fertiliser 1	Koktrap	September-week3 15 days after P2 or as indicated in Note 14	Urea (50 kg/ha); DAP (75kg/ha); KCl (50 kg/ha). Timing of application of fertiliser should occur when the depth of water in the paddy is <20cm but when the whole soil surface is covered. KCl application may be split between the 15 DAS application and the PI application. KCl application may be split between the 15 DAS application and the PI application. **Note**: Where slow release fertiliser (e.g. FDP) is used as a basal, no additional fertiliser is applied in-crop at 15 DAS although a top-up of N may be required at PI.
17			Prateah Lang	September-week3 15 days after P2 or as	Urea (35 kg/ha); DAP (50kg/ha); KCl (50 kg/ha). May be applied as a basal (Note 14). Timing of application of fertiliser should occur when the depth of water in the paddy is <20cm but when the

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
				indicated in Note 14	whole soil surface is covered. KCl application may be split between the 15 DAS application and the PI application. KCl application may be split between the 15 DAS application and the PI application. **Note**: Where slow release fertiliser (e.g. FDP) is used as a basal, no additional fertiliser is applied in-crop at 15 DAS although a top-up of N may be required at PI.
18		Weed control	1, 2	September-week3 15 days after P2	Hand weeding or Chemical weed control. Herbicide either applied in a granular form mixed with the fertiliser or as a liquid using a hand sprayer. Granular application is not recommended due to a lower chemical efficiency but is being used by farmers due to the labour savings. **ACTION: List trade names (must be registered with Ministry Ag by active ingredients) and also check what is available in local markets. Suggest including a photo of labels of locally available herbicides. Note: investigate this for fertilisers also, including FDP.** **a) Pre-emergent herbicide in rice** **Pretilachlor** 1. AI : Pretilachlor 300g/L+safener 2. Brand name: Sofit Syngenta 3. Used to control: Grasses, sedges and broadleaves 4. Rate : 1 to 1.5 L / ha 2) spray volume: 160 to 224 L /ha 5. Application: Wet direct seeded 0-3 DAS **Butachlor** 1. Active Chemical: Butaclor 60% 2. Brand name: Taco600EC 3. Company name: Guangzhou Pesticide factory 4. Used to control: Grasses, sedges and broadleaves 5. Rate: 25ml-30ml/1000m2 (Spray volume: 200L water/ha) 6. Application: Wet direct seeded 1-4 DAS **B) Post emergence herbicide in rice at SVR** **Power** 1. Active Chemical: Quinchlorac 2. Brand name: Power

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
					3. Company name: Agrotech 4. Used to control: Grasses, sedges and broadleaves 5. Rate: 20g/500m2(Spray volume: 300L/ha) **Master** 1. Active Chemical: Chlorinuron Ethyl+ Metsulfuron Methyl 2. Brand name: Master 3. Company name: Agrotech 4. Used to control: sedges and broadleaves 5. Rate: 10g/ha(Spray volume: 200L/ha)
19		Fertiliser 2	Koktrap	At panicle initiation around October-week3	Rates of fertiliser application should be based on crop performance (particularly crop colour), CARDI recommendations are Urea (80 kg/ha). Application timing will vary with rice variety as this application is linked to crop phenology. **Note**: Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 15 DAS although 20kg/ha N (44kg/ha) Urea may be required at PI if crop colour suggests N is required.
19			Prateah Lang	At panicle initiation around October-week3	Rates of fertiliser application should be based on crop performance (particularly crop colour), CARDI recommendations are Urea (55 kg/ha). Application timing will vary with crop variety as this application is linked to crop phenology. **Note**: Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 15 DAS although 20kg/ha N (44kg/ha) Urea may be required at PI if crop colour suggests N is required.
20		Crop maturity and harvest (H2)	1, 2	December-week1 85-100 days after P2)	Harvest: Timing will depend on the duration of the variety being grown but will be between 85 and 110 days from planting.

Koktrap[1]; Prateah Lang[2]

1 (b). Short duration rice-double cropped-direct seeded-rainfed

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
Crop 1-short duration					
1	1	Tillage 1 (T1)	1, 2	May-week1 to May-week4	Tillage undertaken after sufficient rainfall when pond water at a depth of >5mm for >3 days. Tillage is assumed to be done with power tiller. Harrowing and levelling (which are the main reasons for the second tillage) may be done as part of T1 if later access to a power tiller is likely to be difficult.
2		Manure and/or slow release fertiliser	1, 2	5 days after T1 May-week1 to June-week1	Manure: it is difficult to be definitive regarding manure application due to the variability in supply. When available, manure is to be applied prior to T2. The recommended rate is 5000kg/ha (dry weight) but a more typical rate is likely to be 300 to 500 kg/ha (dry weight). Apply whatever is available. Slow release compressed block fertiliser (e.g. FDP) (if being used): incorporate at a rate of 180kg/ha prior to tillage 2 (assuming FDP nutrient concentrations). Where a slow release fertiliser is used, no additional fertiliser is applied at 15 DAS (days after sowing) although extra N may be required at Panicle Initiation (PI), depending on crop performance.
3		Tillage 2 (T2)	1, 2	7 days after T1 May-week1 to June-week1	Tillage undertaken. Assumed to be done with power tiller (see T1 regarding harrowing option)
4		Establishment - drum seeding or hand broadcasting (P1)	1, 2	7 days after T1 May-week2 to June-week1	Drum seeding: Seed soaked for 12 hours and allowed to sit for 12 hours before being sown at a rate of 80 kg/ha (dry seed weight) Hand broadcast: Seed soaked for 24 hours and allowed to sit for 24 hours before being sown at a rate of 150-200 kg/ha (dry seed weight) (rate 15 to 20g/m^2) (dry seed weight)
5		Fertiliser 1	Koktrap	15 days after T1 May-week4 to June-week4 or as indicated in Note 2	Urea (50 kg/ha); DAP (75kg/ha); KCl (50 kg/ha). Timing of application of fertiliser should occur when the depth of water in the paddy is <20cm in depth but when the whole soil surface is covered. KCl application may be split between the 15 DAS application and the PI application. **Note**: Where slow release fertiliser (e.g. FDP) is used as a basal, no additional fertiliser is applied in-crop at 15 DAS although additional N may be required at PI.
5			Prateah Lang	15 days after T1	Urea (35 kg/ha); DAP (50kg/ha); KCl (50 kg/ha). May be applied as a basal (Note 2). Timing of application

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
				May-week4 to June-week4 or as indicated in Note 2	of fertiliser should occur when the depth of water in the paddy is <20cm but when the whole soil surface is covered. KCl application may be split between the 15 DAS application and the PI application. KCl application may be split between the 15 DAS application and the PI application. **Note**: Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 15 DAS although additional N may be required at PI.
6		Weed control	1, 2	15 days after T1 May-week4 to June-week4	Hand weeding or Chemical weed control. Herbicide either applied in a granular form mixed with the fertiliser or as a liquid using a hand sprayer. Granular application is not recommended due to a lower chemical efficiency but is being used by farmers due to the labour savings. **ACTION: List trade names (must be registered with Ministry Ag by active ingredients) and also check what is available in local markets. Suggest including a photo of labels of locally available herbicides. Note: investigate this for fertilisers also, including FDP.** **a) Pre-emergent herbicide in rice** **Pretilachlor** 1. AI : Pretilachlor 300g/L+safener 2. Brand name: Sofit Syngenta 3. Used to control: Grasses, sedges and broadleaves 4. Rate : 1 to 1.5 L / ha 2) spray volume: 160 to 224 L /ha 5. Application: Wet direct seeded 0-3 DAS **Butachlor** 1. Active Chemical: Butaclor 60% 2. Brand name: Taco600EC 3. Company name: Guangzhou Pesticide factory 4. Used to control: Grasses, sedges and broadleaves 5. The usage: 25ml-30ml/1000m2 (Spray volume: 200L water/ha) 6. Application: Wet direct seeded 1-4 DAS **B) Post emergence herbicide in rice at SVR** **Power** 1. Active Chemical: Quinchlorac 2. Brand name: Power

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
					3. Company name: Agrotech 4. Used to control: Grasses, sedges and broadleaves 5. The usage: 20g/500m2(Spray volume: 300L/ha) **Master** 1. Active Chemical: Chlorinuron Ethyl+ Metsulfuron Methyl 2. Brand name: Master 3. Company name: Agrotech 4. Used to control: sedges and broadleaves 5. The usage: 10g/ha(Spray volume: 200L/ha)
7		Fertiliser 2 @ Panicle Initiation	Koktrap	At PI from July-week1 to July-week4	Rates of fertiliser application should be based on crop performance (particularly crop colour), CARDI recommendations are Urea (80 kg/ha). Application timing will vary with rice variety as this application is linked to crop phenology. **Note**: Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 15 DAS although 20kg/ha N (44kg/ha) Urea may be required at PI if crop colour suggests N is required.
7			Prateah Lang	At PI from July-week1 to July-week4	Rates of fertiliser application should be based on crop performance (particularly crop colour), CARDI recommendations are Urea (55 kg/ha). Application timing will vary with crop variety as this application is linked to crop phenology. **Note**: Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 15 DAS although 20kg/ha N (44kg/ha) Urea may be required at PI if crop colour suggests N is required.
8		Crop maturity and harvest (H1)	1, 2	Aug-week3 to Sept-week2	Harvest: Timing will depend on the duration of the variety being grown but will be between 85 and 110 days from planting.
Crop 2-short duration					
9		Stubble removal	1, 2	2 days after H1 Aug-week3 to Sept-week2	Stubble management: to be cut at 10-15cm above the soil to minimise the crop transition time (facilitate ploughing, reduce N tie up) and removed from the field (animal feeding?)
10	2	Tillage 1	1, 2	6 days after H1 Aug-week3 to Sept-week2	Tillage undertaken after sufficient rainfall when pond water at a depth of >5mm for >3 days. Tillage is assumed to be done with power tiller. Harrowing and levelling (which are the main reasons for the second tillage) may be done as part of T1 if later access to a power tiller is likely to be difficult.

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
11		Manure and/or slow release fertiliser	1, 2	7 days after H1 Aug-week4 to Sept-week2	Manure: it is difficult to be definitive regarding manure application due to the variability in supply. When available, manure is to be applied prior to T2. The recommended rate is 5000kg/ha (dry weight) but a more typical rate is likely to be 300 to 500 kg/ha (dry weight). Apply whatever is available. Slow release compressed block fertiliser (e.g. FDP) (if being used): incorporate at a rate of 180kg/ha prior to tillage 2 (assuming FDP nutrient concentrations). Where a slow release fertiliser is used, no additional fertiliser is applied at 15 DAS (days after sowing) although extra N may be required at Panicle Initiation (PI), depending on crop performance.
12		Tillage 2	1, 2	7 days after H1 Aug-week4 to Sept-week2	Tillage undertaken. Assumed to be done with power tiller (see T1 regarding harrowing option)
13		Establishment - drum seeding or hand broadcasting (P2)	1, 2	Aug-week4 to Sept-week2	Drum seeding: Seed soaked for 12 hours and allowed to sit for 12 hours before being sown at a rate of 80 kg/ha (dry seed weight) Hand broadcast: Seed soaked for 24 hours and allowed to sit for 24 hours before being sown at a rate of 150-200 kg/ha (dry seed weight) (rate 15 to 20g/m^2) (dry seed weight)
14		Fertiliser 1	Koktrap	Sept-week2 and week4 15 days after P2 or as indicated in Note 11	Urea (50 kg/ha); DAP (75kg/ha); KCl (50 kg/ha). Timing of application of fertiliser should occur when the depth of water in the paddy is <20cm in depth but when the whole soil surface is covered. KCl application may be split between the 15 DAS application and the PI application. **Note**: Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 15 DAS although additional N may be required at PI.
14			Prateah Lang	Sept-week2 and week4 15 days after P2 or as indicated in Note 11	Urea (35 kg/ha); DAP (50kg/ha); KCl (50 kg/ha). May be applied as a basal (Note 11). Timing of application of fertiliser should occur when the depth of water in the paddy is <20cm but when the whole soil surface is covered. KCl application may be split between the 15 DAS application and the PI application. **Note:** Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 15 DAS although additional N may be required at PI.
15		Weed control	1, 2	Aug-week2 and week4	Hand weeding or Chemical weed control. Herbicide either applied in a granular form mixed with the fertiliser or as a liquid using a hand sprayer. Granular application is not recommended due to a lower chemical efficiency but is being used by farmers due to the labour savings.

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
					ACTION: List trade names (must be registered with Ministry Ag by active ingredients) and also check what is available in local markets. Suggest including a photo of labels of locally available herbicides. Note: investigate this for fertilisers also, including FDP. **a) Pre-emergent herbicide in rice** **Pretilachlor** 1. AI : Pretilachlor 300g/L+safener 2. Brand name: Sofit Syngenta 3. Used to control: Grasses, sedges and broadleaves 4. Rate : 1 to 1.5 L / ha 2) spray volume: 160 to 224 L /ha 5. Application: Wet direct seeded 0-3 DAS **Butachlor** 1. Active Chemical: Butaclor 60% 2. Brand name: Taco600EC 3. Company name: Guangzhou Pesticide factory 4. Used to control: Grasses, sedges and broadleaves 5. Rate: 25ml-30ml/1000m2 (Spray volume: 200L water/ha) 6. Application: Wet direct seeded 1-4 DAS **B) Post emergence herbicide in rice at SVR** **Power** 1. Active Chemical: Quinchlorac 2. Brand name: Power 3. Company name: Agrotech 4. Used to control: Grasses, sedges and broadleaves 5. Rate: 20g/500m2(Spray volume: 300L/ha) **Master** 1. Active Chemical: Chlorinuron Ethyl+ Metsulfuron Methyl 2. Brand name: Master 3. Company name: Agrotech 4. Used to control: sedges and broadleaves 5. Rate: 10g/ha(Spray volume: 200L/ha)
16		Fertiliser 2 @ panicle initiation	Koktrap	At PI from October-week3 to	Rates of fertiliser application should be based on crop performance (particularly crop colour), CARDI recommendations are Urea (80 kg/ha). Application timing will vary with rice variety as this application is

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
				November-week1	linked to crop phenology. **Note:** Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 15 DAS although 20kg/ha N (44kg/ha) Urea may be required at PI if crop colour suggests N is required.
16			Prateah Lang	At PI from October-week3 to November-week1	Rates of fertiliser application should be based on crop performance (particularly crop colour), CARDI recommendations are Urea (55 kg/ha). Application timing will vary with crop variety as this application is linked to crop phenology. **Note:** Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 15 DAS although 20kg/ha N (44kg/ha) Urea may be required at PI if crop colour suggests N is required.
17		Crop maturity and harvest	1, 2	December-week1 to week 3 85-100 days after P2	Harvest: Timing will depend on the duration of the variety being grown but will be between 85 and 110 days from planting.

Koktrap[1]; Prateah Lang[2]

2. Short duration double cropped rice followed by medium duration photo-period sensitive CARDI variety rice-rainfed, direct seeded (crop1), transplanted (Crop2)

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
Crop 1-short duration					
1	1	Tillage 1 (T1)	1, 2	May-week1 to May-week4	Tillage undertaken after sufficient rainfall when pond water at a depth of >5mm for >3 days. Tillage is assumed to be done with power tiller. Harrowing and levelling (which are the main reasons for the second tillage) may be done as part of T1 if later access to a power tiller is likely to be difficult.
2		Manure and/or slow release fertiliser	1, 2	5 days after T1 May-week1 to June-week1	Manure: it is difficult to be definitive regarding manure application due to the variability in supply. When available, manure is to be applied prior to T2. The recommended rate is 5000kg/ha (dry weight) but a more typical rate is likely to be 300 to 500 kg/ha (dry weight). Apply whatever is available. Slow release compressed block fertiliser (e.g. FDP) (if being used): incorporate at a rate of 180kg/ha prior to tillage 2 (assuming FDP nutrient concentrations). Where a slow release fertiliser is used, no additional fertiliser is applied at 15 DAS (days after sowing) although extra N may be required at Panicle Initiation (PI), depending on crop performance.
3		Tillage 2 (T2)	1, 2	7 days after T1 May-week1 to June-week1	Tillage undertaken. Assumed to be done with power tiller (see T1 regarding harrowing option)
4		Establishment - drum seeding or hand broadcasting (P1)	1, 2	7 days after T1 May-week2 to June-week1	Drum seeding: Seed soaked for 12 hours and allowed to sit for 12 hours before being sown at a rate of 80 kg/ha (dry seed weight) Hand broadcast: Seed soaked for 24 hours and allowed to sit for 24 hours before being sown at a rate of 150-200 kg/ha (dry seed weight) (rate 15 to 20g/m^2) (dry seed weight)
5		Fertiliser 1	Koktrap	15 days after T1 May-week4 to June-week4 or as indicated in Note 2	Urea (50 kg/ha); DAP (75kg/ha); KCl (50 kg/ha). Timing of application of fertiliser should occur when the depth of water in the paddy is <20cm but when the whole soil surface is covered. KCl application may be split between the 15 DAS application and the PI application. KCl application may be split between the 15 DAS application and the PI application. **Note:** Where slow release fertiliser (e.g. FDP) is used as a basal, no additional fertiliser is applied in-crop at 15 DAS although a top-up of Urea may be required at PI.

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
5			Prateah Lang	15 days after T1 May-week4 to June-week4 or as indicated in Note 2	Urea (35 kg/ha); DAP (50kg/ha); KCl (50 kg/ha). May be applied as a basal (Note 2). Timing of application of fertiliser should occur when the depth of water in the paddy is <20cm but when the whole soil surface is covered. KCl application may be split between the 15 DAS application and the PI application. **Note:** Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 15 DAS although N may be required at PI.
6		Weed control	1, 2	15 days after T1 May-week4 to June-week4	Hand weeding or Chemical weed control. Herbicide either applied in a granular form mixed with the fertiliser or as a liquid using a hand sprayer. Granular application is not recommended due to a lower chemical efficiency but is being used by farmers due to the labour savings. **ACTION: List trade names (must be registered with Ministry Ag by active ingredients) and also check what is available in local markets. Suggest including a photo of labels of locally available herbicides. Note: investigate this for fertilisers also, including FDP.** **a) Pre-emergent herbicide in rice** **Pretilachlor** 6. AI : Pretilachlor 300g/L+safener 7. Brand name: Sofit Syngenta 8. Used to control: Grasses, sedges and broadleaves 9. Rate : 1 to 1.5 L / ha 2) spray volume: 160 to 224 L /ha 10. Application: Wet direct seeded 0-3 DAS **Butachlor** 7. Active Chemical: Butaclor 60% 8. Brand name: Taco600EC 9. Company name: Guangzhou Pesticide factory 10. Used to control: Grasses, sedges and broadleaves 11. The usage: 25ml-30ml/1000m2 (Spray volume: 200L water/ha) 12. Application: Wet direct seeded 1-4 DAS **B) Post emergence herbicide in rice at SVR**

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
					Power 6. Active Chemical: Quinchlorac 7. Brand name: Power 8. Company name: Agrotech 9. Used to control: Grasses, sedges and broadleaves 10. The usage: 20g/500m2(Spray volume: 300L/ha) **Master** 6. Active Chemical: Chlorinuron Ethyl+ Metsulfuron Methyl 7. Brand name: Master 8. Company name: Agrotech 9. Used to control: sedges and broadleaves 10. The usage: 10g/ha(Spray volume: 200L/ha)
7		Fertiliser 2 @ Panicle Initiation	Koktrap	At PI from July-week1 to July-week4	Rates of fertiliser application should be based on crop performance (particularly crop colour), CARDI recommendations are Urea (80 kg/ha). Application timing will vary with rice variety as this application is linked to crop phenology. **Note:** Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 15 DAS although 20kg/ha N (44kg/ha) Urea may be required at PI if crop colour suggests N is required.
7			Prateah Lang	At PI from July-week1 to July-week4	Rates of fertiliser application should be based on crop performance (particularly crop colour), CARDI recommendations are Urea (55 kg/ha). Application timing will vary with crop variety as this application is linked to crop phenology. **Note:** Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 15 DAS although 20kg/ha N (44kg/ha) Urea may be required at PI if crop colour suggests N is required.
8		Crop maturity and harvest (H1)	1, 2	Aug-week3 to Sept-week2	Harvest: Timing will depend on the duration of the variety being grown but will be between 85 and 110 days from planting. **Note**: A second crop should not be attempted if Harvest 1 occurs after the end of August
Crop 2-medium duration					
9	1	Seedling nursery	1, 2	July-week4 to Aug-week1	Seedling nursery established for medium duration, photo period sensitive CARDI variety. This is only possible if there is sufficient rainfall at nursery establishment.

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
10		Stubble removal	1, 2	2 days after H1 Aug-week3 to Sept-week1	Stubble management: to be cut at 10-15cm above the soil to minimise the crop transition time (facilitate ploughing, reduce N tie up) and removed from the field (animal feeding?)
11	2	Tillage 1	1, 2	6 days after H1 Aug-week3 to Sept-week1	Tillage undertaken after sufficient rainfall when pond water at a depth of >5mm for >3 days. Tillage is assumed to be done with power tiller. Harrowing and levelling (which are the main reasons for the second tillage) may be done as part of T1 if later access to a power tiller is likely to be difficult.
12		Manure/ basal or slow release fertiliser	Koktrap	7 days after H1 Aug-week4 to Sept-week1	Manure: it is difficult to be definitive regarding manure application due to the variability in supply. When available, manure is to be applied prior to T2. The recommended rate is 5000kg/ha (dry weight) but a more typical rate is likely to be 300 to 500 kg/ha (dry weight). Apply whatever is available. Slow release compressed block fertiliser (e.g. FDP) (if being used): incorporate at a rate of 180kg/ha prior to tillage 2 (assuming FDP nutrient concentrations). Where a slow release fertiliser is used, no additional fertiliser is applied at 15 DAS (days after sowing) although extra N may be required at Panicle Initiation (PI), depending on crop performance. or Fertiliser Basal (for transplanted crops): Basal fertiliser will be applied prior to the second tillage. Urea (50 kg/ha); DAP (75kg/ha); KCl (50 kg/ha) instead of at 30DAS (N7). Direct seeded crops will have fertiliser applied at 30DAS.
			Prateah Lang	7 days after H1 Aug-week4 to Sept-week1	Manure: it is difficult to be definitive regarding manure application due to the variability in supply. When available, manure is to be applied prior to T2. The recommended rate is 5000kg/ha (dry weight) but a more typical rate is likely to be 300 to 500 kg/ha (dry weight). Apply whatever is available. Slow release compressed block fertiliser (e.g. FDP) (if being used): incorporate at a rate of 180kg/ha prior to tillage 2 (assuming FDP nutrient concentrations). Where a slow release fertiliser is used, no additional fertiliser is applied at 15 DAS (days after sowing) although extra N may be required at Panicle Initiation (PI), depending on crop performance. or Fertiliser Basal (for transplanted crops): Basal fertiliser will be applied prior to the second tillage. Urea (35 kg/ha); DAP (75kg/ha); KCl (50 kg/ha) instead of at 30DAS (N7). Direct seeded crops will have fertiliser applied at 30DAS.
13		Tillage 2	1, 2	7 days after H1 Aug-week4 to Sept-	Tillage undertaken. Assumed to be done with power tiller (see T1 regarding harrowing option)

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
				week1	
14		Establishment - transplanted (P2)	1, 2	Aug-week3 and week 4	Transplanting: 3-4 seedlings planted in hills spaced at 20 x 20cm configuration or 2-3 seedlings planted in hills spaced at 15 x 15cm. **Note:** A second crop should not be attempted if Harvest 1 occurs after the end of August
15		Weed control	1, 2	Sept-week2 to Oct-week1	Hand weeding or Chemical weed control. Herbicide either applied in a granular form mixed with the fertiliser or as a liquid using a hand sprayer. Granular application is not recommended due to a lower chemical efficiency but is being used by farmers due to the labour savings. **ACTION: List trade names (must be registered with Ministry Ag by active ingredients) and also check what is available in local markets. Suggest including a photo of labels of locally available herbicides. Note: investigate this for fertilisers also, including FDP.** **a) Pre-emergent herbicide in rice** **Pretilachlor** 1. AI : Pretilachlor 300g/L+safener 2. Brand name: Sofit Syngenta 3. Used to control: Grasses, sedges and broadleaves 4. Rate : 1 to 1.5 L / ha 2) spray volume: 160 to 224 L /ha 5. Application: Wet direct seeded 0-3 DAS **Butachlor** 1. Active Chemical: Butaclor 60% 2. Brand name: Taco600EC 3. Company name: Guangzhou Pesticide factory 4. Used to control: Grasses, sedges and broadleaves 5. Rate: 25ml-30ml/1000m2 (Spray volume: 200L water/ha) 6. Application: Wet direct seeded 1-4 DAS **B) Post emergence herbicide in rice at SVR**

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
					Power 1. Active Chemical: Quinchlorac 2. Brand name: Power 3. Company name: Agrotech 4. Used to control: Grasses, sedges and broadleaves 5. Rate: 20g/500m2(Spray volume: 300L/ha) **Master** 1. Active Chemical: Chlorinuron Ethyl+ Metsulfuron Methyl 2. Brand name: Master 3. Company name: Agrotech 4. Used to control: sedges and broadleaves 5. Rate: 10g/ha(Spray volume: 200L/ha)
16		Fertiliser 1 -30 days after transplant/ establishment	Koktrap	Sept-week4 to Oct-week1	Apply Urea (63 kg/ha). Timing of application of fertiliser should occur when the depth of water in the paddy is <20cm but when the whole soil surface is covered. KCl application may be split between the 30DAS application and the PI application. **Note:** Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 30 DAS although a top up of N may be required at PI.
			Prateah Lang	Sept-week4 to Oct-week1	Apply Urea (43 kg/ha). Timing of application of fertiliser should occur when the depth of water in the paddy is <20cm but when the whole soil surface is covered. KCl application may be split between the 30DAS application and the PI application. **Note:** Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 30 DAS although a top up of N may be required at PI.
17		Fertiliser 2 @ Panicle Initiation	Koktrap	Oct-week3 to Oct-week4	Rates of fertiliser application should be based on crop performance (particularly crop colour), CARDI recommendations are Urea (48 kg/ha). Application timing will vary with rice variety as this application is linked to crop phenology. **Note:** Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 30 DAS although 20kg/ha N (44kg/ha) Urea may be required at PI if crop colour suggests N is required.
			Prateah Lang	Oct-week3 to Oct-	Rates of fertiliser application should be based on crop performance (particularly crop colour), CARDI

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
				week4	recommendations are Urea (33 kg/ha). Application timing will vary with crop variety as this application is linked to crop phenology. **Note:** Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 30 DAS although 20kg/ha N (44kg/ha) Urea may be required at PI if crop colour suggests N is required.
18		Crop maturity and harvest (H1)	1, 2	Nov-week3 to Dec-week2	Harvest: Because of the photo-period sensitivity of the variety, maturity will vary but is likely to be 100-110 days from nursery establishment.

3(a). Short duration rice-single cropped-direct seeded-rainfed:

(where only 1 crop is planned or the rains start late and it is not possible to grow a sequence of 2 short duration crops - assume direct seeding (but could also be transplanted)

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
Single crop-short duration					
1	1	Tillage 1 (T1)	1, 2	June-week1 to Aug-week3	Tillage undertaken after sufficient rainfall when pond water at a depth of >5mm for >3 days. Tillage is assumed to be done with power tiller. Harrowing and levelling (which are the main reasons for the second tillage) may be done as part of T1 if later access to a power tiller is likely to be difficult.
2		Manure and/or slow release fertiliser	1, 2	5 days after T1 June-week1 to Aug-week4	Manure: it is difficult to be definitive regarding manure application due to the variability in supply. When available, manure is to be applied prior to T2. The recommended rate is 5000kg/ha (dry weight) but a more typical rate is likely to be 300 to 500 kg/ha (dry weight). Apply whatever is available. Slow release compressed block fertiliser (e.g. FDP) (if being used): incorporate at a rate of 180kg/ha prior to tillage 2 (assuming FDP nutrient concentrations). Where a slow release fertiliser is used, no additional fertiliser is applied at 15 DAS (days after sowing) although extra N may be required at Panicle Initiation (PI), depending on crop performance.
3		Tillage 2	1, 2	7 days after T1 June-week2 to Aug-week4	Tillage undertaken. Assumed to be done with power tiller (see T1 regarding harrowing option)
4		Establishment - drum seeding or hand broadcasting (P1)	1, 2	7 days after T1 June-week2 to Sept-week1	Drum seeding: Seed soaked overnight and sown at 120 kg/ha Hand broadcast: Seed soaked overnight and spread at 120 kg/ha (rate 12g/m^2) **Note: Varieties of >100 days to maturity should not be planted after August week 4, only shorter duration varieties should be planted during this period e.g. IR66 or Vn504**
5		Fertiliser 1	Koktrap	15 days after T1 June-week3 to Sept-week4 or as indicated in Note 2	Urea (50 kg/ha); DAP (75kg/ha); KCl (50 kg/ha). Timing of application of fertiliser should occur when the depth of water in the paddy is <20cm in depth but when the whole soil surface is covered. KCl application may be split between the 15 DAS application and the PI application. **Note:** Where slow release fertiliser (e.g. FDP) is used as a basal, no additional fertiliser is applied in-crop at 15 DAS although a top-up of N may be required at PI.

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
5			Prateah Lang	15 days after T1 June-week3 to Sept-week4 or as indicated in Note 2	Urea (35 kg/ha); DAP (50kg/ha); KCl (50 kg/ha). Timing of application of fertiliser should occur when the depth of water in the paddy is <20cm in depth but when the whole soil surface is covered. KCl application may be split between the 15 DAS application and the PI application. **Note:** Where slow release fertiliser (e.g. FDP) is used as a basal, no additional fertiliser is applied in-crop at 15 DAS although a top-up of N may be required at PI.
6		Weed control	1, 2	15 days after T1 June-week3 to Sept-week4	Hand weeding or Chemical weed control. Herbicide either applied in a granular form mixed with the fertiliser or as a liquid using a hand sprayer. Granular application is not recommended due to a lower chemical efficiency but is being used by farmers due to the labour savings. **ACTION: List trade names (must be registered with Ministry Ag by active ingredients) and also check what is available in local markets. Suggest including a photo of labels of locally available herbicides. Note: investigate this for fertilisers also, including FDP.** **a) Pre-emergent herbicide in rice** **Pretilachlor** 1. AI : Pretilachlor 300g/L+safener 2. Brand name: Sofit Syngenta 3. Used to control: Grasses, sedges and broadleaves 4. Rate : 1 to 1.5 L / ha 2) spray volume: 160 to 224 L /ha 5. Application: Wet direct seeded 0-3 DAS **Butachlor** 1. Active Chemical: Butaclor 60% 2. Brand name: Taco600EC 3. Company name: Guangzhou Pesticide factory 4. Used to control: Grasses, sedges and broadleaves 5. Rate: 25ml-30ml/1000m2 (Spray volume: 200L water/ha) 6. Application: Wet direct seeded 1-4 DAS **B) Post emergence herbicide in rice at SVR** **Power**

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
					1. Active Chemical: Quinchlorac 2. Brand name: Power 3. Company name: Agrotech 4. Used to control: Grasses, sedges and broadleaves 5. Rate: 20g/500m2(Spray volume: 300L/ha) **Master** 1. Active Chemical: Chlorinuron Ethyl+ Metsulfuron Methyl 2. Brand name: Master 3. Company name: Agrotech 4. Used to control: sedges and broadleaves 5. Rate: 10g/ha(Spray volume: 200L/ha) **** Note for ag extension workers that they need to check for BPH risk – critical stage is max tillering (booting and flowering most risky for plant growth, but water can control).** **Suggest that DRC may want to include advice for other pests also**
7		Fertiliser 2 @ Panicle Initiation	Koktrap	Aug-week1 to Oct-week4	Rates of fertiliser application should be based on crop performance (particularly crop colour), CARDI recommendations are: Urea (80 kg/ha). Application timing will vary with rice variety as this application is linked to crop phenology. **Note:** Where slow release fertiliser (e.g.FDP) is used, no additional fertiliser is applied in-crop at 15 DAS although 20kg/ha N (44kg/ha Urea) may be required at PI if crop colour suggests N is required.
7			Prateah Lang	Aug-week1 to Oct-week4	Rates of fertiliser application should be based on crop performance (particularly crop colour), CARDI recommendations are: Urea (55 kg/ha). Application timing will vary with crop variety as this application is linked to crop phenology. **Note:** Where slow release fertiliser (e.g.FDP) is used, no additional fertiliser is applied in-crop at 15 DAS although 20kg/ha N (44kg/ha Urea) may be required at PI if crop colour suggests N is required.
8		Crop maturity and harvest (H1)	1, 2	Sept-week3 to Dec-week4	Harvest: Timing will depend on the short duration variety planted but will be between 85 and 110 days after P1. **Agreement from PDA SR that end Dec is hard deadline for harvest in 'normal' years.**

3(b). Short duration rice-single cropped-direct seeded-supplementary irrigation

(where only 1 crop is planned or the rains start late and it is not possible to grow a sequence of 2 short duration crops - assume direct seeding (but could also be transplanted)

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
Single crop-short duration					
1	1	Tillage 1 (T1)	1, 2	May-week1 to Aug-week3	Tillage undertaken after sufficient rainfall or irrigation when pond water at a depth of >5mm for >3 days. Tillage is assumed to be done with power tiller. Harrowing and levelling (which are the main reasons for the second tillage) may be done as part of T1 if later access to a power tiller is likely to be difficult.
2		Manure and/or slow release fertiliser	1, 2	5 days after T1 May-week1 to Aug-week4	Manure: it is difficult to be definitive regarding manure application due to the variability in supply. When available, manure is to be applied prior to T2. The recommended rate is 5000kg/ha (dry weight) but a more typical rate is likely to be 300 to 500 kg/ha (dry weight). Apply whatever is available. Slow release compressed block fertiliser (e.g. FDP) (if being used): incorporate at a rate of 180kg/ha prior to tillage 2 (assuming FDP nutrient concentrations). Where a slow release fertiliser is used, no additional fertiliser is applied at 15 DAS (days after sowing) although extra N may be required at Panicle Initiation (PI), depending on crop performance.
3		Tillage 2	1, 2	7 days after T1 May-week2 to Aug-week4	Tillage undertaken. Assumed to be done with power tiller (see T1 regarding harrowing option)
4		Establishment - drum seeding or hand broadcasting (P1)	1, 2	7 days after T1 May-week2 to Sept-week1	Drum seeding: Seed soaked overnight and sown at 120 kg/ha Hand broadcast: Seed soaked overnight and spread at 120 kg/ha (rate 12g/m^2) **Note: Varieties of >100 days to maturity should not be planted after August week 4, only shorter duration varieties should be planted during this period e.g. IR66 or Vn504**
5		Fertiliser 1	Koktrap	15 days after T1 May-week3 to Sept-week4 or as indicated in Note 2	Urea (50 kg/ha); DAP (75kg/ha); KCl (50 kg/ha). Timing of application of fertiliser should occur when the depth of water in the paddy is <20cm in depth but when the whole soil surface is covered. KCl application may be split between the 15 DAS application and the PI application. **Note:** Where slow release fertiliser (e.g. FDP) is used as a basal, no additional fertiliser is applied in-crop at 15 DAS although a top-up of N may be required at PI.

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
5			Prateah Lang	15 days after T1 May-week3 to Sept-week4 or as indicated in Note 2	Urea (35 kg/ha); DAP (50kg/ha); KCl (50 kg/ha). Timing of application of fertiliser should occur when the depth of water in the paddy is <20cm in depth but when the whole soil surface is covered. KCl application may be split between the 15 DAS application and the PI application. **Note:** Where slow release fertiliser (e.g. FDP) is used as a basal, no additional fertiliser is applied in-crop at 15 DAS although a top-up of N may be required at PI.
6		Weed control	1, 2	15 days after T1 May-week3 to Sept-week4	Hand weeding or Chemical weed control. Herbicide either applied in a granular form mixed with the fertiliser or as a liquid using a hand sprayer. Granular application is not recommended due to a lower chemical efficiency but is being used by farmers due to the labour savings. **ACTION: List trade names (must be registered with Ministry Ag by active ingredients) and also check what is available in local markets. Suggest including a photo of labels of locally available herbicides. Note: investigate this for fertilisers also, including FDP.** **a) Pre-emergent herbicide in rice** **Pretilachlor** 1. AI : Pretilachlor 300g/L+safener 2. Brand name: Sofit Syngenta 3. Used to control: Grasses, sedges and broadleaves 4. Rate : 1 to 1.5 L / ha 2) spray volume: 160 to 224 L /ha 5. Application: Wet direct seeded 0-3 DAS **Butachlor** 1. Active Chemical: Butaclor 60% 2. Brand name: Taco600EC 3. Company name: Guangzhou Pesticide factory 4. Used to control: Grasses, sedges and broadleaves 5. Rate: 25ml-30ml/1000m2 (Spray volume: 200L water/ha) 6. Application: Wet direct seeded 1-4 DAS

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
					B) Post emergence herbicide in rice at SVR **Power** 1. Active Chemical: Quinchlorac 2. Brand name: Power 3. Company name: Agrotech 4. Used to control: Grasses, sedges and broadleaves 5. Rate: 20g/500m2(Spray volume: 300L/ha) **Master** 1. Active Chemical: Chlorinuron Ethyl+ Metsulfuron Methyl 2. Brand name: Master 3. Company name: Agrotech 4. Used to control: sedges and broadleaves 5. Rate: 10g/ha(Spray volume: 200L/ha) **** Note for ag extension workers that they need to check for BPH risk – critical stage is max tillering (booting and flowering most risky for plant growth, but water can control).** **Suggest that DRC may want to include advice for other pests also**
7		Fertiliser 2 @ Panicle Initiation	Koktrap	July-week1 to Nov-week1	Rates of fertiliser application should be based on crop performance (particularly crop colour), CARDI recommendations are: Urea (80 kg/ha). Application timing will vary with rice variety as this application is linked to crop phenology. **Note:** Where slow release fertiliser (e.g.FDP) is used, no additional fertiliser is applied in-crop at 15 DAS although 20kg/ha N (44kg/ha Urea) may be required at PI if crop colour suggests N is required.
7			Prateah Lang	Aug-week1 to Nov-week1	Rates of fertiliser application should be based on crop performance (particularly crop colour), CARDI recommendations are: Urea (55 kg/ha). Application timing will vary with crop variety as this application is linked to crop phenology. **Note:** Where slow release fertiliser (e.g.FDP) is used, no additional fertiliser is applied in-crop at 15 DAS although 20kg/ha N (44kg/ha Urea) may be required at PI if crop colour suggests N is required.
8		Crop maturity and harvest (H1)	1, 2	Aug-week3 to Dec-week4	Harvest: Timing will depend on the short duration variety planted but will be between 85 and 110 days after P1.

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
					Agreement from PDA SR that end Dec is hard deadline for harvest in ‘normal’ years.

4 (a). Medium duration rice-single crop –direct seeded or transplanted-supplementary irrigation

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
Single crop-medium duration					
1	1	Seedling nursery	1, 2	May-week4 to June-week2	Seedling nursery established if required
2		Tillage 1 (T1)	1, 2	June-week1 to June-week3	Tillage undertaken after sufficient rainfall when pond water at a depth of >5mm for >3 days. Tillage is assumed to be done with power tiller. Harrowing and levelling (which are the main reasons for the second tillage) may be done as part of T1 if later access to a power tiller is likely to be difficult.
3		Manure/ basal or slow release fertiliser	Koktrap	June-week3 to June-week1	Manure: it is difficult to be definitive regarding manure application due to the variability in supply. When available, manure is to be applied prior to T2. The recommended rate is 5000kg/ha (dry weight) but a more typical rate is likely to be 300 to 500 kg/ha (dry weight). Apply whatever is available. Fertiliser Basal: Applied before the second tillage. Urea (18 kg/ha); DAP (75kg/ha); KCl (50 kg/ha). Note that fertiliser rate varies with soil type. or Slow release compressed block fertiliser (e.g. FDP): incorporate at a rate of 180kg/ha prior to tillage 2 (assuming FDP nutrient concentrations). Where a slow release fertiliser is used, no additional fertiliser is applied at 15 DAS (days after sowing) although extra N may be required at Panicle Initiation (PI), depending on crop performance.
			Prateah Lang	June-week3 to June-week1	Manure: it is difficult to be definitive regarding manure application due to the variability in supply. When available, manure is to be applied prior to T2. The recommended rate is 5000kg/ha (dry weight) but a more typical rate is likely to be 300 to 500 kg/ha (dry weight). Apply whatever is available. Fertiliser Basal: Fertiliser will be applied before the second tillage. Urea (13 kg/ha); DAP (50kg/ha); KCl (50 kg/ha). Note that fertiliser rate varies with soil type. or Slow release compressed block fertiliser (e.g. FDP): incorporate at a rate of 180kg/ha prior to tillage 2 (assuming FDP nutrient concentrations). Where a slow release fertiliser is used, no additional fertiliser is applied at 15 DAS (days after sowing) although extra N may be required at Panicle Initiation (PI), depending on crop performance.

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
4		Tillage 2 (T2)	1, 2	June-week3 to June-week1	Tillage undertaken. Assumed to be done with power tiller (see T1 regarding harrowing option)
5		Establishment – transplanting, drum seeding or hand broadcasting (P1)	1, 2	June-week4 to July-week2	Transplanting: 2-3 seedlings planted in hills spaced at 20 x 20cm configuration Drum seeding: Seed soaked for 12 hours and allowed to sit for 12 hours before being sown at a rate of 80 kg/ha (dry seed weight) Hand broadcast: Seed soaked for 24 hours and allowed to sit for 24 hours before being sown at a rate of 150-200 kg/ha (dry seed weight) (rate 15 to 20g/m^2) (dry seed weight)
6		Weed control	1, 2	July-week2 to July-week4	Hand weeding or Chemical weed control. Herbicide either applied in a granular form mixed with the fertiliser or as a liquid using a hand sprayer. Granular application is not recommended due to a lower chemical efficiency but is being used by farmers due to the labour savings. **ACTION: List trade names (must be registered with Ministry Ag by active ingredients) and also check what is available in local markets. Suggest including a photo of labels of locally available herbicides. Note: investigate this for fertilisers also, including FDP.** **a) Pre-emergent herbicide in rice** **Pretilachlor** 1. AI : Pretilachlor 300g/L+safener 2. Brand name: Sofit Syngenta 3. Used to control: Grasses, sedges and broadleaves 4. Rate : 1 to 1.5 L / ha 2) spray volume: 160 to 224 L /ha 5. Application: Wet direct seeded 0-3 DAS **Butachlor** 1. Active Chemical: Butaclor 60% 2. Brand name: Taco600EC 3. Company name: Guangzhou Pesticide factory 4. Used to control: Grasses, sedges and broadleaves

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
					5. Rate: 25ml-30ml/1000m2 (Spray volume: 200L water/ha) 6. Application: Wet direct seeded 1-4 DAS **B) Post emergence herbicide in rice at SVR** **Power** 1. Active Chemical: Quinchlorac 2. Brand name: Power 3. Company name: Agrotech 4. Used to control: Grasses, sedges and broadleaves 5. Rate: 20g/500m2(Spray volume: 300L/ha) **Master** 1. Active Chemical: Chlorinuron Ethyl+ Metsulfuron Methyl 2. Brand name: Master 3. Company name: Agrotech 4. Used to control: sedges and broadleaves 5. Rate: 10g/ha(Spray volume: 200L/ha)
7		Fertiliser 1 -30 days after direct seeding establishment	Koktrap	July-week4 to Aug-week2	Direct seeded crops: Urea (63 kg/ha). Timing of application of fertiliser should occur when the depth of water in the paddy is <20cm but when the whole soil surface is covered. KCl application may be split between the 30DAS application and the PI application. NOTE: transplanted crops have basal application prior to T2 (see N5) **Note:** Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 30 DAS although a top up of N may be required at PI.
			Prateah Lang	July-week4 to Aug-week2	Direct seeded crops: Urea (43 kg/ha). Timing of application of fertiliser should occur when the depth of water in the paddy is <20cm but when the whole soil surface is covered. KCl application may be split between the 30DAS application and the PI application. NOTE: transplanted crops have basal application prior to T2 (see N5) **Note:** Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 30 DAS although a top up of N may be required at PI.
8		Fertiliser 2 @ Panicle Initiation	Koktrap	Sept-week1 to Sept-week3	Rates of fertiliser application should be based on crop performance (particularly crop colour), CARDI recommendations are Urea (48 kg/ha). Application timing will vary with rice variety as this application is linked to crop phenology. **Note:** Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 30 DAS although 20kg/ha N (44kg/ha Urea) may be required at PI if crop colour suggests N is required.
			Prateah Lang	Sept-week1 to Sept-	Rates of fertiliser application should be based on crop performance (particularly crop colour), CARDI

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
				week3	recommendations are Urea (33 kg/ha). Application timing will vary with crop variety as this application is linked to crop phenology. **Note:** Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 30 DAS although 20kg/ha N (44kg/ha Urea) may be required at PI if crop colour suggests N is required.
9		Crop maturity and harvest (H1)	1, 2	Nov-week3 to Dec-week1	Harvest: Timing will depend on variety length but will be between 120 and 140 days from planting.

4b). Medium duration rice-single crop-direct seeded or transplanted-rainfed

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
Single crop-medium duration					
1	1	Seedling nursery	1, 2	June-week1-week2	Seedling nursery established if required
2		Tillage 1 (T1)	1, 2	June-week1-week2	Tillage undertaken after sufficient rainfall when pond water at a depth of >5mm for >3 days. Tillage is assumed to be done with power tiller. Harrowing and levelling (which are the main reasons for the second tillage) may be done as part of T1 if later access to a power tiller is likely to be difficult.
3		Manure/ basal or slow release fertiliser	Koktrap	June-week2-week3	Manure: it is difficult to be definitive regarding manure application due to the variability in supply. When available, manure is to be applied prior to T2. The recommended rate is 5000kg/ha (dry weight) but a more typical rate is likely to be 300 to 500 kg/ha (dry weight). Apply whatever is available. Fertiliser Basal: Applied before the second tillage. Urea (18 kg/ha); DAP (75kg/ha); KCl (50 kg/ha). Note that fertiliser rate varies with soil type. or Slow release compressed block fertiliser (e.g. FDP): incorporate at a rate of 180kg/ha prior to tillage 2 (assuming FDP nutrient concentrations). Where a slow release fertiliser is used, no additional fertiliser is applied at 15 DAS (days after sowing) although extra N may be required at Panicle Initiation (PI), depending on crop performance.
			Prateah Lang	June-week2-week3	Manure: it is difficult to be definitive regarding manure application due to the variability in supply. When available, manure is to be applied prior to T2. The recommended rate is 5000kg/ha (dry weight) but a more typical rate is likely to be 300 to 500 kg/ha (dry weight). Apply whatever is available. Fertiliser Basal: Fertiliser will be applied before the second tillage. Urea (13 kg/ha); DAP (50kg/ha); KCl (50 kg/ha). Note that fertiliser rate varies with soil type. or Slow release compressed block fertiliser (e.g. FDP): incorporate at a rate of 180kg/ha prior to tillage 2 (assuming FDP nutrient concentrations). Where a slow release fertiliser is used, no additional fertiliser is applied at 15 DAS (days after sowing) although extra N may be required at Panicle Initiation (PI), depending on crop performance.

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
4		Tillage 2 (T2)	1, 2	July-week2-week3	Tillage undertaken. Assumed to be done with power tiller (see T1 regarding harrowing option)
5		Establishment – transplanting, drum seeding or hand broadcasting (P1)	1, 2	July-week2-week3	Transplanting: 2-3 seedlings planted in hills spaced at 20 x 20cm configuration Drum seeding: Seed soaked for 12 hours and allowed to sit for 12 hours before being sown at a rate of 80 kg/ha (dry seed weight) Hand broadcast: Seed soaked for 24 hours and allowed to sit for 24 hours before being sown at a rate of 150-200 kg/ha (dry seed weight) (rate 15 to 20g/m^2) (dry seed weight)
6		Weed control	1, 2	Aug Week1-week2	Hand weeding or Chemical weed control. Herbicide either applied in a granular form mixed with the fertiliser or as a liquid using a hand sprayer. Granular application is not recommended due to a lower chemical efficiency but is being used by farmers due to the labour savings. **ACTION: List trade names (must be registered with Ministry Ag by active ingredients) and also check what is available in local markets. Suggest including a photo of labels of locally available herbicides. Note: investigate this for fertilisers also, including FDP.** **a) Pre-emergent herbicide in rice** **Pretilachlor** 1. AI : Pretilachlor 300g/L+safener 2. Brand name: Sofit Syngenta 3. Used to control: Grasses, sedges and broadleaves 4. Rate : 1 to 1.5 L / ha 2) spray volume: 160 to 224 L /ha 5. Application: Wet direct seeded 0-3 DAS **Butachlor** 1. Active Chemical: Butaclor 60% 2. Brand name: Taco600EC 3. Company name: Guangzhou Pesticide factory 4. Used to control: Grasses, sedges and broadleaves

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
					5. Rate: 25ml-30ml/1000m2 (Spray volume: 200L water/ha) 6. Application: Wet direct seeded 1-4 DAS **B) Post emergence herbicide in rice at SVR** **Power** 1. Active Chemical: Quinchlorac 2. Brand name: Power 3. Company name: Agrotech 4. Used to control: Grasses, sedges and broadleaves 5. Rate: 20g/500m2(Spray volume: 300L/ha) **Master** 1. Active Chemical: Chlorinuron Ethyl+ Metsulfuron Methyl 2. Brand name: Master 3. Company name: Agrotech 4. Used to control: sedges and broadleaves 5. Rate: 10g/ha(Spray volume: 200L/ha)
7		Fertiliser 1 -30 days after direct seeding establishment	Koktrap	Aug-week2-week3	Direct seeded crops: Urea (63 kg/ha). Timing of application of fertiliser should occur when the depth of water in the paddy is <20cm but when the whole soil surface is covered. KCl application may be split between the 30DAS application and the PI application. NOTE: transplanted crops have basal application prior to T2 (see N5) **Note:** Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 30 DAS although a top up of N may be required at PI.
			Prateah Lang	Aug-week2-week3	Direct seeded crops: Urea (43 kg/ha). Timing of application of fertiliser should occur when the depth of water in the paddy is <20cm but when the whole soil surface is covered. KCl application may be split between the 30DAS application and the PI application. NOTE: transplanted crops have basal application prior to T2 (see N5) **Note:** Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 30 DAS although a top up of N may be required at PI.
8		Fertiliser 2 @ Panicle Initiation	Koktrap	Sept-week1 to Sept-week2	Rates of fertiliser application should be based on crop performance (particularly crop colour), CARDI recommendations are Urea (48 kg/ha). Application timing will vary with rice variety as this application

Note	Crop	Action	Soil type[1, 2]	Timing window	Rules
					is linked to crop phenology. **Note:** Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 30 DAS although 20kg/ha N (44kg/ha Urea) may be required at PI if crop colour suggests N is required.
			Prateah Lang	Sept-week1 to Sept-week2	Rates of fertiliser application should be based on crop performance (particularly crop colour), CARDI recommendations are Urea (33 kg/ha). Application timing will vary with crop variety as this application is linked to crop phenology. **Note:** Where slow release fertiliser is used, no additional fertiliser is applied in-crop at 30 DAS although 20kg/ha N (44kg/ha Urea) may be required at PI if crop colour suggests N is required.
9		Crop maturity and harvest (H1)	1, 2	Nov-week4 to Dec-week2	Harvest: Timing will depend on variety length but will be between 120 and 140 days from planting

Appendix 4 – Laing et al. 2015: Dry direct seeding discussion paper Lao PDR

Direct seeding of rice in Lao PDR – a discussion paper

Alison Laing, Christian Roth, Khamphouvieng Phouisombath, Vanthong Phengvichith, Sipaseuth, Xaysathid Souliyavongsa, Khammone Thiravong, Sysavanh Vorlasan and John Schiller

Submitted to Dept. of Agriculture, MAF

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Direct seeded rice in Lao PDR

Summary of learnings from the ACCA and ACCA-SRA projects

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April 2015

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The research team is grateful for the interest and enthusiasm in the direct seeders shown by the farmers in Outhoumphone and Champhone districts, their willingness to engage in the project's farmer demonstration testing, and for their suggestions for further improvement to the seeders and to systems of mechanised rice production. We are also grateful to our colleagues Dr Silinthone Sacklokham and Mr Lytoua Chialue (both NUOL), Ms Liana Williams (CSIRO) and Dr Clemens Grunbuhel (AIT) for their assistance and support facilitating stakeholder engagement with farmers.

Staff from NAFRI, PAFO Savannakhet, DAFO Outhoumphone, DAFO Champhone and DAEC were invaluable in disseminating information and training materials on the direct seeder and in ensuring the successful establishment of on-farm demonstrations of the direct seeder.

We are grateful to Mr Sombat Phakham and his colleagues at World Vision Thailand for their ongoing support and knowledge-sharing in relation to using the direct seeder, and to their assistance sourcing additional project machines.

Abbreviations

ACCA	Shorthand for the LWR-2008-019 project, *Developing multi-scale climate change adaptation strategies for farming communities in Cambodia, Lao PDR, Bangladesh and India*
ACCA-SRA	Shorthand for the LWR-2012-110 project, *Regional co-learning in simple mechanised tools for rice planting*
DAFO	District Agriculture and Forestry Office
DAEC	Department of Agricultural Education and Cooperatives
DS	Direct seed/ed/ing
DSR	Direct seeded rice
FP	Farmer practice
GAP	Good agricultural practice; a system of crop management developed and recommended by NAFRI
GM	Gross margin
IFAD	International Fund for Agricultural Development
NAFRI	National Agriculture and Forestry Research Institute
NUOL	National University of Laos
PAFO	Provincial Agriculture and Forestry Office
TP	Transplant/ed/ing
PTR	Puddled transplanted rice (traditional rice establishment practice)

Executive summary

Mechanised dry direct seeding was tested on farms in Savannakhet Province, Lao PDR as part of activities conducted under the ACIAR-funded ACCA (LWR/2008/019: *Developing multi-scale climate change adaptation strategies for farming communities in Cambodia, Lao PDR, Bangladesh and India*) and ACCA-SRA (LWR/2012/110: *Regional co-learning in simple mechanised tools for rice planting*) projects in 2013 and 2014. For most of the households which participated in the testing demonstrations this was the first opportunity to experiment with mechanised dry direct seeding of rice (DSR).

In 2013 on-farm trials were conducted to introduce rainfed rice farmers in the districts of Outhoumphone and Champhone to dry direct seeding of wet season rice, provide them with training and support throughout the growing season and learn with them the potential for direct seeding in this region. Sixty six farmers participated in the on-farm testing and over 100ha was sown with the direct seeder. Farmers were most interested in the potential benefits from reduced labour required to establish a rice crop. Through the season we learned that traditional weed control methods (in particular, using standing water to suppress weeds) cannot be relied on in a direct seeded crop and farmers must use other techniques, often at different times of the growing season (e.g. prior to sowing) to control weeds.

In 2014 in a smaller trial, on nine farms, a new locally produced seeder which dispersed fertiliser with the seed at sowing was tested. As well, a large emphasis was placed on weed control through land preparation prior to sowing; manual weeding was compared to the application of a post-emergent herbicide. Yield results demonstrated that comparable results could be achieved under both DSR and transplanted rice (PTR), and that similar results can be obtained under manual or chemical weed control. Farmers are reluctant to rely on herbicides for weed control.

Gross margins calculated using average 2014 data are higher under DSR+GAP than under PTR+ GAP (and higher again under DSR with chemical weed control). Under a range of labour cost and rice price sensitivities, producing rice under DSR+GAP compared to PTR+GAP, where weeds are well controlled, buffers against an increase in labour cost of up to 50 per cent.

These on-farm trials are a proof of concept that DSR is a viable technology to reduce production costs in rainfed lowland Lao PDR; additionally it holds promise to reduce farmers' exposure to climate risks. A number of key challenges remain outstanding, in particular development of supply chains which will enable all farmers who are interested in mechanised rice to have access to DSR. Many of these issues, in particular sourcing machinery and increasing the capacity and training of key extension partners such as DAEC, PAFO and DAFO will need to be addressed at the policy level.

The trials demonstrated many research questions remain to be investigated to better understand DSR in lowland rainfed areas of Lao PDR and to support the households who farm there. These include optimal weed management; timing and placement of fertiliser; time of planting; variety selection; tailoring DSR use to specific soils and/or positions within the toposequence; and practical seeder modifications and improvements.

Farmers who participated in this research expressed a keen interest in DSR and, with assistance from local research and extension agencies, are eager to continue to engage in and experiment with dry direct seeded rice to decrease their production costs while maintaining or improving food security and resilience against increasing climate variability and change.

Rationale for direct seeding

Rice production practices

Rice is traditionally transplanted in rainfed lowland areas of Lao PDR. Farmers plant between two and four nursery crops at staggered intervals approximately two weeks apart from late April to early June, on pre-monsoon showers or, if it is available, with supplementary irrigation from ponds. When the monsoon rains come, in late June or July, the most viable nursery seedlings are transplanted into bunded paddies. Once the nursery is established farmers plough and prepare their main paddies. Rice is optimally transplanted into standing water, which also suppresses weeds and into which fertiliser is broadcast. If there is insufficient rain for standing water to accumulate in bunded paddies farmers will apply supplementary water in the event that it is available (on limited rainfall this is not an option for many farmers) or will delay transplanting beyond the optimal window. Rice transplanted without standing water does not generally thrive nor produce yield sufficient for households' needs.

In many years rice yields are constrained by a lack of, or poorly timed, rainfall (Schiller et al., 2006). Year to year wet season rainfall in southern Lao PDR is highly variable, in terms of the onset and cessation of the rains as well as the timing of the intra-monsoon dry period, which generally occurs for two to four weeks between mid-June and mid-July (Schiller et al., 2006). The amount of rainfall received during any wet season varies greatly and there is little to no correlation between early season rainfall amounts and the total wet season rainfall received (Lacombe et al., 2012). In general only a few spatial or temporal trends in rainfall have been identified; those which do exist are of low statistical significance and cannot be used to accurately predict rainfall throughout the growing season (Lacombe, 2012).

Most rice produced in lowland rainfed Lao PDR is for domestic food consumption: rice prices are low and input costs comparatively high (and the use of inputs not well enough understood) that few farmers aim to grow more rice than they expect their household to eat (Schiller et al., 2013).

Most rural households have experienced some labour migration; family members work off farm for some or all of the year to increase the family's food security and to facilitate the education of others, the purchase of machinery, agricultural tools and inputs, and other household expenses.

Directly sowing rice into prepared paddy land, in contrast to sowing a nursery and transplanting seedlings into paddies, has been practised in the dry season in small irrigated areas of lowland Lao PDR since the early 2000s (Schiller et al., 2006). This dry season rice is established by broadcasting seed or, more recently, through mechanised establishment. Direct seeding[1] in rainfed paddies in the wet season is a new innovation which has been concurrently introduced into the region by a number of research projects, including the ACIAR-funded ACCA (LWR/2008/019: *Developing multi-scale climate change adaptation strategies for farming communities in Cambodia, Lao PDR, Bangladesh and India*) and ACCA-SRA (LWR/2012/110: *Regional co-learning in simple mechanised tools for rice planting*) projects. An important, and unique, approach of these two projects has been to support the introduction of the direct seeder through interactions between key Thai and Lao researchers and to facilitate the transfer of knowledge from north east Thailand (where rainfed, wet season direct seeding has been practised for some time) to Savannakhet Province of Lao PDR.

[1] We follow the general IRRI terminology, whereby *direct seeding rice* (DSR) is the sowing of seed into the soil, in contrast to *transplanting rice* (PTR). Direct seeding can be undertaken as dry direct seeding into tilled soil using a tractor-mounted seeder, (as used here) or by broadcasting into dry soil, often followed by cultivation. Wet direct seeding is either undertaken with a drum seeder on puddled soil or done by broadcasting seed directly onto wet soil

Reducing exposure to climate risks

By direct seeding rice farmers can take advantage of the same early-season rains (in late May and early June) which germinate and sustain their seedling nurseries. Because the rice is planted in situ in the paddies from where it will be harvested, standing water (required for transplanting) is not necessary at any time during the wet season. Instead smaller rainfall events early in the wet season are sufficient for germination and crop development.

Physiologically, direct seeded rice plants are better protected against early and/or intermittent droughting events as root systems are better developed earlier in the season and are thus better able to withstand short term rainfall deficits. In lower terraces or floodplains, early seeded rice plants are also taller sooner and better able to withstand short-term flooding events during the main season rains (Figure 1). Additionally, direct seeded rice matures earlier in the wet season and is less likely to be exposed to terminal drought stress around harvest.

Planting rice with a direct seeder will increase the year to year reliability of crop production. This increased food security will enable farmers to more reliably plan other activities and to budget for agronomic inputs.

Figure 1: Direct seeded rice at the farmer demonstration trials in Ban Wattana (Champhone) at the top (left), middle (centre) and lowest (right) points in the toposequence (pictures taken on 8 July 2013)

Economic savings

DSR is faster and requires significantly less labour than PTR to establish a crop: a skilled tractor operator plants around 1ha per day with a seeder, while it takes about 20 people to transplant 1ha per day. The reduction in hired labour required to establish the crop greatly reduces the cost of production; additionally it reduces the number of household members necessary on farm for crop establishment, with the result that they are able to seek alternative, often more remunerative, off-farm work. For most farmers the potential to reduce labour, and thus input costs, by using the direct seeder is its primary attraction.

Where weeds are well controlled, e.g. via thorough land preparation and manual weeding early in the season, gross margins from DSR are higher than those under PTR, due to labour savings.

Direct seeder demonstration trials

On-farm trials: 2013

In 2013 66 farming households participated in on-farm demonstrations of the direct seeder under the ACCA and ACCA-SRA projects. The key aims of the trials were to raise awareness of the direct seeder in rainfed lowland Savannakhet and to identify key strengths and weaknesses of planting with the seeder. Participating households came from the villages of Phin Nua (9 farmers), Nonsavang (6), Phin Thai (3), and Sibounheuang (3) in Outhoumphone district, and in the villages of Toad (9 farmers), Taleo (9), Sakheun (9), Sivilay (9) and Vangmao (9) in Champhone district. Farms in Outhoumphone are largely drought-prone; those in Champhone are a mixture of drought- and flood-prone.

The seeder tested was a Thai-built model which uses discs to plough furrows into which seed is sown (Figure 2). Farmers tested three fertiliser options:

T1: Fertiliser applied as soon as possible after sowing at a rate recommended by NAFRI;

T2: Fertiliser applied approximately ten days after plant emergence, into standing water, at a rate recommended by NAFRI. In many instances fertiliser application was delayed due to insufficient rainfall; and

T3: No fertiliser applied.

There was considerable interest by Savannakhet farmers in testing the direct seeder: for the most part farmers, who had no previous experience with mechanised establishment, were interested in potential labour savings.

Figure 2: The Thai-built, disc-based direct seeder used in the farmer demonstration trials in western Savannakhet

In addition to the planned demonstration sites, PAFO Savannakhet facilitated the use of the direct seeder in other villages; in total an area of approximately 100 ha was direct seeded in the 2013 wet season across Savannakhet Province. A key constraint to increased adoption was the lack of access to more direct seeding machines.

2013 trial results and farmer feedback

A visit to Savannakhet Province in late June and early July 2013 showed promising trial results, ranging from plots with excellent establishment and high yield potential, to some plots where weed pressure of lack of fertiliser was likely to depress yields. In most areas the seeder had been tested on fields in higher positions within the toposequence, on more marginal land, due to farmers' inherent risk aversion and cautious engagement with a new technology: the primary goal for most rainfed farmers in lowland Lao PDR is food security, not high yield or maximising profit.

In some areas traditional transplanting of nursery-matured seedlings had not been possible due to poor rains to at the beginning of the 2013 wet season, and the direct-seeded rice paddies were the only well established plots. In other areas transplanted rice was significantly less well matured than the direct seeded rice.

Farmer focus groups discussions were conducted prior and after the wet season 2013 trials. The results have been reported by Chialue *et al* (2013), and are summarised below.

Twenty-two farmers were interviewed about their initial experiences with the direct seeder in early July: overall farmers were cautiously positive about their testing of the direct seeder. They noted that mechanised establishment brought new challenges in terms of weed control, however they also appreciated the potential savings in labour, time and costs, as well as the reduced exposure to climate risks such as the severe early season drought experienced in 2013. Many farmers highlighted that direct seeding was the only technique which enabled them to plant rice where otherwise the lack of rain precluded timely transplanting. Overall, farmers were keen to compare their yields under PTR and DSR at the conclusion of the season, and reflect on the inputs required to achieve these yields.

During a return visit to Savannakhet Province in December 2013 farmers were interviewed again about their experiences with the direct seeder. Farmers remained interested in the direct seeder, in particular its potential to save labour and reduce production costs, however they very clearly identified that weed control is important, and traditional methods (which rely on ponded water to suppress weeds and growing seedlings to outcompete any surviving weeds) are no long appropriate. Some farmers stated that they had not followed NAFRI recommendations relating to weed control in the on-farm testing as they had not, previously, appreciated their value. Farmers and researchers reflected that better field trial results were obtained from fields in the middle and lower positions within the toposequence: greater water availability and ponding resulted in better weed control and application of fertiliser in a timely manner. Farmers also observed that row planting made weeding much easier, regardless of whether the weeding was done with a hoe or a rotary weeder.

Households' experiences with DS varied significantly, and depended on factors such as the toposequential position of the field in which the seeder was tested, paddy size, and availability of (paid and unpaid) labour. Despite many farmers expressing some concerns with the seeder, particularly around weed control, they noted their limited experience in using it, and were interested in testing the seeder again in 2014 with some modifications (e.g. a new field, better soil preparation prior to sowing, different fertiliser regimes).

Limited quantitative data were available for analysis from the 2013 field trials, however yield results (Table 1 and Figure 3) show inconsistent trends between the three fertiliser treatments. There is a trend of DSR achieving lower yields than PTR which is reported in the literature (e.g. Cabangon et al., 2002; Lantican et al., 1999).

In the fertiliser treatments the high degree of variation between yields suggests farmers may interpret fertiliser application advice differently. Anecdotal evidence suggests that where fertiliser is applied at sowing (close to the rice seed) it is preferentially used by rice plants and enables them to develop faster than proximate weed seeds. Where fertiliser is applied after crop emergence, into standing water, it is used by both rice and weeds: greater weed growth was reported by farmers in these treatment groups. However applications of fertiliser after crop emergence were, in many cases, delayed by late rains: this is likely to have affected the growth of rice plants.

Table 1: 2013 field trial results from Outhoumphone and Champhone villages

Village	n	T1: PTR + sowing N (kg/ha)[1]	T2: PTR + post sowing N (kg/ha)[1]	T3: PTR no N (kg/ha)[1]	T4: DSR + sowing N (kg/ha)[1]	T5: DSR + post sowing N (kg/ha)[1]	T6: DSR no N (kg/ha)[1]
Sakheun	3	2303.0 (2359.3, 2213.4)	2006.2 (2306.0, 1775.5)	1975.6 (2044.7, 1931.8)	2520.6 (2908.5, 2238.4)	2576.2 (2963.6, 1801.4)	1850.8 (2274.0, 1595.7)
Phin Neua	3	2919.9 (3417.8, 2241.6)	3012.8 (3174.1, 2757.8)	2507.5 (2821.0, 1957.5)	2502.0 (3354.0, 1956.0)	2570.0 (2759.0, 2470.0)	1706.7 (2481.0, 1159.0)
Nonsavang[2]	3: T1, T2, T4, T6 1: T3 & T5	4197.3 (4932.6, 3289.1)	3566.3 (3587.2, 3545.3)	3875.0	3079.4 (3437.7, 2566.2)	4171.7 (5672.9, 2670.6)	2489.0
Phin Thai[2]	1	5684.9	3009.9	2852.7	4258.5	3171.6	2312.3
Sibounheuang[2]	1	2646.0	2639.0	2947.0	2116.0	1801.0	2562.0
Average	11	3326.5 (5684.9, 2213.4)	2783.8 (3587.2, 1775,5)	2569.3 (3875.0, 1931.8)	2789.1 (4258.5, 1956.0)	2875.5 (5672.9, 2562.0)	2004.0 (2562.0, 1159.0)

[1] Maximum and minimum yields are shown in parentheses, where n >1

[2] For Treatments 3 and 6 in Nonsavang and for all treatments in Phin Thai and Sibounheuang results from only one farm are available

In many instances, average PTR treatments yielded higher than the corresponding average DSR treatments. DSR was established early in the season, in a year where low early-season rains resulted in excellent conditions for weed growth which was matched by little management response from farmers who were unable to rely on ponded water to suppress weeds, could not afford (or source) labour to manually weed larger areas, and who are not interested in chemical weed control. Once established, traditionally (although late-sown) PTR crops had sufficient water and were judged by most farmers to result in average yields. Another possible source of yield depression in DSR may be discrepancies in the interpretation of GAP advice by individual farmers in relation to DSR.

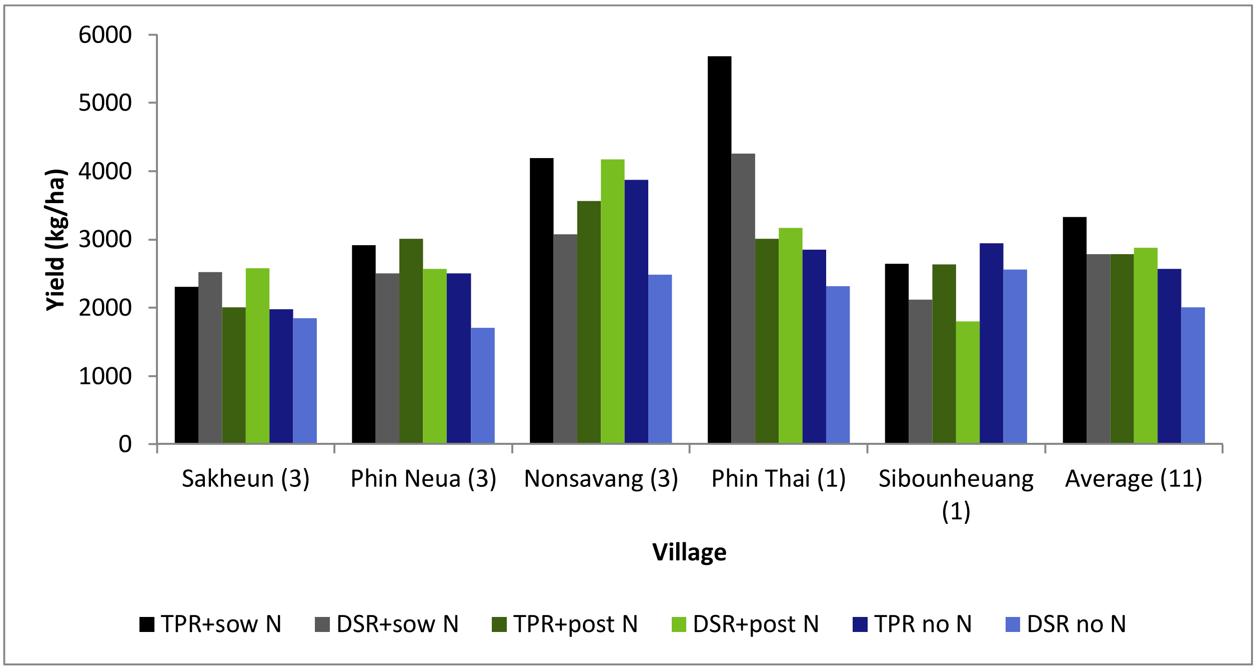

Figure 3: Average on-farm yields from the 2013 wet season at five villages across Savannakhet Province, and across all farms. Numbers in parentheses refer to the number of farmers participating in each village. "+ sow N": fertiliser added at time of sowing; "+ post N": fertiliser added at emergence; "no N": no fertiliser added.

Where farmers were able to manage weeds well in DSR (by using some or all of sufficient ponded water, good land preparation prior to sowing, and comprehensive weeding) yields were comparable to transplanted crops. These farmers were more positive in their reflections on the DSR than those who had experienced greater weed challenges.

On-farm trials: 2014

The focus of on-farm testing in 2014 was to work with a smaller cohort of farmers and to concentrate on collecting higher quality data throughout the wet season. Nine farmers in three villages in Outhoumphone (Phin Neua village) and Champhone (Alan Wattana and Toad villages) districts participated in testing of the DSR in fields at the middle position within the toposequence. The key aims of the testing were i) to explore avenues to control weeds and ii) to test placing fertiliser with the seed in the soil at sowing, using a new DSR machine which was modified in collaboration with Dr Leigh Vial (Figure 4). Four treatments were tested relative to a control:

T1: PTR with GAP weed control as recommended by NAFRI

T2: DSR with GAP weed control as recommended by NAFRI;

T3: DSR with post emergent herbicide weed control;

T4: DSR with farmer weed management practices; and

C1: PTR with farmer weed management practices. Results from this control treatment were recorded in Phin Neua only.

Figure 4: The modified, tine-based Thai seeder with dual seed and fertiliser box trialled by farmers in Savannakhet in wet season 2014

Many farmers who began testing DSR in 2013 continued to experiment with the seeder through the 2014 wet season independently of the ACCA and ACCA-SRA projects. NAFRI data show that 103.87ha in Savannakhet Province were sown with a mechanical seeder: 91.03ha were sown with a dry direct seeder and the remainder were sown with a drum seeder. Independently of the ACCA-SRA testing 47 farmers used the DSR in six districts; the majority of these were in Champhone. Additionally, DAFO staff and village heads who have been involved in DSR testing with the ACCA and ACCA-SRA projects have each bought their own direct seeders which they used on their own farms and contracted out to other farmers. Many farmers were interested in accessing machines and ongoing frustration at difficulties acquiring access to a seeder in a timely manner was reported.

2014 trial results and farmer feedback

DSR was established in early June 2014; in contrast sufficient rain for transplanting nursery-established rice seedlings was only received in early July and transplanting was late in many areas (Figure 5). Due to the lateness of PTR farmers were concerned about increased risk of terminal drought stress towards the end of the wet season.

Figure 5: Direct seeded rice (fore) and less mature transplanted rice (rear) in Alan Wattana, early July 2014

Farmers had learned from the weed challenges experienced in 2014 and controlled weeds well in DSR plots. Land preparation prior to DSR had been more rigorous than in 2013; as well a greater amount of standing water had better contributed to weed suppression. There was little difference in weed presence between plots where weeds were manually controlled and those in which chemical herbicide had been applied.

The DSR treatment in which fertiliser was applied into the soil with seed at sowing was greatly favoured by farmers compared to the previous method of broadcasting fertiliser into the paddy as soon after sowing as there was sufficient water. Farmers reported that drilling the fertiliser into the soil advantaged rice seed over weeds. Some paddies, however, displayed evidence of intermittent uneven distribution of seed and fertiliser: the ongoing development of dry direct seeders which dispense both seed and fertiliser and which are light and readily manoeuvrable is an area of high research need.

Farmers particularly appreciated the labour savings (and subsequent reduction in labour costs) gained by using the dry direct seeder, while remaining cautious about weed control under a range of growing season conditions in the longer term. More research is required to ensure weeds are adequately controlled in all years.

Average yields (Table 2) across the nine farms were 3.3t/ha for both PTR+GAP and DSR+ GAP; 3.4t/ha for DSR with herbicide; 2.3t/ha for DSR with farmer weed management practices (FP); and 2.0t/ha for PTR with farmer weed management practices (this last result is the average of three farms, from Phin Neua only).

Table 2: 2014 field trial results from Outhoumphone and Champhone villages

Treatment	Number of farms	Average yield (kg/ha)[1]
1: PTR + GAP	9	3330.7 (242.1)
2: DSR + GAP	9	3271.9 (271.7)
3: DSR + herbicide	9	3398.0 (262.2)
4: DSR + FP	9	2271.8 (193.1)
5: PTR + FP	3	2014.9 (106.8)

[1] Standard deviations are shown in parentheses

Yields under GAP management are consistently higher, regardless of establishment method, than those with traditional farmer weed management practices (Figure 6). In 2014 main wet season rains were later than normal: transplanting in field trial paddies occurred in mid to late July, which is at the late end of the transplanting window and, in many cases, was earlier than was possible for many paddies not in the field trial. DSR was sown in June which is later than recommended: the late sowing was also as a result of dry conditions early in the growing season.

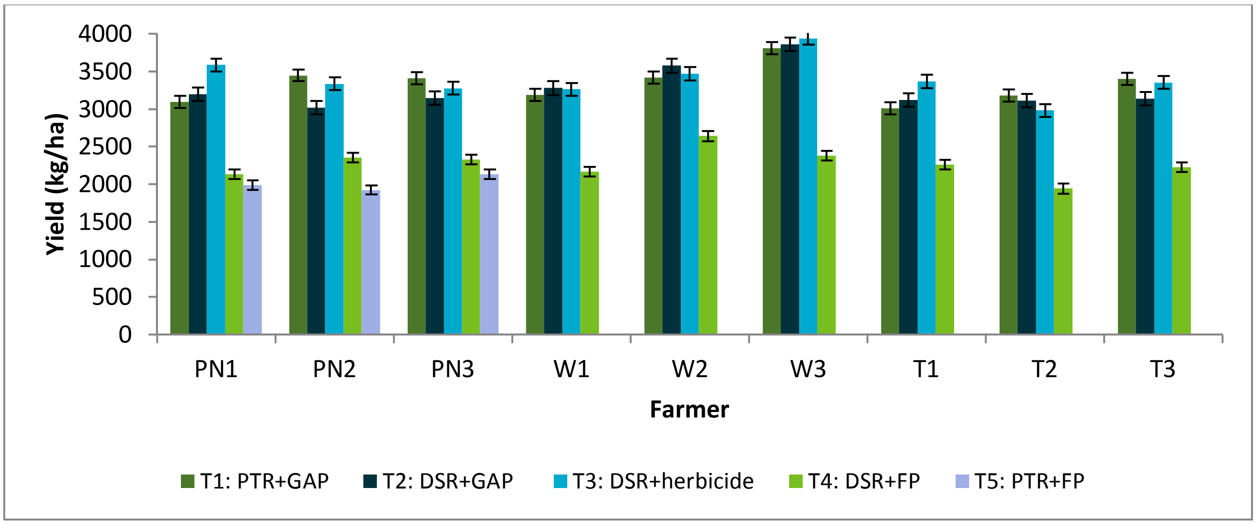

Figure 6: Average yields (kg/ha) from nine field trial sites in Savannakhet Province for the 2014 wet season. Error bars show one standard deviation; data for the PTR+FP treatment are only available for the three Phin Neua sites

In all GAP treatments weeds were well controlled: paddies were tilled twice before sowing and, during the growing season, weeds were removed soon after emergence. Compared to DSR testing in 2013, when farmers had not realised the importance of thorough and early weed control, there were few weeds this wet season. There is very little yield difference between the PTR+GAP (T1) and DSR+GAP (T2) treatments and the DSR + herbicide treatment (T3).

Economic analyses of direct seeding

Comparison of gross margins

DSR has the potential to return a higher gross margin than PTR, regardless of weed management practices (manual or chemical), as long as weeds *are* well managed. Good agricultural practice provides a useful framework for weed management.

As rice is produced largely for domestic consumption in Lao PDR (primarily using unpaid household labour) these gross margin (GM) calculations do not represent a cash gain or loss a household incurs: rather GMs are a tool to compare the opportunity costs of different establishment methods.

Using data from the 2014 wet season on-farm demonstration trials (averaged across participating households) gross margins have been calculated for:

T1: PTR + GAP;
T2: DSR + GAP;
T3: DSR + poor early weed control necessitating additional labour later in the wet season (for weeding) and a yield penalty relative to DSR+GAP; and
T4: DSR + herbicide.

The calculations of GM for each treatment are detailed in Appendix A and summarised in Table 3.

Table 3: Gross margins under different establishment treatments

Treatment	Yield (t/ha)	GM (LAK[1])/ha	Change from baseline (per cent)	Labour to achieve yield (person days/ha)	Change from baseline (person days)
T1: PTR+GAP	3.3	2,053,200	0 (baseline)	73	0 (baseline)
T2: DSR+GAP	3.3	3,128,400	52.4	52	-21
T3: DSR+poor early weed control	2.9	1,409,000	-31.4	68	-5
DSR+herbicide	3.4	3,885,600	89.2	40	-33

[1]In April 2015 1 AUD = 6,500 LAK

Using herbicide returns a higher GM than manually controlling weeds because labour demand is lower, however farmers consistently report that they are not interested in chemical weed control as it increases their input costs. As well, farmers are not confident they know how to use herbicide safely and they are concerned about the potential negative impacts on paddy biota (frogs, fish, snails, etc), which are important protein sources during the wet season. Applying herbicide is not supported by the Lao PDR government.

Economics under different labour and rice prices

Using the gross margins calculated in Table 3 as a baseline, a sensitivity analysis has been performed to examine changes in rice and labour prices, as these are elements of the cropping systems which are likely to vary and which directly affect GMs (Tables 4 to 7). Variability in the rice price has been reflected by examining increases and decreases of 10 and 20 per cent from a baseline of 2,200 LAK/kg; the cost of labour has been modelled at a 50 per cent increase (to 75,000 LAK/day) and at a 100 per cent increase (to 100,000 LAK/day) from a baseline of 50,000 LAK/day.

Table 4: Gross margins (LAK/ha) under a range of labour costs and rice prices for transplanted rice where weeds are well controlled manually through GAP

Change in rice price[1]	Labour: 50,000 LAK/day	Labour: 75,000 LAK/day	Labour: 100,000 LAK/day
-20%	237,560	-1,587,440	-3,412,440
-10%	970,380	-854,620	-2,679,620
0%	1,703,200	-121,800	-1,946,800
+10%	2,436,020	611,020	-1,213,980
+20%	3,168,840	1,343,840	-481,160

[1]Change is relative to a baseline rice price of 2,200 LAK/kg

Table 5: Gross margins(LAK/ha) under a range of labour costs and rice prices for direct seeded rice where weeds are well controlled manually through GAP

Change in rice price[1]	Labour: 50,000 LAK/day	Labour: 75,000 LAK/day	Labour: 100,000 LAK/day
-20%	1,488,720	188,720	-1,111,280
-10%	2,208,560	908,560	-391,440
0%	2,928,400	1,628,400	328,400
+10%	3,648,240	2,348,240	1,048,240
+20%	4,368,080	3,060,080	1,768,080

[1]Change is relative to a baseline rice price of 2,200 LAK/kg

Table 6: Gross margins(LAK/ha) under a range of labour costs and rice prices for direct seeded rice where weeds are poorly controlled manually

Change in rice price[1]	Labour: 50,000 LAK/day	Labour: 75,000 LAK/day	Labour: 100,000 LAK/day
-20%	113,200	-1,586,800	-3,286,800
-10%	761,100	-938,900	-2,638,900
0%	1,409,000	-291,000	-1,991,000
+10%	2,056,900	356,900	-1,343,100
+20%	2,704,800	1,004,800	-695,200

[1]Change is relative to a baseline rice price of 2,200 LAK/kg

Table 7: Gross margins (LAK/ha) under a range of labour costs and rice prices for direct seeded rice where weeds are well controlled with herbicide

Change in rice price[1]	Labour: 50,000 LAK/day	Labour: 75,000 LAK/day	Labour: 100,000 LAK/day
-20%	2,190,480	1,190,480	190,480
-10%	2,938,040	1,938,040	938,040
0%	3,685,600	2,685,600	1,685,600
+10%	4,433,160	3,433,160	2,433,160
+20%	5,180,720	4,180,720	3,180,720

[1]Change is relative to a baseline rice price of 2,200 LAK/kg

Where weeds are well controlled with GAP GMs are above 0 LAK/ha when the cost of labour is 50,000 LAK/day for both PTR (i.e. the baseline scenario) and DSR (Figure 7). Increasing labour costs in a TPR+GAP system, from 50,000 LAK/day to 75,000 LAK/day, reduces GMs by around 40 per cent. This loss can be considerably offset (all but 9 per cent) by changing from PTR to DSR, regardless of rice price and without introducing chemical herbicides.

Under PTR when labour costs increase to 75,000 LAK/day GMs fall below 0 LAK/ha when the rice price declines from the current baseline (2,200 LAK/kg). When labour costs increase to 100,000 LAK/day, GMs fall below 0 LAK/ha in all rice price scenarios simulated (i.e. between -20 per cent and +20 per cent from the baseline). Under DSR with a labour price of 100,000 LAK/day GMs are above 0 LAK/day for rice prices 5 per cent below the current baseline or higher.

Where rice prices remain about the same and labour doubles farmers who change to DSR+GAP will reduce their GMs relative to the baseline but will be significantly better off (in terms of GM) compared to those farmers who remain with PTR+GAP. Where PTR becomes unattractive from a GM perspective it may still be an attractive option for some risk averse households seeking to ensure food security, particularly under low rice prices and where uncosted labour is available.

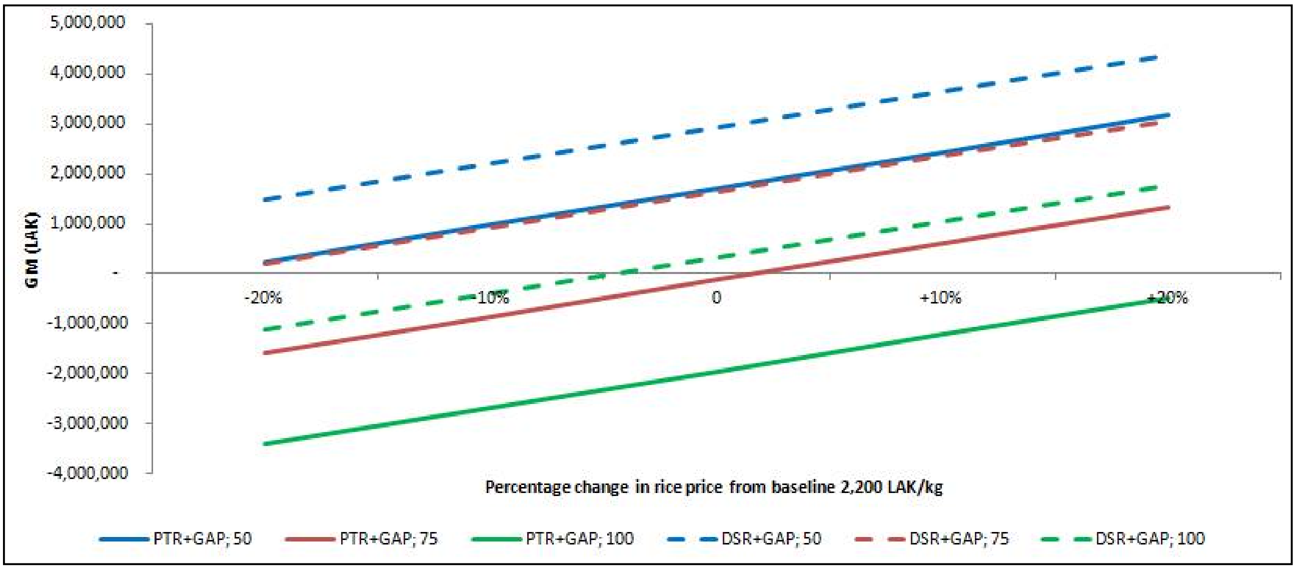

Figure 7: Gross margins (LAK/ha) under PTR+GAP (baseline scenario) and DSR+GAP for a range of rice prices and labour costs. The number in the description of each element represents the daily labour cost in '000 LAK

Under DSR where weeds are poorly managed, GMs are lower than the PTR+GAP baseline for all scenarios (Figure 8). Poor early management of weeds under DSR doubles the labour required for weeding during the growing season and reduces crop yield.

Where labour costs increase to 75,000 LAK/day, GMs for DSR with poor weed control reduce below 0 LAK/ha for a rice price below 2,200 LAK/kg; where labour costs increase to 100,000 LAK/day, GMs reduce below 0 LAK/ha for all rice prices simulated.

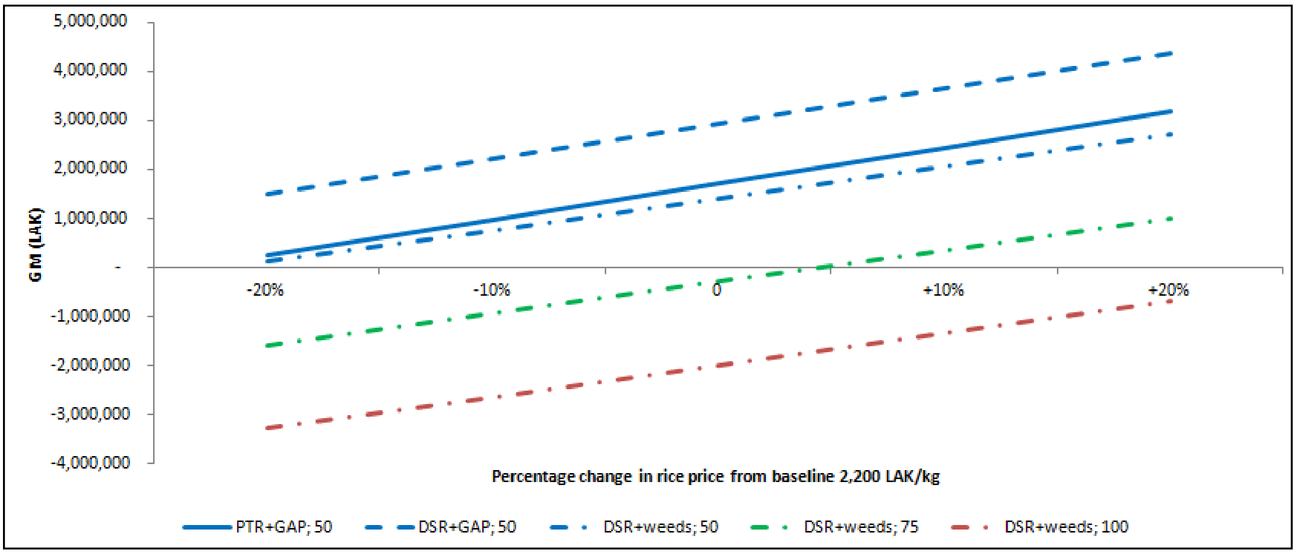

Figure 8: Gross margins (LAK/ha) under PTR+GAP (baseline scenario), DSR+GAP and DSR with poor weed control for a range of rice prices and labour costs. The number in the description of each element represents the daily labour cost in '000 LAK

Using herbicide to control weeds – and thus reduce labour required to produce a crop – will return a higher GM than PTR+GAP for all labour cost and rice price scenarios (Figure 9). Where herbicide, rather than manual labour, is used to control weeds GMs increase around 116 per cent over the PTR+GAP baseline scenario (for no change in rice price or labour cost). This increase is due to the considerable reduction in person days required to produce the crop under DSR (40) compared to that required for PTR+GAP (73).

Where labour prices increase to 100,000 farmers who use DSR with chemical weed control will see comparable GMs to those achieved under TPR+GAP and a labour price of 50,000 LAK/day, regardless of rice price.

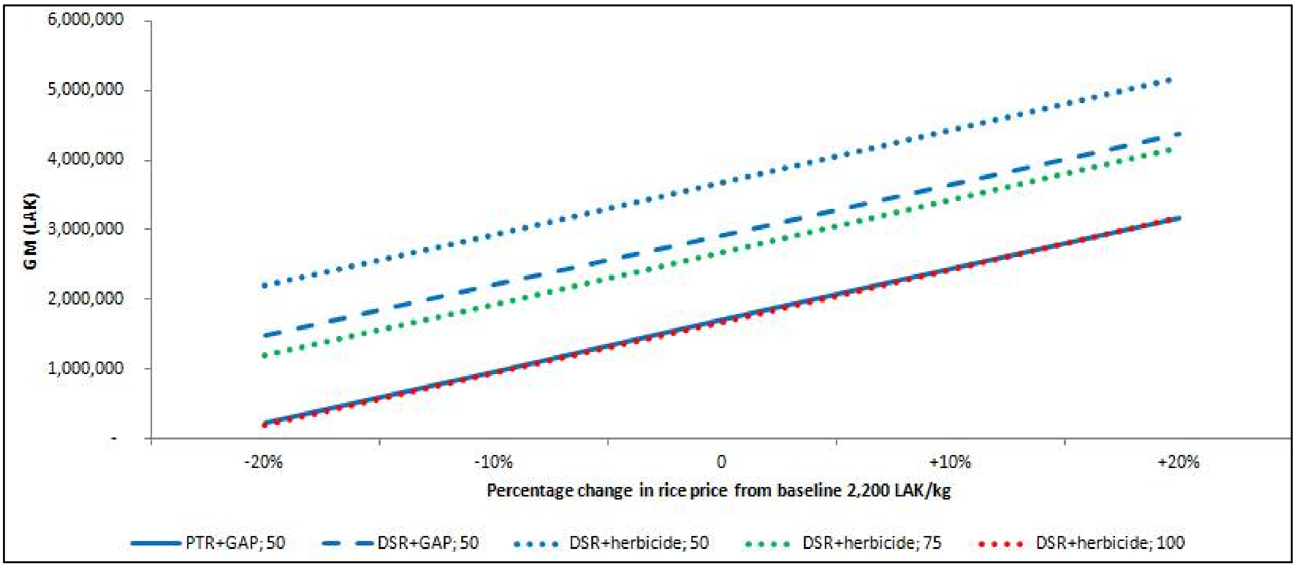

Figure 9: Gross margins (LAK/ha) under PTR+GAP (baseline scenario), DSR+GAP and DSR with chemical weed control for a range of rice prices and labour costs. The number in the description of each element represents the daily labour cost in '000 LAK

The yield return on labour required to produce a rice crop under DSR+GAP is 62.9 kg/person day (Figure 10). This is a more attractive establishment option than PTR+GAP (yield return 45.6 kg/person day), DSR+FP (43.3 kg/person day) or DSR+herbicide (85.0 kg/person day) which is not attractive to farmers because of the greater risks (in terms of inputs required and environmental and personal health concerns) surrounding the additional use of chemicals.

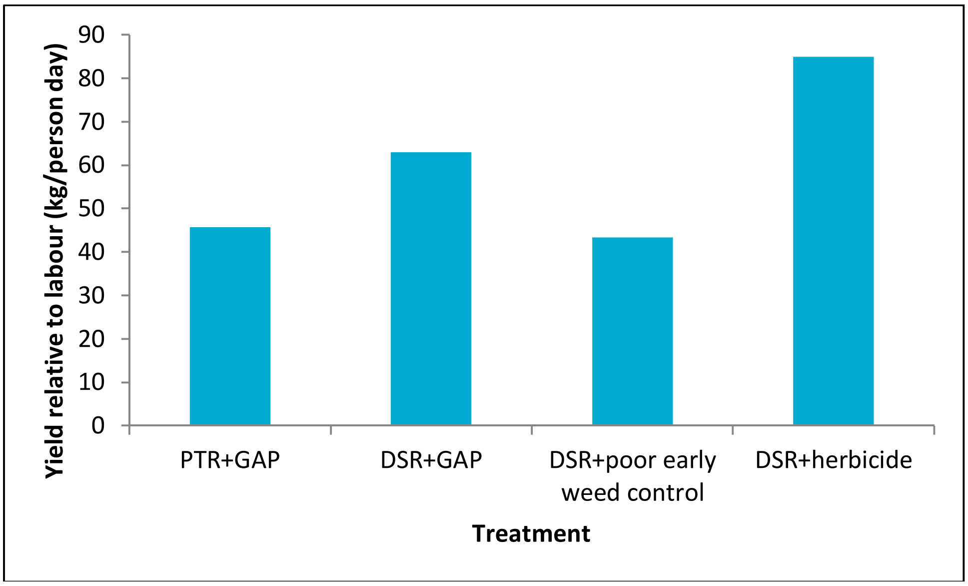

Figure 10: Yield relative to labour required to produce a rice crop (kg/person day)

Key findings

Introducing the direct seeder to farmers in Savannakhet Province in 2013 and extending and improving on-farm testing in 2014 has resulted in encouraging results and interest from rainfed rice farmers and other direct stakeholders in NAFRI, PAFO and DAFO. At the same time there are a range of agronomic, technical and institutional capacity issues which need to be addressed in order to support a wider dissemination and use of direct seeders in rainfed lowland rice growing areas of Lao PDR. These considerations are briefly summarised below.

Agronomic considerations

Weed control

Weeds are a greater challenge in a direct seeded crop than in a traditionally transplanted crop. Two main strategies are necessary to adequately control weeds: thorough land preparation and manual weeding early in the growing season.

The current minimum land preparation recommended prior to direct seeding is to plough the rice fields twice, with a period of about 10 days between each cultivation to allow weed germination. This should be followed by harrowing just before sowing. This recommendation requires at least three weeks' land preparation and may be more (and differently timed) preparation than that to which farmers are currently accustomed.

In-crop weeding was commonly implemented with a small hoe-like tool (Figure 11). Rotary weeders (Figure 12) are also available but can only be used when standing water is present. Many farmers found weeding easier to manage when the crop was in clear rows and did not experience any difficulty controlling weeds early in the wet season. Some farmers, however, were put off by the unexpected weediness of their plots – whether this resulted from insufficiently thorough land preparation is unclear. The farmers experiencing greater weed problems were those at higher toposequences, where soil moisture is lower, increasing the labour involved in both pre-sowing land preparation and manual weed cultivation.

Figure 11: A farmer demonstrates weed removal using a small handheld tool

Most farmers perceive herbicides as a high-cost input, the use of which jeopardises the safe human consumption of small in-paddy animals (e.g. fish, snails, frogs and crabs) which are often relied upon as protein sources in the wet season. Some farmers (those with larger landholdings) were attracted by the labour savings possible in applying herbicides rather than paying for labourers to weed crops.

The issues around weed management in direct seeded rice crops notwithstanding, most participating farmers viewed weed management as a challenge to be overcome and/or managed rather than a factor which would prevent the adoption of the direct seeding.

Figure 12: (left) Rotary weeding tools; (right) Mr Lytoua Chialue, a project researcher from NUOL, demonstrating the rotary weeder in Ban Sakheun, Champhone

Fertiliser: timing and placement

In traditional transplanted rice cropping systems there are a range of fertiliser application regimes followed by farmers in lowland Lao PDR: applying fertiliser basally; after transplanting; both basally and after transplanting; and not fertilising at all. The decisions to fertilise or not are informed by the position of the farmer's field in the toposequence, relative soil fertility, previous experience and training, land and household size, financial position and how well the season is developing.

Most farmers interviewed believe they have insufficient knowledge to optimise their fertiliser use: very few farmers have an understanding of the appropriate selection, timing and application rates for the fertilisers they access. Extension and agricultural services within Savannakhet province work hard to pass on their knowledge, but are often under-resourced and capacity-constrained themselves.

In direct seeded systems fertiliser applications at sowing can be made either in the furrow, with the seed, or on the soil surface, after sowing is complete. The latter method is likely to result in less fertiliser available to and taken up by rice plants as it is at risk of volatilisation and/or an uneven redistribution in the paddy following untimely rain. Adding fertiliser into the furrow with the seed is likely to promote rice plant growth over early weed development and was preferred by the farmers who tested this option. This requires seeders that have dual seed and fertiliser boxes and separate seed and fertiliser dispensing systems.

Top dressing is applied into standing water; usually approximately 25 and 40 (if two top dressings are applied) days after transplanting. If sufficient rainfall to achieve standing water does not occur in an appropriate interval top dressing will be delayed. While the direct seeding method cannot influence the amount of standing water in the paddy, and thus farmers' ability to top dress (under current methods), a direct seeded crop which has been fertilised at sowing is likely to be better nourished early in the season (before standing water is more reliable). Equally, a direct seeded crop, established earlier in the season, may reach a growth stage where top dressing is desirable before standing water occurs in the paddy: alternative methods of in-crop fertiliser application may become more attractive in future.

Planting time

Early sowing may have challenges which will need to be resolved by local communities (i.e. not individual households) in order for the practice to be successful. These include: livestock management, 'green island' effects and rice maturation times. Advancing the sowing date may also enable farmers to combat a key pest, gall midge.

Currently, livestock (particularly cattle and buffalo) are allowed to roam fairly freely until seedbed nursery establishment; many farmers who participated in the direct seeding demonstrations erected fences around their demonstration plots to protect them from livestock. Fencing may cease to be a practical solution if larger areas are sown with the direct seeder in future. One option which was mentioned a number of times is to pen animals and, concurrent with the introduction of the direct seeder, move to a cut-and-carry livestock production system for at least part of the year: this may have follow-on implications in labour-constrained environments.

If a few farmers in an area plant early, with the direct seeder, their ripening crops are likely to form a 'green island' which may be targeted by birds and other pests. A critical mass of farmers planting early will minimise this effect and protect each other's yields.

Farmers currently plant their nursery seedlings in about three tranches, each sown approximately two to three weeks apart. This spreads farmers' exposure to short term climate stressors (droughts, floods) and reduces the intensity of transplanting, and therefore the daily labour requirements (although this practice also extends the duration of the transplanting window). With direct sowing areas of the farm can be sown in discrete, temporally distinct, blocks, continuing the climate risk mitigation strategies farmers currently practise.

A significant pest in rainfed rice crops is gall midge, against which the most effective strategy identified to date is the early planting and transplanting of crops. The aim is to get the young cultivated rice crop past the growth stage where its yield potential can be affected by gall midge before the midge becomes active in nearby wild rice plants, in which it is endemic. Using the direct seeder both to plant earlier in the season and to eliminate plant growth delays associated with transplant shock may help protect domesticated rice plants from gall midge attack at critical plant growth stages.

Varieties

The maturity time, and photoperiod sensitivity, of varieties used with the direct seeder are important: if rice is sown earlier in the season farmers need to ensure their harvest is likely to be well-timed in terms of end-of-season rainfall.

At this stage, the selection of rice varieties used in the demonstration trials has not included consideration of whether particular varieties are better suited to direct seeding than others. As farmers become more confident in the technology and are gradually able to plant earlier, choice of varieties will become a research priority to ensure there is no mismatch between harvest date and end of wet season, as well as considering photoperiodicity.

Soils

The projects' direct seeders work best on sandy soils and loams and is likely to be inappropriate for use on heavier loam or clay soils that may form clods. Surface soils in Outhoumphone and Champhone districts are generally loamy sands and or sandy loams over a lateritic pan.

Sowing into different soil types is likely to require sowing at different depths. Also, a range of implements to open the soil may be necessary, depending on variations in soil type. Different implements can be used to create furrows in which to place seed, and they can be broadly categorised into disc or tine based openers. Depending on the furrow opener being used and on the soil condition and type, different implements to close the furrow may be required (e.g. press wheels in conjunction with discs; chains or scrapers following tines). Smaller, lighter direct seeders than the one being tested by the projects, while they have many benefits, may not always be strong enough to dig furrows deep enough to sow at appropriate depths.

Position in toposequence

Rice grown at higher toposequences is generally at greater risk of droughting while that at low toposequences is more flood prone. Early sowing using the direct seeder has the potential to mitigate farmers' exposure to both. Soil properties differ across toposequences: drainage is usually greater in fields positioned higher in the toposequence, while water logging is a concern in lower-lying paddies. Different management strategies for direct seeding apply at different positions and toposequence-specific management guidelines for the use of the direct seeder need to be developed.

Machinery considerations

Accessing seeders

The small number of seeders available to farmers in Outhoumphone and Champhone have been in high demand: many farmers stated that they would have preferred more time with the seeder and more flexibility when they used it, relative to their land preparation regimes. Many were considering buying, either individually or in small family groups, their own direct seeders for future wet seasons.

The first seeders used by the projects in 2013 were sourced from Thailand; despite access being facilitated by researchers from a recently completed ACIAR-funded project in north east Thailand (CIM/2007/215: *Improving the reliability of rainfed rice/livestock farming systems in NE Thailand*) the projects were unable to buy as many seeders as originally contemplated. It is highly likely that, as awareness of the seeders increases, demand will increase in lowland Lao PDR and access for farmers will remain a challenge. In 2014, a modified version of the Thai seeder was used. This had a dual seed and fertiliser box (but no separate dispenser) and used tines instead of disc coulters. The modifications were carried out in Savannakhet with the assistance of PAFO and Dr Leigh Vial, then with IRRI. Figure 4, above, shows this modified version.

Alternative seeders are also available: one farmer had bought a smaller, cheaper seeder (Figure 13) in Mukdahan, Thailand, and had used it to sow all his 2013 wet season rice. He stated that the limitations of his seeder were different from those of the projects' seeders (his seeder is smaller and lighter than the projects' seeders; it is also less robust and requires more thorough land preparation prior to sowing) and that he is very pleased with his purchase. He feels the labour savings he will make will more than compensate him for any additional weed control measures needed, and that he will recoup his investment in the short term.

Figure 13: The smaller, lighter, tine-based Thai seeder trialled independently by farmers in Savannakhet in wet season 2013

The projects' seeders cost approximately 20,000 THB each in 2013[2]; the smaller Thai seeder cost around 10,000 THB. It is anticipated that as supply is increased (and perhaps made available locally) seeders will become cheaper and more readily accessible to more farmers.

Significant progress has been made on the modification and deployment of a Brazilian dry direct seeder by the IFAD-funded Sustainable NRM and Productivity Enhancement Program (SNRMPEP). A local manufacturer in Pakse (Champassak Province) is now constructing 140 units using imported components, ordered and based on modifications and suggested by SNRMPEP (Figure 14). The machine has a dual seed/fertiliser seed box, with separate delivery tubes, and variable rate meters, which makes it very versatile and capable of being used for sowing different grain crops with varying fertiliser rates. The current estimated cost of this machine is around 500-600 USD.

Figure 14: The modified Brazilian, disc based, dry direct seeder being manufactured in Pakse, Lao PDR

Ease of use and seeder design

The seeders purchased by the projects, particularly the first model tested, were found by some farmers to be heavy and difficult to manoeuvre. Many farmers relied on assistance from government or village officials to sow with the direct seeder. Some farmers, in particular those who were older, more risk averse, or who currently contracted out land preparation, expressed interest in hiring a contractor to directly sow their paddies in future.

In general terms, the design of seeders is a compromise between ease of use, machinery cost and its versatility to cope with a range of soil and planting conditions. The current machines are functional, but they need to be refined for local edaphic and topographic conditions. Dr Jacky Desbiolles, who in Cambodia evaluated the Thai seeder being tested by the projects in Lao PDR, has recommended analysis and improvement in the following areas:

- *Seed dispersal mechanism*: currently creates seed damage. Modifying hard edges with brushes or soft rubber could ameliorate this.
- *Metering system*: most seeders have a fixed rate of around 80kg/ha. An adjustable seed rate would be more attractive to farmers.
- *Road travel clearance:* little clearance for road travel makes the handling cumbersome and tiring for the operator unless the discs are allowed to run on the ground.

The lighter, cheaper Thai seeder was viewed as a more attractive option by some farmers, however many acknowledged that seed was not sown as deeply as when the project seeders were used. If planting was followed by heavy rain this dispersed the seed from the initial row alignment and impeded crop management and weeding. Additionally there was no capacity with the lighter seeder to pause seed discharge while there was seed in the dispensing drum. The larger seeders have a gearing mechanism which enables the user to initiate or pause seed flow and to control the rate at which seed is discharged.

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[2] In April 2013 1 AUD was approximately equal to 30 THB

Seeders with tines, which create more permanent furrows than do disc seeders, may be more advantageous at higher toposequences: the furrows may help to channel the small rainfall received early in the wet season down to seeds (and away from weeds) whereas a flatter paddy surface may not encourage preferential watering of crop seeds. Conversely, tines are more prone to raking residues and clogging.

Development considerations

Village-level planting decisions

As noted earlier, village communities may need to reconsider the timing of events in the agronomic calendar which will be optimally managed as a group. These include: the timing of sowing; the timing and allocation of communal irrigation water (if available); and livestock grazing near rice paddies. Other research projects (e.g. the ACIAR-funded World Vision project, *Improving the reliability of rainfed rice/livestock farming systems in NE Thailand*) have demonstrated the potential, in comparable smallholder farming systems, of implementing cut-and-carry systems of livestock production. If done communally penning livestock, for at least some months of the year, would eliminate the need to erect fences around rice paddies and may bring additional benefits, in terms of increased liveweight gain and animal production, to farmers. Another benefit of longer periods of cattle penning is that greater amounts of manure can be collected for use as fertiliser.

Implications for women and marginal farmers

Transplanting and weeding are traditionally mainly done by women whereas land preparation and other tractor-oriented tasks are done by men. Changing from PTR to DSR is likely to reduce the amount of work required by women to produce a rice crop (particularly where weeds are well controlled), while making little change to the time and labour required by men. This will mean women have greater opportunities to seek off farm income: farmers observed that family economics were changing as it was the young female members who had greatest access to cash, which they provided to their parents.

Conversely, marginal and landless farmers rely on transplanting and other labour-intensive activities on larger farms as a key income source. Reducing the amount of labour required over the cropping season is likely to increase migration away from rural areas and into urban centres.

The longer-term social and cultural implications of DSR for marginalised groups are not well understood in Lao PDR.

Sourcing machines

In order to ensure the continued uptake and use of direct seeding, adequate production and supply, as well as post-sales support, is required. This may be best facilitated by targeted government policies encouraging the importation and sale of the seeders, as well as domestic production (the seeder design has deliberately not been patented to encourage widespread uptake in developing countries). National, provincial and district government organisations have valuable roles to play linking traders and input suppliers to farmers and ensuring that domestic manufacture of seeders is facilitated where possible. Additionally, NGOs may be able to demonstrate, through established practices and outscaling networks, methods to source additional machines and distribute them to interested communities.

Poorer farmers and those with smaller landholdings are more likely to be challenged by sourcing seeders at fair prices and, ultimately, by purchasing them. These groups are likely to rely on contractors for land preparation and seeding. As more large farmers acquire seeders and act as contractors, access to seeders should also improve for small farmers. However, it is important to ensure no farmer groups are overlooked in the extension of this new technology; hence government institutions have a critical support role for these groups. Another option might be to establish communal access to seeders (e.g. in small family groups).

Capacity and training

If the interest in, and uptake of, direct seeding continues at current high levels DAEC, PAFO and DAFO may experience resource limitations to adequately train all farmers in lowland Lao PDR interested in the seeder. Private sector third parties are likely to have a role in this process: the model successfully developed by the NGO SNV where millers work with farmers and end-users to enable high-quality rice production tailored to consumers' needs is a model to explore further.

Provision of information and training on the direct seeder may be facilitated by millers and/or other third parties keen to see the development of more reliable rice production: in this process government organisations such as DAEC, PAFO and DAFO would play a vital role training contractors and other third parties to use, service and adapt seeders. The process would also contribute to and expedite locally appropriate adaptations of the basic seeder. While regional capacity is limited and interest is growing it is imperative to bring in private industry, donor organisations and NGOs and to facilitate their interactions with key government organisations in order to increase availability and timely uptake of the direct seeder. To date IFAD and the NGO SNV have expressed an interest in piloting the wider dissemination and provision of direct seeders.

Conclusions and issues for future action

The 2013 and 2014 on-farm demonstration trials of the direct seeder in Outhoumphone and Champhone districts of Savannakhet undertaken as part of the ACCA and ACCA-SRA projects have provided a widespread proof of concept that direct seeding is a viable technology to reduce labour costs, as well as holding promise to reduce climate risk and the following conclusions can be drawn:

- Direct seeding into unpuddled soils is proving to be an effective alternative to traditional transplanting.
- Farmers in Outhoumphone and Champhone districts of Savannakhet have continued to show a very strong interest in direct seeding (even independently of the on-farm trials) largely because of the significant potential labour savings.
- The dry start of both the 2013 and 2014 wet seasons showed that direct seeding can help reduce the impact of climate risk. In several locations farmers were not able to transplant rice on upper and middle terraces in a timely manner due to drought; however, in all of these sites, direct seeded rice had been established successfully and was growing well.
- In lowland areas, early direct seeding of rice is likely to reduce the risk of crop damage due to flooding, as the rice is already tall enough to avoid being fully submerged when heavy rainfall commences in July and August.
- At all toposequence positions weeds need to be well managed in DSR and different strategies to those traditionally used in PTR will be appropriate. Formal training and guidance for farmers around weed control in DSR will reduce their exposure to this risk.

Despite proof of concept and initial strong interest by farmers, we caution against rolling out the technology too rapidly and without taking into consideration some of the constraints and problems discussed in this report. Key issues that will need to be addressed include:

- *Closing the gap between farmer demand and access to direct seeders*: this will require support from relevant Lao PDR government institutions and international donors to support the development of supply chains to source direct seeders and make them available at low cost to farmers. Alternatively, consideration should be given to establishing a local manufacturing base in Lao PDR, supported by improved seeder designs (e.g. the IFAD-SNRMPEP supported manufacturing of machines in Pakse)
- *Capacity building needs:* successful out-scaling of the technology will also require dedicated training of PAFO and DAFO extensionists, future contractors/tractor operators and input suppliers.
- *Weed management:* farmers will need to adhere to recommended land preparation practices prior to sowing, and to rigorously control in-crop weeds manually.
- *Matching the technology to local conditions:* direct seeding is not suitable to all locations, for all rice varieties or for all soils: more research needs to be done to determine in which soils direct seeding is appropriate, for which varieties, and how the planters can be improved to better match different soil conditions and to simultaneously place fertilisers with the seeds.
- *Establishing farmer groups:* many farmers expressed the wish to participate in farmer groups designed to share knowledge on using direct seeders (and, potentially, other agronomic topics). NAFRI, DAEC and PAFO are keen to establish such groups.

While direct seeding in itself is not a complex technology, its widespread uptake is likely to trigger major changes across the wider farming system (e.g. changes to whole farm systems through alterations in livestock management, timing of the cropping season and labour demands). Understanding and facilitating altering agronomic practices into whole farm and village-wide cultural and socio-economic contexts will require ongoing systems research.

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Appendix A: Gross margin calculations for PTR and DSR

1. Per-hectare GM for PTR+GAP. Yield and labour data are averaged from figures reported from farmers participating in the 2014 on-farm testing in Outhoumphone District; input costs were provided by NAFRI

	Unit	Amount	Cost/unit	Total LAK
Establishment				
Nursery cultivation (2x ploughing, 1x harrowing)	Person day	1	50,000	50,000
Nursery bed preparation, sowing, fertiliser application	Person day	1	50,000	50,000
Gasoline for nursery cultivation (5l/day @ 10,000 LAK/l x 2days)	LAK	10	10,000	100,000
Seed cost[1]	Kg	60	6,000	360,000
Transplanting cultivation	Person day	3	50,000	150,000
Puddling and levelling	Person day	2	50,000	100,000
Gasoline for cultivation before TP (5l/day @10,000 LAK/l x 5 days)	LAK	25	10,000	250,000
Uprooting nursery	Person day	4	50,000	200,000
Transplanting	Person day	20	50,000	1,000,000
			Subtotal: establishment	***2,260,000***
Fertiliser				
Nursery fertiliser (urea) cost	Kg	7	5,000	35,000
Applying basal fertiliser (NPK)	Person day	3	50,000	150,000
Fertiliser (NPK) cost	Kg	120	4,000	480,000
Applying top dressing #1 (urea)	Person day	3	50,000	150,000
Applying top dressing #2 (urea)	Person day	3	50,000	150,000
Fertiliser (urea) cost for 2 top dressings	Kg	150	5,000	750,000
			Subtotal: fertiliser	***1,715,000***
Weed control				
Hand weeding	Person day	11	50,000	550,000
			Subtotal: weed control	***550,000***
Harvesting and processing				
Harvesting	Person day	18	50,000	900,000
Threshing and cleaning	Person day	2	50,000	100,000
Drying and weighing	Person day	2	50,000	100,000
			Subtotal: Harvesting and processing	***1,100,000***
Total average cost	**LAK**			**5,675,000**
Average yield	Kg	3331		
Rice price	Kg	2,200		
Average income	**LAK**			**7,328,200**
Average gross margin	**LAK/ha**			**1,703,200**

[1] In all years there is a cost for seed – either a direct financial cost (seed is purchased about one year in three) or a loss of potential "income" from the previous year's yield as rice which could otherwise have been eaten or sold is retained for the next season's crop.

2. Per-hectare GM for DSR+GAP. Yield and labour data are averaged from figures reported from farmers participating in the 2014 on-farm testing in Outhoumphone District; input costs were provided by NAFRI

	Unit	Amount	Cost/unit	Total LAK
Establishment				
First cultivation	Person day	2	50,000	100,000
Second cultivation	Person day	2	50,000	100,000
Gasoline for cultivation (5l/day @ 10,000 LAK/l x4 days)	LAK	20	10,000	200,000
Seed cost	Kg	40	6,000	240,000
Sowing	Person day	4	50,000	200,000
			Subtotal: establishment	***840,000***
Fertiliser				
Fertiliser (NPK) cost	Kg	120	4,000	480,000
Applying top dressing #1 (urea)	Person day	3	50,000	150,000
Applying top dressing #2 (urea)	Person day	3	50,000	150,000
Fertiliser (urea) cost for 2 top dressings	Kg	150	5,000	750,000
			Subtotal: fertiliser	***1,530,000***
Weed control				
Hand weeding	Person day	16	50,000	800,000
			Subtotal: weed control	***800,000***
Harvesting and processing				
Harvesting	Person day	18	50,000	900,000
Threshing and cleaning	Person day	2	50,000	100,000
Drying and weighing	Person day	2	50,000	100,000
			Subtotal: Harvesting and processing	***1,100,000***
Total average cost	**LAK**			**4,270,000**
Average yield	Kg	3272		
Rice price	Kg	2,200		
Average income	**LAK**			**7,198,400**
Average gross margin	**LAK/ha**			**2,928,400**

3. Per-hectare GM for DSR with poor weed control. Yield and labour data are averaged from figures reported from farmers participating in the 2014 on-farm testing in Outhoumphone District; input costs were provided by NAFRI

	Unit	Amount	Cost/unit	Total LAK
Establishment				
First cultivation	Person day	2	50,000	100,000
Second cultivation	Person day	2	50,000	100,000
Gasoline for cultivation (5l/day @ 10,000 LAK/l x4 days)	LAK	20	10,000	200,000
Seed cost	Kg	40	6,000	240,000
Sowing	Person day	4	50,000	200,000
Subtotal: establishment				***840,000***
Fertiliser				
Fertiliser (NPK) cost	Kg	120	4,000	480,000
Applying top dressing #1 (urea)	Person day	3	50,000	150,000
Applying top dressing #2 (urea)	Person day	3	50,000	150,000
Fertiliser (urea) cost for 2 top dressings	Kg	150	5,000	750,000
Subtotal: fertiliser				***1,530,000***
Weed control[1]				
Hand weeding	Person day	32	50,000	1,600,000
Subtotal: weed control				***1,600,000***
Harvesting and processing				
Harvesting	Person day	18	50,000	900,000
Threshing and cleaning	Person day	2	50,000	100,000
Drying and weighing	Person day	2	50,000	100,000
Subtotal: Harvesting and processing				***1,100,000***
Total average cost	**LAK**			**5,070,000**
Average yield	Kg	2945		
Rice price	Kg	2,200		
Average income	**LAK**			**6,479,000**
Average gross margin	**LAK/ha**			**1,409,000**

[1] Poor land preparation and early weed control necessitates both a doubling of the labour required to control weeds and a 10 per cent yield penalty relative to the DSR+GAP scenario

4. Per-hectare GM for DSR with chemical weed control. Yield and labour data are averaged from figures reported from farmers participating in the 2014 on-farm testing in Outhoumphone District; input costs were provided by NAFRI

	Unit	Amount	Cost/unit	Total LAK
Establishment				
First cultivation	Person day	2	50,000	100,000
Second cultivation	Person day	2	50,000	100,000
Gasoline for cultivation (5l/day @ 10,000 LAK/l x 2 days)	LAK	20	10,000	200,000
Seed cost	Kg	40	6,000	240,000
Sowing	Person day	4	50,000	200,000
			Subtotal: establishment	***840,000***
Fertiliser				
Fertiliser (NPK) cost	Kg	120	4,000	480,000
Applying top dressing #1 (urea)	Person day	3	50,000	150,000
Applying top dressing #2 (urea)	Person day	3	50,000	150,000
Fertiliser (urea) cost for 2 top dressings	Kg	150	5,000	750,000
			Subtotal: fertiliser	***1,530,000***
Weed control				
Applying herbicide	Person day	4	50,000	200,000
Herbicide cost	Kg	1	120,000	120,000
			Subtotal: weed control	***320,000***
Harvesting and processing				
Harvesting	Person day	18	50,000	900,000
Threshing and cleaning	Person day	2	50,000	100,000
Drying and weighing	Person day	2	50,000	100,000
			Subtotal: Harvesting and processing	***1,100,000***
Total average cost	**LAK**			**3,790,000**
Average yield	Kg	3398		
Rice price	Kg	2,200		
Average income	**LAK**			**7,475,600**
Average gross margin	**LAK/ha**			**3,685,600**

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Appendix 5 – Gaydon et al. 2015: Compilation of APSIM results

Compilation of ACCA Modelling Results

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November 2015

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Compilation of ACCA Modelling Results

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1.INTRODUCTION

Benchmarking of farmer practices against current climate variability and evaluating the performance of adaptation practices under future climates was carried out through modelling, constituting one of ACCA's three main research emphasis. This requires the parameterisation of a suitable cropping systems model to reflect local soil and crop conditions and farmer management practices using on farm data. To confidently reflect cropping systems for the case study sites, the cropping systems model needed to be able to incorporate farmer decision rules and to be able to simulate long term cropping sequences.

The Agricultural Productions Systems Simulator (APSIM) model was chosen because of its ability to meet these prerequisites. However, at the beginning of the project, the ability of APSIM to simulate rice-based cropping systems was limited, so a major enabling activity in 1.3 was the validation of APSIM-ORYZA across multiple rice environments in Asia, as well as studies to develop specific process routines for salinity.

This work was mainly conducted in Bangladesh and Los Baños (IRRI) and has confirmed the ability of APSIM to reliably capture the key climate, crop, soil and management processes of rice-based cropping systems in Asia. Thus tested, APSIM was parameterised at each ACCA project location using local climate, crop and soil data and incorporating local farmer management practices obtained primarily from the on farm research.

The parametrisation and validation of APSIM was followed by a first and second series of scenario analyses using the locally parameterised APSIM helped determine how well current farmer practices perform, in particular with respect to present climate variability, as well as allowing an evaluation of how these practices might perform under future climates. The first scenario analysis results were presented to partners, farmers and other stakeholders, and their feedback was then used to inform the second scenario analysis. The results of this second iteration are the basis of papers and the ACCA final report (Volume 1).

The purpose of this report is to compile some of the simulation outputs as well as to provide an overview of the scenarios tested in each country. Because of the sheer number of simulation results the ACCA project generated, we provide the results of the second iteration of scenario analyses performed for India as an example only, while providing an overview of scenario analysis runs conducted in the other three ACCA countries.

2. GENERAL APPROACH TO MODEL TESTING

The initial task for the ACCA Modelling Team was to examine evidence regarding applicability of the APSIM model in South and South-East Asian cropping systems for simulation of different management practices, and their performances under current and future climates. This involved:

i. Seeking and collating experimental datasets to cover a broad range of environments, climates, varieties, and management practices within the region. This model testing effort encompassed several ACIAR projects (ACCA and the SAARC-Australia Project)
ii. Parameterising and calibrating the model at each site through comparison of available variables, generally grain yield but also water balance terms and soil state variables (where available)
iii. Use of robust statistics to validate the model performance on independent datasets to those used in (ii)
iv. Identification of areas for required model improvement

The work of the team in this regard has been reported in a number of published papers and papers in preparation:

Gaydon, DS, ME Probert, RJ Buresh, H Meinke, A Suriadi, A Doberman, B Bouman and J Timsina (2012a). Rice in cropping systems – modelling transitions between flooded and non-flooded soil environments. *European Journal of Agronomy*, 39:9-24.

Gaydon DS, ME Probert, RJ Buresh, H Meinke and J Timsina (2012b). Modelling the role of algae in rice crop nutrition and soil organic carbon maintenance. *European Journal of Agronomy*, 39:35-43.

Gaydon, D.S., Balwinder-Singh, P.L. Poulton, H. Horan, B. Ahmad, F.Ahmed, S. Akhter, I. Ali, R. Amarasingha, A. K. Chaki, B.U. Choudhury, R. Darai, Z. Hochman, E.Y Hosang, T. Li, V.P. Kumar, A.S.M.M.R. Khan, W. Malaviachichi, M.A. Muttaleb, G.S. Rai, Md. H. Rashid, U. Rathanayake, M.M. Sarker, D.K. Sena, M. Shamim, N. Subash, L.P. Suriyagoda, A. Suriadi, T. Veasna, R.K. Yadav, and C.H. Roth. Evaluation of the APSIM model in cropping systems of Asia. *Ecological Modelling and Software* in November 2015

Poulton, PL, V Touch, N Dalgliesh, V Seng. (2015) Applying APSIM to improved rice varieties in reducing the on farm yield gap in Cambodian lowland rice ecosystems.
Experimental Agriculture 50:2 264-284

In summary, APSIM's performance was assessed against assembled replicated experimental datasets from the four ACCA countries, as well as a range of other countries in Asia. The revealed error between simulated and observed data for grain yield was within the bounds of the experimental error, indicating robustness in model performance (eg. for rice crop performance, n = 361, R^2 = 0.83 with low bias (slope, α = 1.1, intercept, β = -246 kg/ha), RMSE = 1084 kg ha^{-1} (cf. SD of measured data = 2038 kg ha^{-1})).

Once properly parameterised and calibrated locally, the model performed well in simulating the diversity of cropping systems to which it was applied, with particular strengths in simulation of multi-crop sequences and specification of realistic dynamics in farmer management practices. APSIM was shown to be a useful tool to investigate sustainability issues associated with management change in the cropping systems of Asia, however to keep the model relevant for emerging practices in the region, some areas for future improvement were identified.

3. METHODS OF ANALYSIS OF ADAPTATION OPTIONS

The parameterised, calibrated and validated APSIM model was applied in each of India, Bangladesh, Laos and Cambodia to explore the long-term performance of a range of locally-identified adaptation options in both historical climate (testing the performance of the adaptations to climate variability) and projected future climates (testing them as adaptations to climatic change). The evaluations focussed on several key variables of assessment, with an overarching aim to be economically viable and environmentally sustainable[4].

Climate data and future climate scenarios

The baseline data set used daily historic weather data recorded at weather stations in close proximity to the case study villages. For future climate projections we used the linear, mixed-effect state-space (LMESS) method to generate location specific projections to 2021-2040 (Kokic et al. 2011), drawing on historical data for the case study locations and using outputs from two contrasting Global Circulation models (ECHAM5 for a relatively cooler and GFDL CM2.1 for a relatively hotter future climate) under the A2 SRES emissions scenario (approximately equivalent to representative concentration pathway RCP6) to 2021-2040.

The LMESS methodology was applied as described in Kokic and Crimp (2011). A multivariate state-space modelling approach was used to establish empirical relationships between GCM variables and location-specific climate. In so doing, we maintained important information regarding local observed trends and variability but also introduced important drivers of change from the GCMs. The state-space approach was used to jointly model quantiles of rainfall and temperature at monthly level, then a bootstrap simulation procedure (Efron, 1982) based on quantile matching was used to simulate future daily climate (Kokic et al. 2011). APSIM climate files also require solar radiation, vapour pressure and evapotranspiration. These variables where predicted from rainfall and temperature using empirical relationships based on NCEP reanalysis climate data for locations close to each climate station. This approach ensures that the future simulated climate is coherent across variables and temporally, and displays distributional characteristics highly consistent with point level climate data.

Climate-smart agriculture

An emerging concept for dealing with multiple aspects of climate change is climate-smart agriculture (http://www.fao.org/climate-smart-agriculture/41760-0c193f4f5f7f53aa75f8927278f97362e.pdf). Climate-smart agricultural practices are those which aspire to contribute towards three outcomes: (i) Sustainable and equitable increases in agricultural productivity and incomes; (ii) Greater resilience of food systems and farming livelihoods; and (iii) Reduction of greenhouse gas emissions associated with agriculture. We adopted these criteria in our investigation of identified adaptations.

Scenario simulation outputs

Simulation outputs included yields; net water used; soil carbon status; soil nitrate leached beyond the root zone; and nitrous oxide emissions. Gross margins were calculated using cost

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[4] The economic analyses for Bangladesh scenarios are being undertaken by a John Allwright Fellowship PhD student at University of Queensland, Mr Jahangir Kabir (BARI), and are not yet available for this report

and income data collected from the representative case study households. Post simulation analysis enabled the calculation of gross margins and this enabled the calculation of average gross margins and stability, represented by the coefficient of variation (CV) of gross margins. Environmental impacts were calculated as intensities (e.g. nitrous oxide emissions/ $ value of product).

Evaluation of scenario performance

The outputs listed in the paragraph above are represented as sustainability polygons (Ten Brink et al. 1991, Moeller et al. 2014). These polygons allow for an integrated graphic representation of multiple sustainability indicators. They are designed to provide a holistic visual summary of how sustainable (or climate-smart) competing adaptation practices are. Each sustainability indicator is represented by a relative value from 1 to 0 where 1 is the most desirable outcome (highest or lowest depending on context (e.g. highest gross margin per ha or lowest carbon emission per ton of yield). For a desirable attribute (e.g. gross margin per ha) the relative sustainability value for any adaptation is calculated as the value of the adaptation divided by the value calculated for the highest among the competing adaptation options. For an undesirable attribute (e.g. carbon emissions per ton of yield) the sustainability value of an adaptation is calculated by dividing the lowest value among competing adaptations by the value of that adaptation. When all sustainability indicators are presented in a polygon and assuming equal weighting for all indicators, the most climate-smart practice would encompass the largest area. Ideally the most climate-smart practice will have all values close to 1.0. However, when this is not the case we have to consider tradeoffs among the desirable indicators. Choice of which adaptation is the most climate-smart may require subjective weighting of the various sustainability indicators. Relative weighting of indicators is essentially subjective but might be informed by the importance assigned to each indicator but also by the range of values that each indicator displays. We therefore also display the range of absolute values for each of the sustainability indicators[5].

Although APSIM's simulation of soil C balance (and hence C emissions) has been validated in a number of studies in both flooded (Gaydon et al., 2012) and non-flooded soil environments (Huth et al., 2010) , the model makes no attempt to segregate gaseous C losses from soil organic matter cycling between carbon dioxide (CO2) and methane (CH_4). This necessitates additional consideration of the global warming impact of simulated C-emissions when the cropping system is alternately flooded and non-flooded (such as a rice-wheat system), due to the different global warming potential of CO_2 and CH_4 (21 times the effect of CO_2 for same mass). We did not progress to this level of analysis in evaluation of the emissions simulated.

References

Efron, B., 1982. The Jackknife, the bootstrap, and other resampling plans, Society for Industrial and Applied Mathematics, Philadelphia.

Gaydon, D.S., Probert, M.E., Buresh, R.J., Meinke, H., Timsina, J., 2012. Capturing the role of algae in rice crop production and soil organic carbon maintenance, European Journal of Agronomy 39, 35-43.

Huth, N. I., Thorburn, P. J., Radford, B. J., and Thornton, C. M., 2010. Impacts of fertilisers and legumes on N2O and CO2 emissions from soils in subtropical agricultural systems: a simulation study. Agriculture, Ecosystems & Environment 136(3), 351-357.

[5] The final results for India, Cambodia and Laos are presented as Sustainability Polygons in this appendix. Those for Bangladesh will be developed into the same form following final economic analyses, and details published independently.

Kokic, P., Crimp, S., Howden, M., 2011. Forecasting climate variables using a mixed-effect state-space model. Environmetrics 22, 409–419.

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Ten Brink B.J.E., Hosper, S.H., Colijn, F., 1991. A quantitative method for description and assessment of ecosystems: the AMOEBA-approach. Marine Pollution Bulletin 23, 265-270.

4. MODELING RESULTS FOR INDIA

Initial scenario analyses

The long-term implication of strategic cotton irrigation scenarios was examined through initial APSIM simulations in 2012.

Four sets of scenarios were examined to date, both for historical and future (2030) climates:

1. Testing the 50mm and 75mm antecedent rainfall planting rule for rainfed cotton and maize
2. Testing whether the PJTSAU and SRI rice management packages perform better than farmer practice
3. The value of strategic (or 'life saving') irrigation in cotton
4. The comparative benefit of distributing water between rice and cotton (to enable strategic irrigation without further pressure on groundwater tables)

The latter set of scenarios examined consisted of an irrigation rule for cotton crops where 50mm irrigation water is applied when soil moisture is depleted to 50% PAWC with additional restrictions of at least 14 days between irrigations and a maximum of three irrigations per season. The irrigation water was to be made available by incrementally reducing the paddy area. In the example shown four scenarios are compared with the current practice for a small farm in the Gorita village in Andhra Pradesh:

- Current Practice: 2 acres irrigated rice, 3 acres rainfed cotton
- Scenario 1: 1.5 acres irrigated rice, 3.5 acres cotton; strategically use the water saved from 0.5 acre rice to irrigate cotton
- Scenario 2: 1.0 acre irrigated rice, 4.0 acres cotton; strategically use the water saved from 1.0 acre rice to irrigate cotton
- Scenario 3: 1.0 acre irrigated rice, 4.0 acres cotton; strategically use the water saved from 1.0 acre rice to irrigate cotton but unlimited number of irrigations are allowed
- Scenario 4: 0.5 acre irrigated rice, 4.5 acres cotton; strategically use the water saved from 1.5 acre rice to irrigate cotton

The results of the above simulations were workshopped with partners and collaborating farmers. This led to a number of change in the in the model parameterisation, as well as to more refined management practices coded into the APSIM MANAGER module.

Second iteration of scenario analyses

Adaptation strategies for paddy rice, cotton and maize crops grown during the kharif (summer monsoon) were simulated for the three case study villages of Bairanpally, Gorita and Nemmani. Details of the case study villages can be found in Hochman *et al.* (2015a). Simulations were conducted using historical climate (1978-2009) and projected future climates ECHAM5 and GFDL CM2.1 (2021-2040).

Adaptations and controls

Adaptation strategies simulated are summarised below. Further details can be found in Hochman *et al.* (2015a) and Hochman *et al.* (2015b).

1. Sowing rules for cotton and maize

Cotton and maize are primarily rainfed crops sown between June 1 and July 17 if sowing criteria are met. If the sowing criteria are not met, the crops are not sown. The criteria vary between villages and farmers. For example, some farmers sow at the official onset of the monsoon defined by the India Meteorological Department (IMD) as two consecutive days in which rainfall is greater than 2.5mm. Other farmers will inspect their soil and will sow if there is sufficient moisture in the top 15 cm to allow the soil to form a ball. Simulations were used to test the following sowing rules using the sowing window 1 June – 17 July:

i) Sow at the onset of the monsoon as defined by the IMD ie 2 consecutive days in which daily rainfall >= 2.5mm
ii) Sow when cumulative rainfall equals or exceeds 75mm (accumulated over 4, 7, 10, 14 days or entire sowing window)
iii) Sow when cumulative rainfall equals or exceeds 50mm (accumulated over 4, 7, 10, 14 days or entire sowing window)
iv) Sow when soil moisture in the top 15cm of the soil is at 50% of the soil's plant available water capacity (PAWC) in the black soils found at Bairanpally or at 66% PAWC in the red soils found at Gorita and Nemmani. This sowing rule represents sufficient soil moisture in the top 15cm to allow the soil to form a ball.

2. Strategic irrigation of rainfed crops

Simulations were used to test the effects of strategic irrigation on cotton and maize crops. Crops had 50mm irrigation applied when soil moisture reached 50% PAWC. There was at least 14 days between irrigations and a maximum of 3 irrigations per season. Irrigation of cotton crops started at 30 days after sowing (das) and stopped at 120 das. Irrigation of maize crops started at 14 das and stopped 21 days after anthesis. Water is a limited resource in the study area. The irrigation of rainfed crops could be achieved through water savings by reducing the irrigation of paddy rice as detailed in adaptation strategies 3 and 4 below.

3. Reduced irrigation of rice

Simulations were used to test the effects of reduced irrigation of rice paddies. Simulated nurseries were started on 7 June for all three villages. Seedlings were transplanted after 25 das when cumulative rainfall (from 7 June) exceeded 35mm. If 35mm rainfall had not fallen in 50 days at Bairanpally, seedlings were transplanted at 50 das. If 35mm rainfall had not fallen in 60 days at Gorita and Nemmani, seedlings were transplanted at 60 das. Four irrigation strategies were simulated the first two being currently used by farmers:

i) Irrig-1: Maintain 10cm pond depth by irrigating every second day to top up pond to 10cm (if required)
ii) Irrig-2: Maintain 5cm pond depth by irrigating every day to top up pond to 5cm (if required)
iii) AWD1: Alternate wetting and drying – irrigate when pond depth = 0cm, fill to 5cm
iv) AWD2: Alternate wetting and drying – irrigate 2 days after pond depth = 0cm, fill to 5cm

4. Reduced rice area for strategic irrigation of rainfed crops

Simulations were used to test the effects of reducing farm area sown with rice to use water saved to irrigate rainfed crops (cotton and maize). Three farm sizes, small (5 acres), medium (8 acres) and large (15 acres) were examined. Farms consisted of either rice and cotton or rice and maize. Rice was irrigated using irrigation strategy Irrig-2 (maintain 5cm pond depth by irrigating every day to top up pond to 5cm, if required). Cotton and maize crops were sown using sowing rule iv) (based on soil moisture). These practices are currently being used by some farmers. The following options were simulated:

Small Farm (5 acres)

Current Practice:	2.0 acres irrigated rice and 3.0 acres rainfed cotton (or maize)
Option 1:	1.5 acres irrigated rice and 3.5 acres cotton (or maize). Use the water saved from 0.5 acre rice to irrigate cotton (or maize) with strategic irrigation rules.
Option 2:	1.0 acre irrigated rice and 4.0 acres cotton (or maize). Use the water saved from 1.0 acre rice to irrigate cotton (or maize) with strategic irrigation rules.
Option 3:	1.0 acre irrigated rice and 4.0 acres cotton (or maize). Use the water saved from 1.0 acre rice to irrigate cotton (or maize) with strategic irrigation rules but allow more than 3 irrigations per season (unlimited number of irrigations).
Option 4:	0.5 acre irrigated rice and 4.5 acres cotton (or maize). Use the water saved from 1.5 acres rice to irrigate cotton (or maize) with strategic irrigation rules.

Medium Farm (8 acres)

Current Practice:	2.0 acres irrigated rice and 6.0 acres rainfed cotton (or maize)
Option 1:	1.5 acres irrigated rice and 6.5 acres cotton (or maize). Use the water saved from 0.5 acre rice to irrigate cotton (or maize) with strategic irrigation rules.
Option 2:	1.0 acre irrigated rice and 7.0 acres cotton (or maize). Use the water saved from 1.0 acre rice to irrigate cotton (or maize) with strategic irrigation rules.
Option 3:	0.5 acre irrigated rice and 7.5 acres cotton (or maize). Use the water saved from 1.5 acres rice to irrigate cotton (or maize) with strategic irrigation rules.

Large Farm (15 acres)

Current Practice:	3.0 acres irrigated rice and 12.0 acres rainfed cotton (or maize)
Option 1:	2.5 acres irrigated rice and 12.5 acres cotton (or maize). Use the water saved from 0.5 acre rice to irrigate cotton (or maize) with strategic irrigation rules.
Option 2:	2.0 acres irrigated rice and 13.0 acres cotton (or maize). Use the water saved from 1.0 acre rice to irrigate cotton (or maize) with strategic irrigation rules.
Option 3:	1.5 acres irrigated rice and 13.5 acres cotton (or maize). Use the water saved from 1.5 acres rice to irrigate cotton (or maize) with strategic irrigation rules.
Option 4:	1.0 acre irrigated rice and 14.0 acres cotton (or maize). Use the water saved from 2.0 acres rice to irrigate cotton (or maize) with strategic irrigation rules.
Option 5:	0.5 acre irrigated rice and 14.5 acres cotton (or maize). Use the water saved from 2.5 acres rice to irrigate cotton (or maize) with strategic irrigation rules.

Basis of comparison

The following simulation outputs were compared for each adaptation strategy:

1. Cotton and Maize crops
- Yield: seed cotton (the unprocessed/unginned cotton containing seed and lint) for cotton crops and grain yield for maize crops

- Gross margin (GM): calculated using cost and income data collected from representative case study households. Values for cotton at Bairanpally are in Table 1, for Gorita are in Table 3 and for Nemmani are in Table 5. Maize values for Bairanpally are in Table 2, for Gorita are in Table 4 and for Nemmani are in Table 6. Values for small farms were used for comparisons.
- Yield and GM stability: the standard deviation of yield and GM
- N_2O emission: calculated as kg N_2O / t yield produced
- C emission: calculated as kg C / t yield produced
Note: N_2O and C emissions from failed crops (0 t/ha yield) were ignored in emission comparisons.
INR 60 ~ USD 1.
2. Rice crops
The same outputs as listed for cotton and maize crops above (rice yield reported as rough rice yield) as well as:
- Water productivity: GM / irrigation applied
- Net water use: irrigation applied – deep drainage below the root zone
Values used for GM calculations at Bairanpally are in Table 1, for Gorita are in Table 3 and for Nemmani are in Table 5. Values for small farms were used for comparisons.

3. Farm cropping comparisons:
- Gross margin: Values for rice and cotton small, medium and large farms at Bairanpally are in Table 1, at Gorita are in Table 3 and at Nemmani are in Table 5. Values for rice and maize small, medium and large farms at Bairanpally are in Table 2, at Gorita are in Table 4 and at Nemmani are in Table 6.
- Gross margin stability: Coefficient of variation (CV) of gross margin
- Irrigation applied
- Recharge: deep drainage below the root zone ie aquifer recharge
- Irrigation water productivity: GM / irrigation applied
- N leached
- N2O emission: calculated as kg N2O / 100000 INR GM / ha / yr
- C emission: calculated as kg C / 100000 INR GM / ha / yr

Table 1. Data for gross margin calculations for small, medium and large rice and cotton farms at Bairanpally.

Production Costs	Small Farm (5 acres)		Medium Farm (8 acres)		Large Farm (15 acres)	
	Rice	Cotton	Rice	Cotton	Rice	Cotton
Seed (INR/acre)	665	810	570	1080	600	1275
Fertiliser (INR/acre)	2200	3600	2100	2500	1900	1800
Manure (INR/acre)	900	400	600	0	0	0

Pesticides (INR/acre)	600	800	300	500	500	2000
Hired Labour (INR/acre)	5000	2000	5000	5000	2000	3500
Hired Implements (INR/acre)	2100	1600	2600	1800	1500	0
Hired Bullocks (INR/acre)	1000	1000	0	0	0	0
Income						
Value of yield (INR/kg)	11	25	12	25	18	25

Table 2. Data for gross margin calculations for small, medium and large rice and maize farms at Bairanpally.

Production Costs	Small Farm (5 acres)		Medium Farm (8 acres)		Large Farm (15 acres)	
	Rice	Maize	Rice	Maize	Rice	Maize
Seed (INR/acre)	665	800	600	750	600	1500
Fertiliser (INR/acre)	2200	2100	2100	1900	1900	1200
Manure (INR/acre)	900	0	0	0	0	0
Pesticides (INR/acre)	600	280	300	200	500	800
Hired Labour (INR/acre)	5000	3000	4000	3000	2000	1500
Hired Implements (INR/acre)	2100	1800	3000	1600	1500	0
Hired Bullocks (INR/acre)	1000	825	1000	1000	0	0
Income						
Value of yield	11	8	12	8.5	18	8.5

(INR/kg)

Table 3. Data for gross margin calculations for small, medium and large rice and cotton farms at Gorita.

Production Costs	Small Farm (5 acres)		Medium Farm (8 acres)		Large Farm (15 acres)	
	Rice	Cotton	Rice	Cotton	Rice	Cotton
Seed (INR/acre)	850	996	660	800	540	765
Fertiliser (INR/acre)	1600	1900	2000	2500	1700	1200
Manure (INR/acre)	1600	0	1333	0	533	267
Pesticides (INR/acre)	500	800	300	450	350	1500
Hired Labour (INR/acre)	2000	3000	6000	9600	3000	3000
Hired Implements (INR/acre)	2500	1600	1800	1600	0	0
Hired Bullocks (INR/acre)	0	0	0	0	0	0
Income						
Value of yield (INR/kg)	8.5	30	9.5	31	10.5	32

Table 4. Data for gross margin calculations for small, medium and large rice and maize farms at Gorita.

Production Costs	Small Farm (5 acres)		Medium Farm (8 acres)		Large Farm (15 acres)	
	Rice	Maize	Rice	Maize	Rice	Maize

Seed (INR/acre)	570	1600	540	700	540	560
Fertiliser (INR/acre)	1850	850	1600	1200	1700	1200
Manure (INR/acre)	1200	0	1200	667	533	267
Pesticides (INR/acre)	600	800	350	300	350	400
Hired Labour (INR/acre)	2000	1000	2000	1500	3000	1000
Hired Implements (INR/acre)	1500	0	0	0	0	0
Hired Bullocks (INR/acre)	0	0	0	0	0	0
Income						
Value of yield (INR/kg)	12	7	10.5	8	10.5	8

Table 5. Data for gross margin calculations for small, medium and large rice and cotton farms at Nemmani.

Production Costs	Small Farm (5 acres)		Medium Farm (8 acres)		Large Farm (15 acres)	
	Rice	Cotton	Rice	Cotton	Rice	Cotton
Seed (INR/acre)	540	693	540	693	540	693
Fertiliser (INR/acre)	1500	750	1500	750	1500	1000
Manure (INR/acre)	1200	800	1200	300	2400	600
Pesticides (INR/acre)	350	2000	500	2500	450	2500
Hired Labour (INR/acre)	4200	3000	4200	3600	3600	3000

Hired Implements (INR/acre)	1500	0	1500	0	0	0
Hired Bullocks (INR/acre)	0	0	0	0	0	0
Income						
Value of yield (INR/kg)	9.5	28	10.5	28	10.5	28

Table 6. Data for gross margin calculations for small, medium and large rice and maize* farms at Nemmani.

Production Costs	Small Farm (5 acres)		Medium Farm (8 acres)		Large Farm (15 acres)	
	Rice	Maize	Rice	Maize	Rice	Maize
Seed (INR/acre)	540	1600	540	700	540	560
Fertiliser (INR/acre)	1500	850	1500	1200	1500	1200
Manure (INR/acre)	1200	0	1200	667	2400	267
Pesticides (INR/acre)	350	800	500	300	450	400
Hired Labour (INR/acre)	4200	1000	4200	1500	3600	1000
Hired Implements (INR/acre)	1500	0	1500	0	0	0
Hired Bullocks (INR/acre)	0	0	0	0	0	0
Income						
Value of yield (INR/kg)	9.5	7	10.5	8	10.5	8

* Note: Maize values are from Gorita, no values were available for Nemmani.

Results

Adaptation to Climate Variability

1. Sowing rules for cotton and maize

A comparison of the effects of sowing rules on the percentage of years in which cotton and maize crops are not sown or in which seedlings fail are presented in Table x7.

Table 7. The percentage of years in which cotton and maize crops are not sown or in which seedlings fail when various sowing rules are applied to crops at Bairanpally, Gorita and Nemmani villages in India (1978-2009).

Sowing rule	Bairanpally			Gorita			Nemmani		
	Not sown (%)	Cotton fails (%)	Maize fails (%)	Not sown (%)	Cotton fails (%)	Maize fails (%)	Not sown (%)	Cotton fails (%)	Maize fails (%)
IMD 2 day	0.0	16.1	18.8	9.7	10.7	10.3	6.3	23.3	26.7
75mm in 4 days	43.8	0.0	0.0	71.9	11.1	11.1	84.4	0.0	20.0
75mm in 7 days	37.5	0.0	0.0	51.6	6.7	6.3	62.5	0.0	8.3
75mm in 10 days	28.1	0.0	0.0	35.5	5.0	4.8	56.3	0.0	7.1
75mm in 14 days	25.0	0.0	0.0	25.8	4.3	4.2	46.9	0.0	5.9
75mm	9.7	0.0	0.0	6.5	3.4	0.0	12.5	17.9	21.4
50mm in 4 days	15.6	0.0	3.7	34.4	4.8	4.8	56.3	0.0	7.1
50mm in 7 days	9.4	0.0	6.9	18.8	3.8	3.8	40.6	0.0	5.3
50mm in 10 days	9.4	3.4	3.4	12.5	3.6	3.6	34.4	0.0	4.8

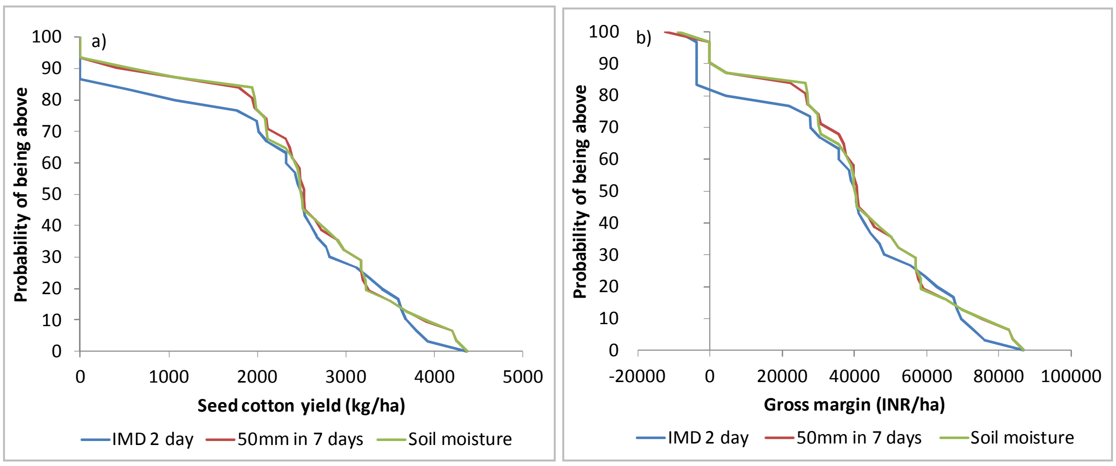
50mm in 14 days	9.4	6.9	6.9	6.3	10.0	6.7	25.0	4.2	8.3
50mm	3.1	16.1	16.1	0.0	3.1	3.1	6.3	13.3	16.7
Soil moisture	9.4	0.0	3.4	3.1	0.0	3.2	15.6	0.0	3.7

At Bairanpally the IMD 2 day sowing rule ensured a sowing opportunity in all years, however, it also resulted in seedling failures in 16.1% years for cotton and 18.8% years for maize. Of the remaining sowing rules the two with optimal tradeoffs between sowing opportunity and seedling failure for cotton are the 50mm in 7 days and soil moisture sowing rules. For maize, the two sowing rules with optimal tradeoffs between sowing opportunity and seedling failure are the 75mm and soil moisture sowing rules (Table 7).

At Gorita the IMD 2 day sowing rule resulted in no sowing opportunity in 9.7% years and also resulted in seedling failures in 10.7% years for cotton and 10.3% years for maize. Of the remaining sowing rules, the two with optimal tradeoffs between sowing opportunity and seedling failure are the 50mm and soil moisture sowing rules for both cotton and maize (Table 7).

At Nemmani the IMD 2 day sowing rule resulted in no sowing opportunity in 6.3% years and also resulted in seedling failures in 23.3% years for cotton and 26.7% years for maize. Of the remaining sowing rules, the two with optimal tradeoffs between sowing opportunity and seedling failure are the 50mm and soil moisture sowing rules for both cotton and maize (Table 7).

A comparison of the yield and gross margin response of crops grown using the IMD 2 day sowing rule and the remaining two sowing rules with optimal tradeoffs between sowing opportunity and seedling failure for each village are presented in Fig 1 for cotton and Fig 2 for maize.



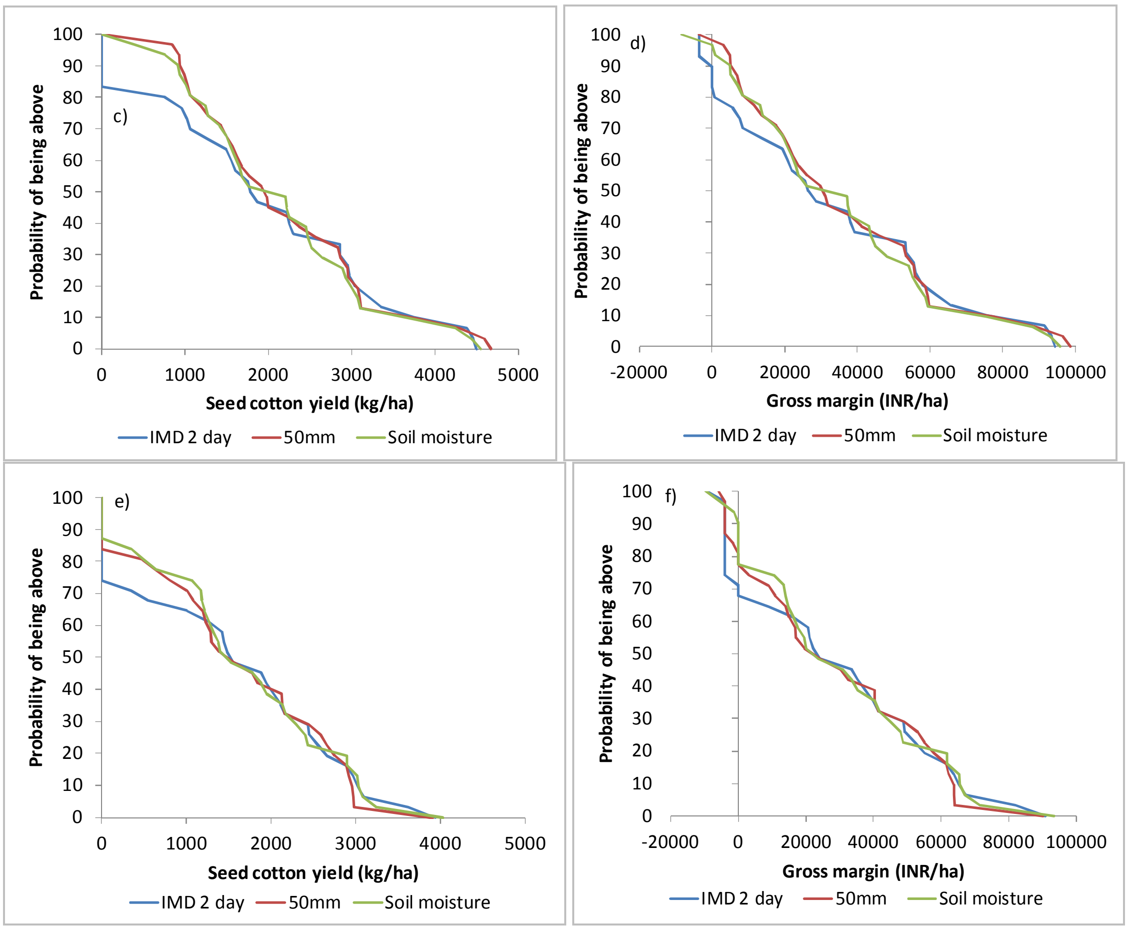
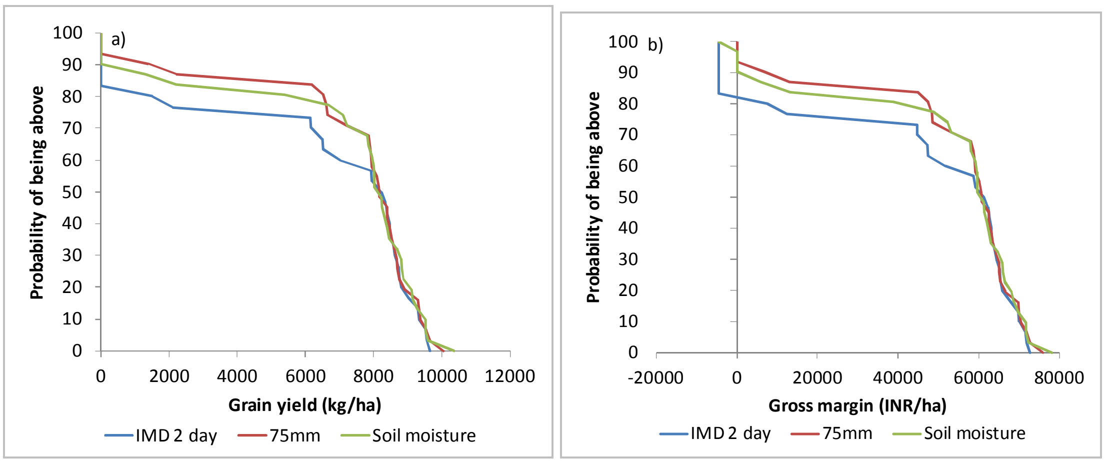


Fig 1. Response of seed cotton yield at a) Bairanpally, c) Gorita and e) Nemmani and gross margin at b) Bairanpally, d) Gorita and f) Nemmani to sowing rule. Simulation results are for period 1978-2009 at each village.



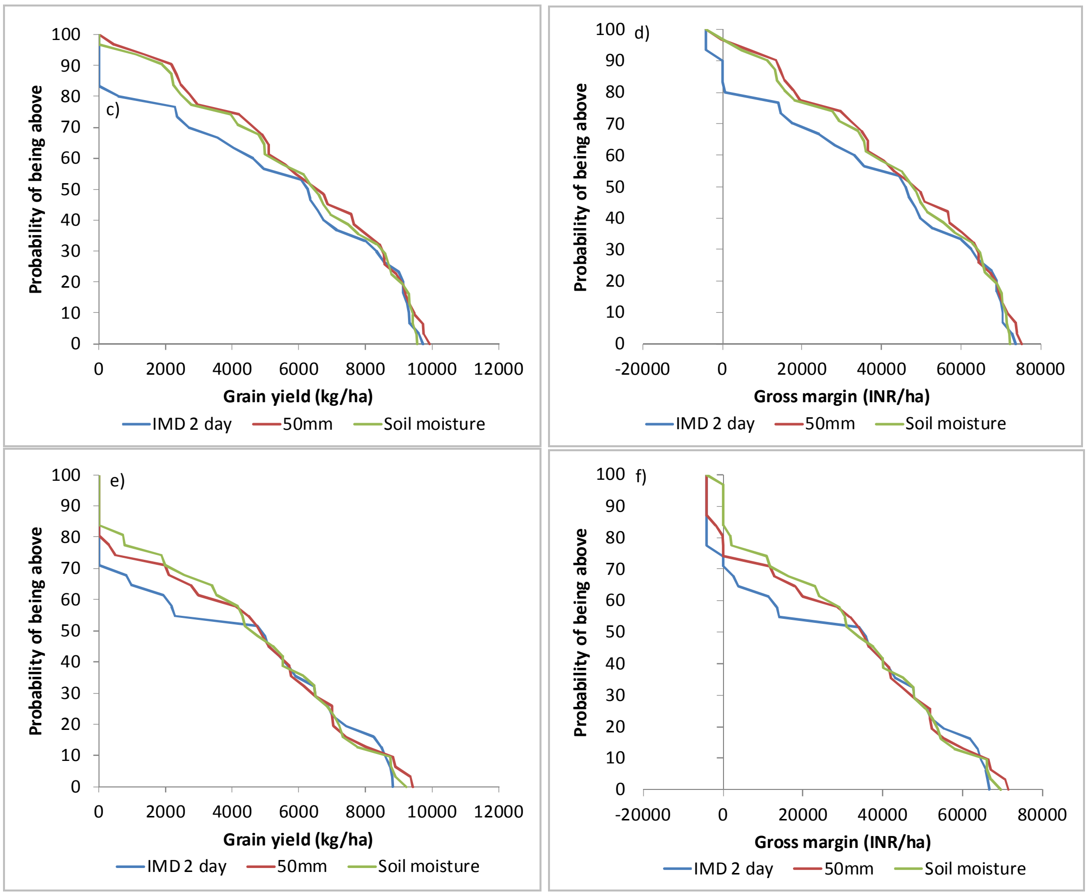


Fig 2. Response of maize grain yield at a) Bairanpally, c) Gorita and e) Nemmani and gross margin at b) Bairanpally, d) Gorita and f) Nemmani to sowing rule. Simulation results are for period 1978-2009 at each village.

A comparison of the yield, gross margin, yield stability, gross margin stability, N_2O and C emissions of cotton and maize crops grown using the different sowing rules for each village are presented in Fig 3.

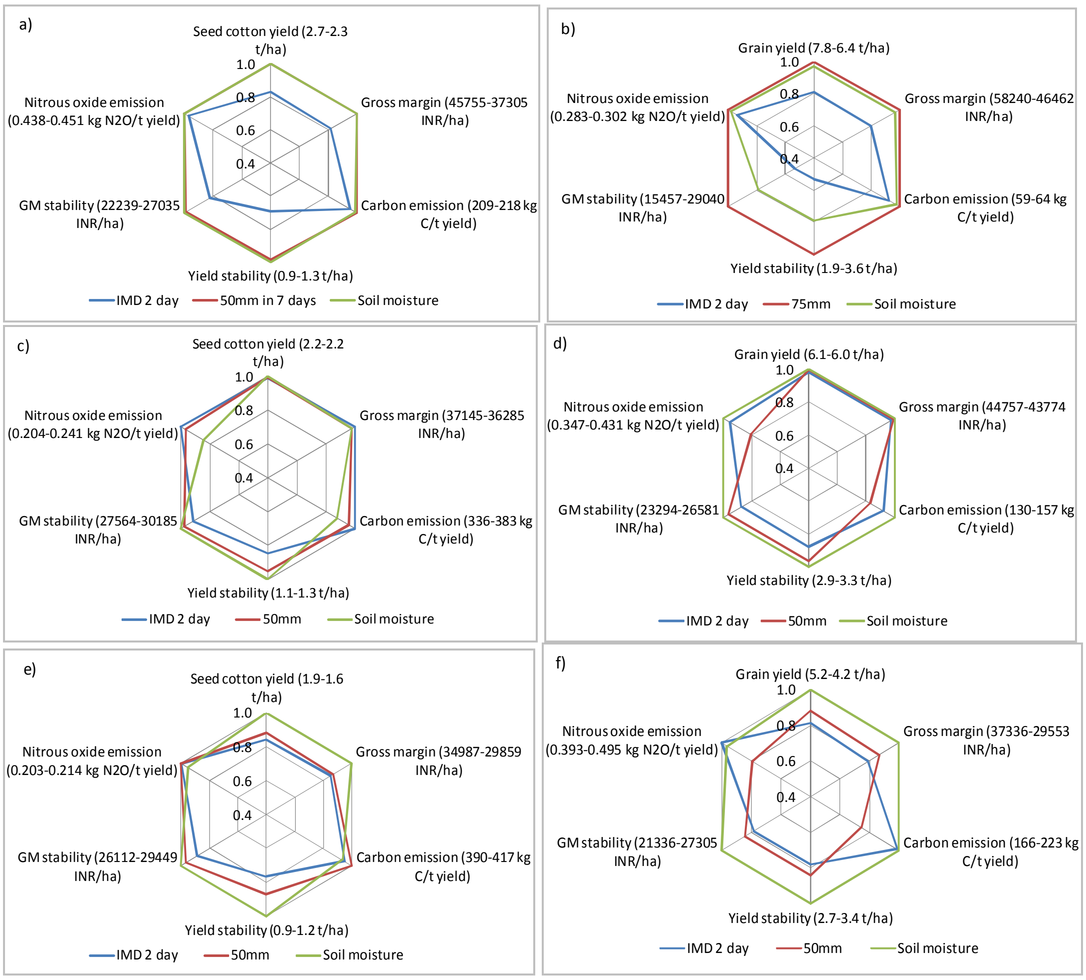


Fig 3. Comparison of yield, gross margin, yield stability, gross margin stability, N2O and C emissions of cotton crops grown at a) Bairanpally, c) Gorita, e) Nemmani and maize crops grown at b) Bairanpally, d) Gorita and f) Nemmani using the IMD 2 day sowing rule and the remaining two sowing rules with optimal tradeoffs between sowing opportunity and seedling failure for each village. Simulation results are for period 1978-2009.

2. Strategic irrigation of rainfed crops

A comparison of the effects of strategic irrigation on yield and gross margin response of crops to IMD 2 day sowing rule and the remaining two sowing rules with optimal tradeoffs between sowing opportunity and seedling failure for each village are presented in Fig 4 for cotton and Fig 5 for maize.

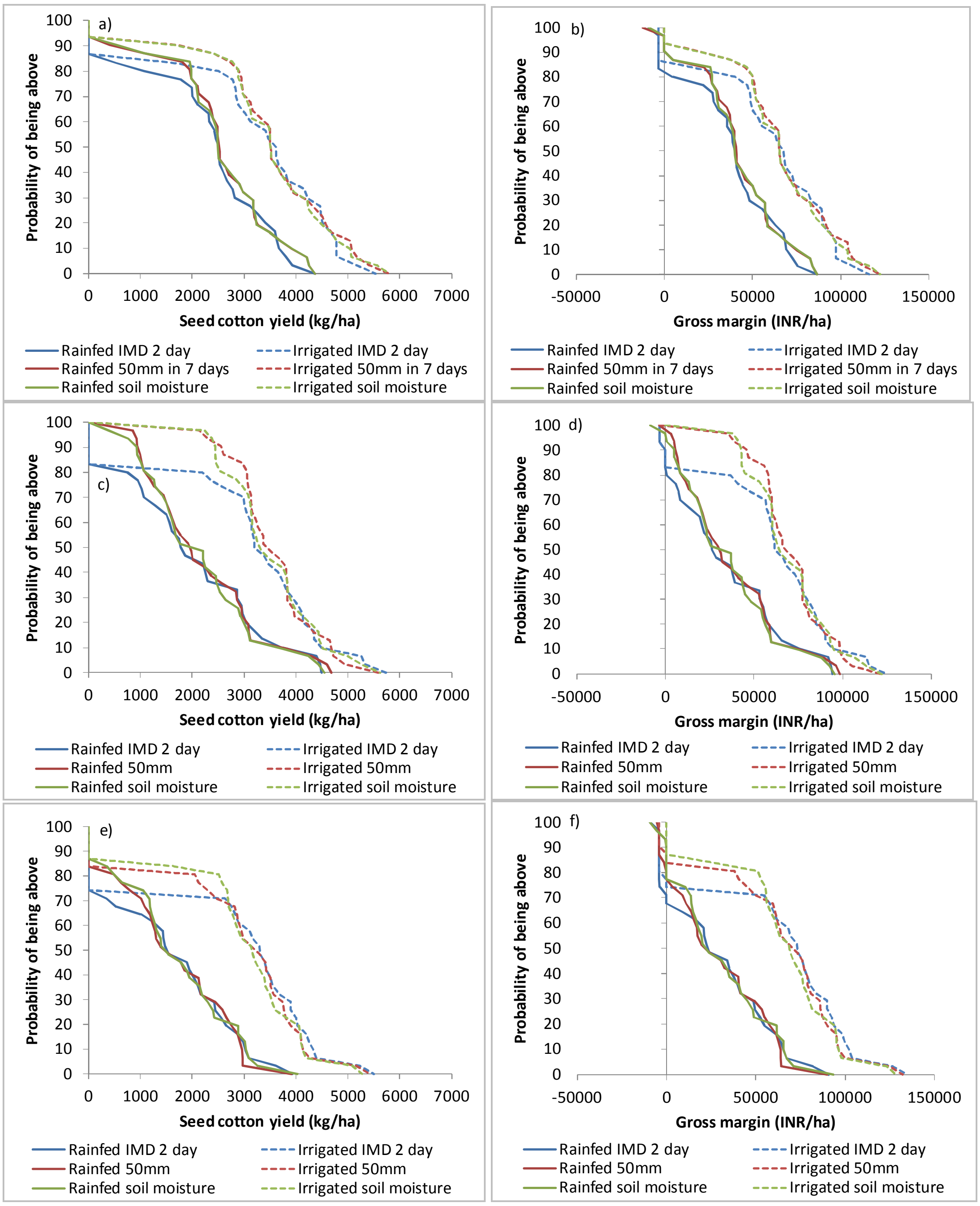


Fig 4. The effect of strategic irrigation on the response of seed cotton yield at a) Bairanpally, c) Gorita and e) Nemmani and gross margin at b) Bairanpally, d) Gorita and f) Nemmani to sowing rule. Simulation results are for period 1978-2009 at each village.

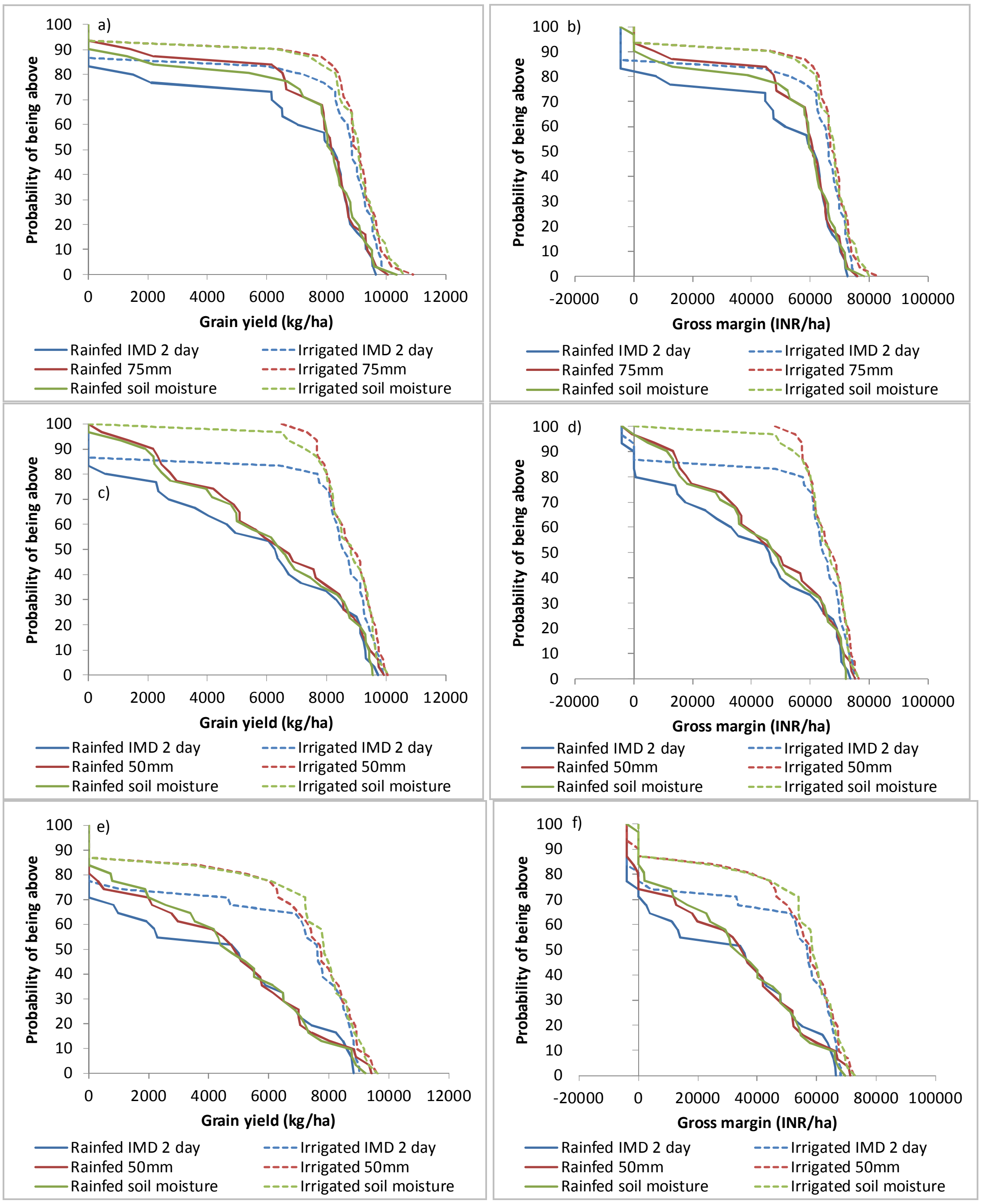


Fig 5. The effect of strategic irrigation on the response of maize grain yield at a) Bairanpally, c) Gorita and e) Nemmani and gross margin at b) Bairanpally, d) Gorita and f) Nemmani to sowing rule. Simulation results are for period 1978-2009 at each village.

A comparison of the yield, gross margin, yield stability, gross margin stability, N_2O and C emissions of rainfed and strategically irrigated cotton and maize crops simulated using the soil moisture sowing rule for each village are presented in Fig 6.

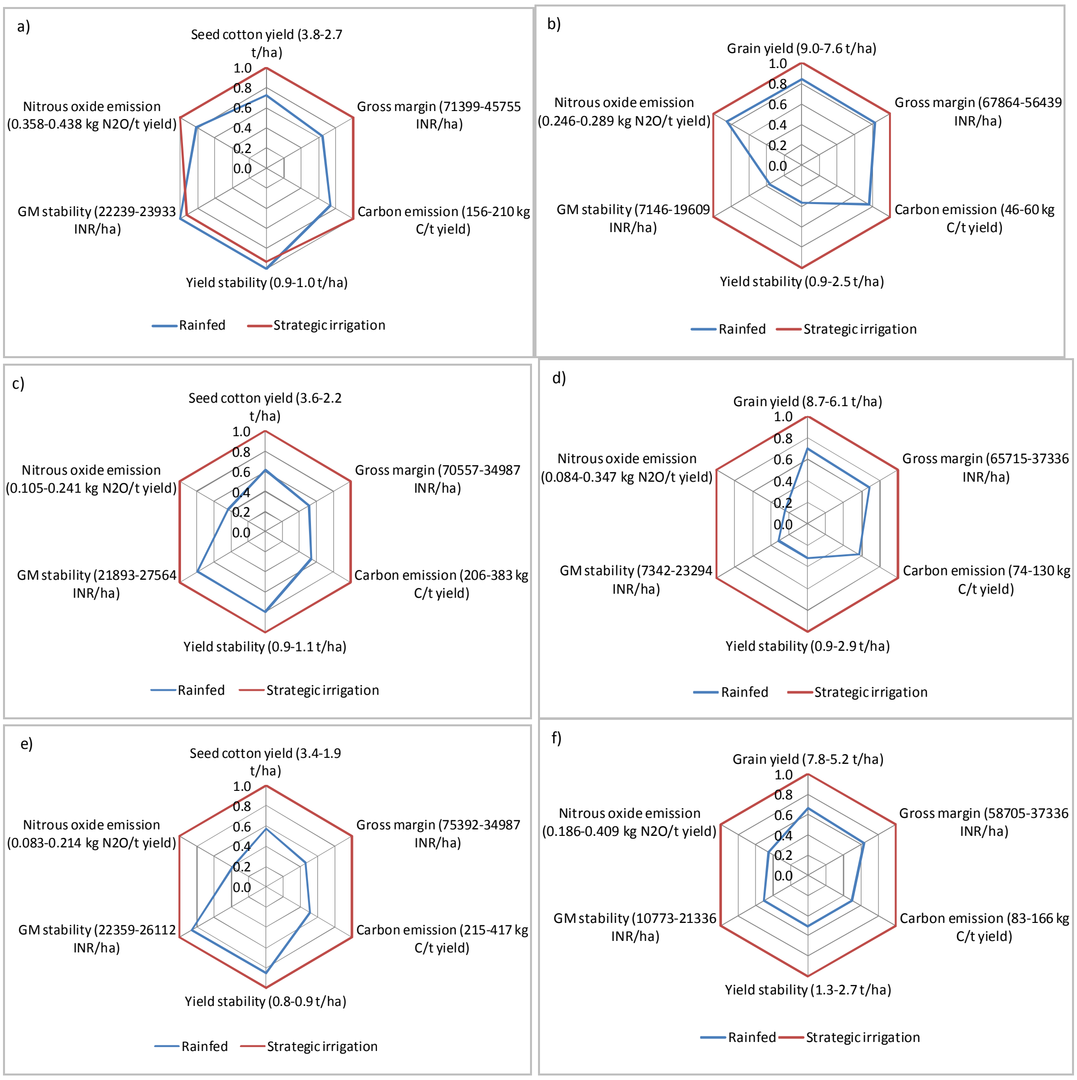


Fig 6. Comparison of yield, gross margin, yield stability, gross margin stability, N2O and C emissions of rainfed and strategically irrigated cotton crops grown at a) Bairanpally, c) Gorita, e) Nemmani and rainfed and strategically irrigated maize crops grown at b) Bairanpally, d) Gorita and f) Nemmani using the soil moisture sowing rule for each village. Simulation results are for period 1978-2009.

3. Reduced irrigation of rice

A comparison of the response of rough rice yield and net water use (irrigation – deep drainage below the root zone) of rice crops grown using the four irrigation rules for each village are presented in Fig 7.

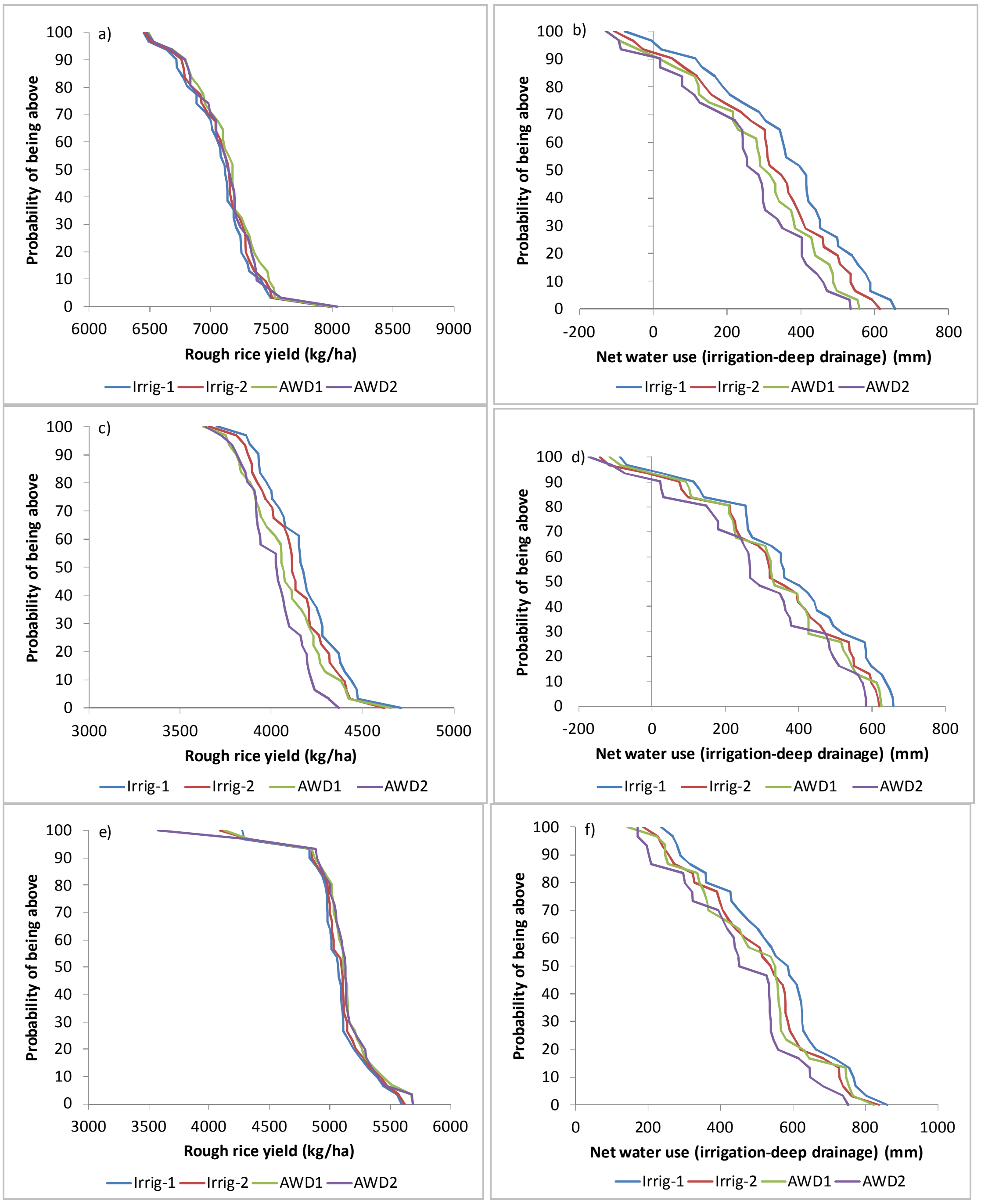


Fig 7. Response of rough rice yield at a) Bairanpally, c) Gorita and e) Nemmani and net water use at b) Bairanpally, d) Gorita and f) Nemmani to irrigation rule. Simulation results are for period 1978-2009 at each village.

A comparison of the yield, gross margin, yield stability, gross margin stability, N_2O and C emissions, irrigation water productivity and net water use of rice crops simulated using the four irrigation rules for each village are presented in Fig 8.

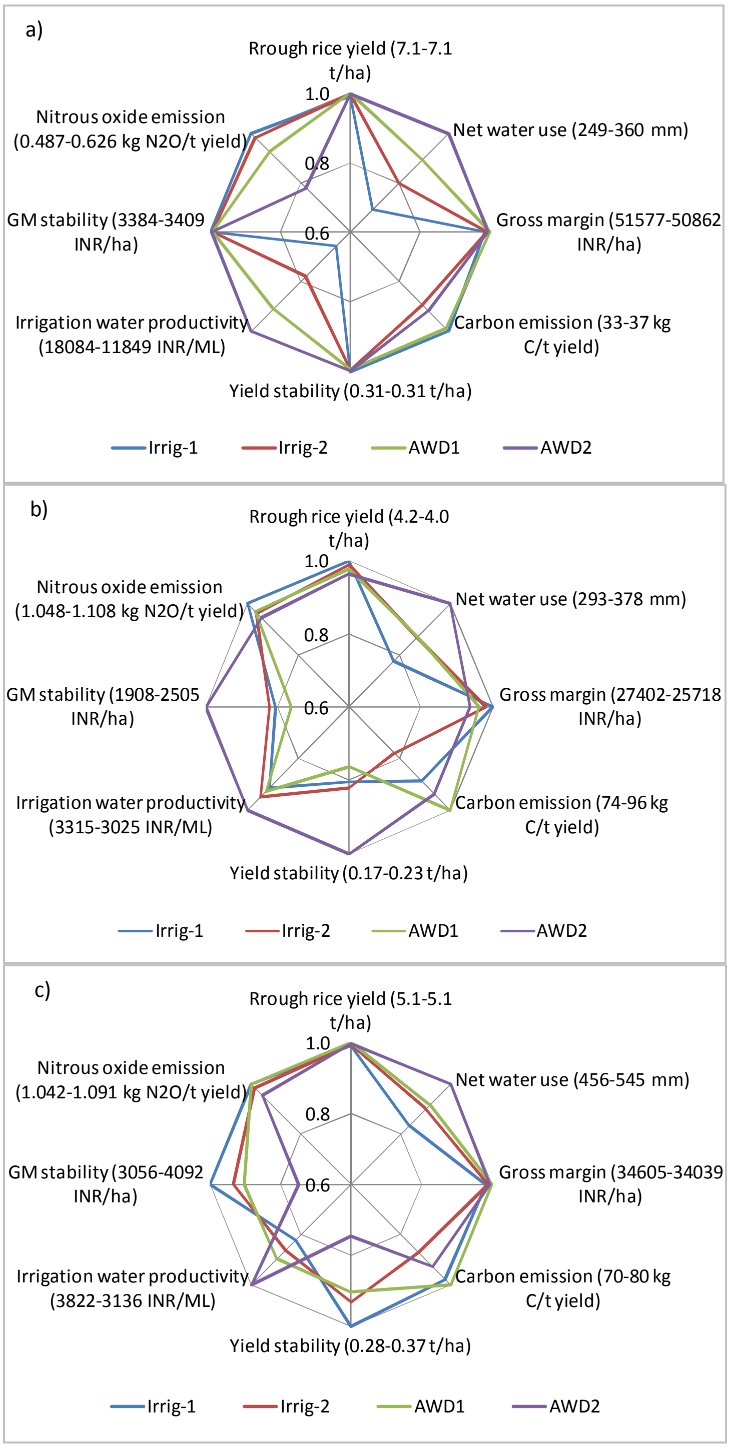


Fig 8. Comparison of yield, gross margin, yield stability, gross margin stability, N_2O and C emissions, irrigation water productivity and net water use of rice crops grown at a) Bairanpally, b) Gorita and c) Nemmani using the four irrigation rules for each village. Simulation results are for period 1978-2009.

4. Reduced rice area for strategic irrigation of rainfed crops

A comparison of the average gross margin and net water use as well as the gross margin, gross margin stability, N_2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for small, medium and large farms growing rice and cotton crops at Bairanpally are presented in Fig 9.

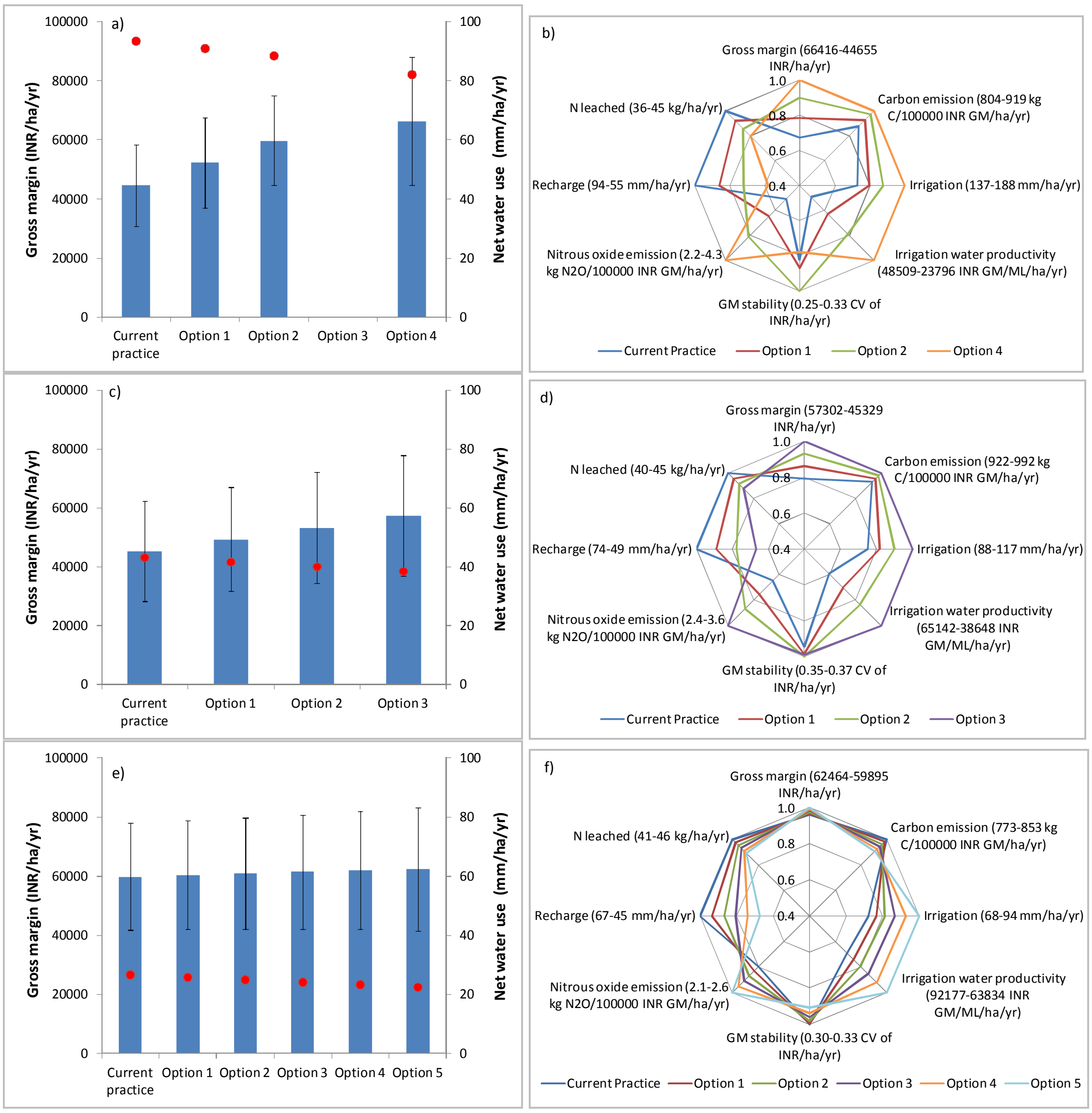


Fig 9. Gross margin (blue bars) and net water use (red dots) for adaptation options used on farms growing rice and cotton for a) small farm, c) medium farm and e) large farms at Bairanpally. Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N2O emission, aquifer recharge and N leached for each of the adaptation options on b) small farm, d) medium farm and f) large farms at Bairanpally. Note: option 3 on small farms is not applicable at Bairanpally as there was not enough excess water for unlimited irrigations. Simulation results are for period 1978-2009.

A comparison of the average gross margin and net water use as well as the gross margin, gross margin stability, N2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for small, medium and large farms growing rice and maize crops at Bairanpally are presented in Fig 10.

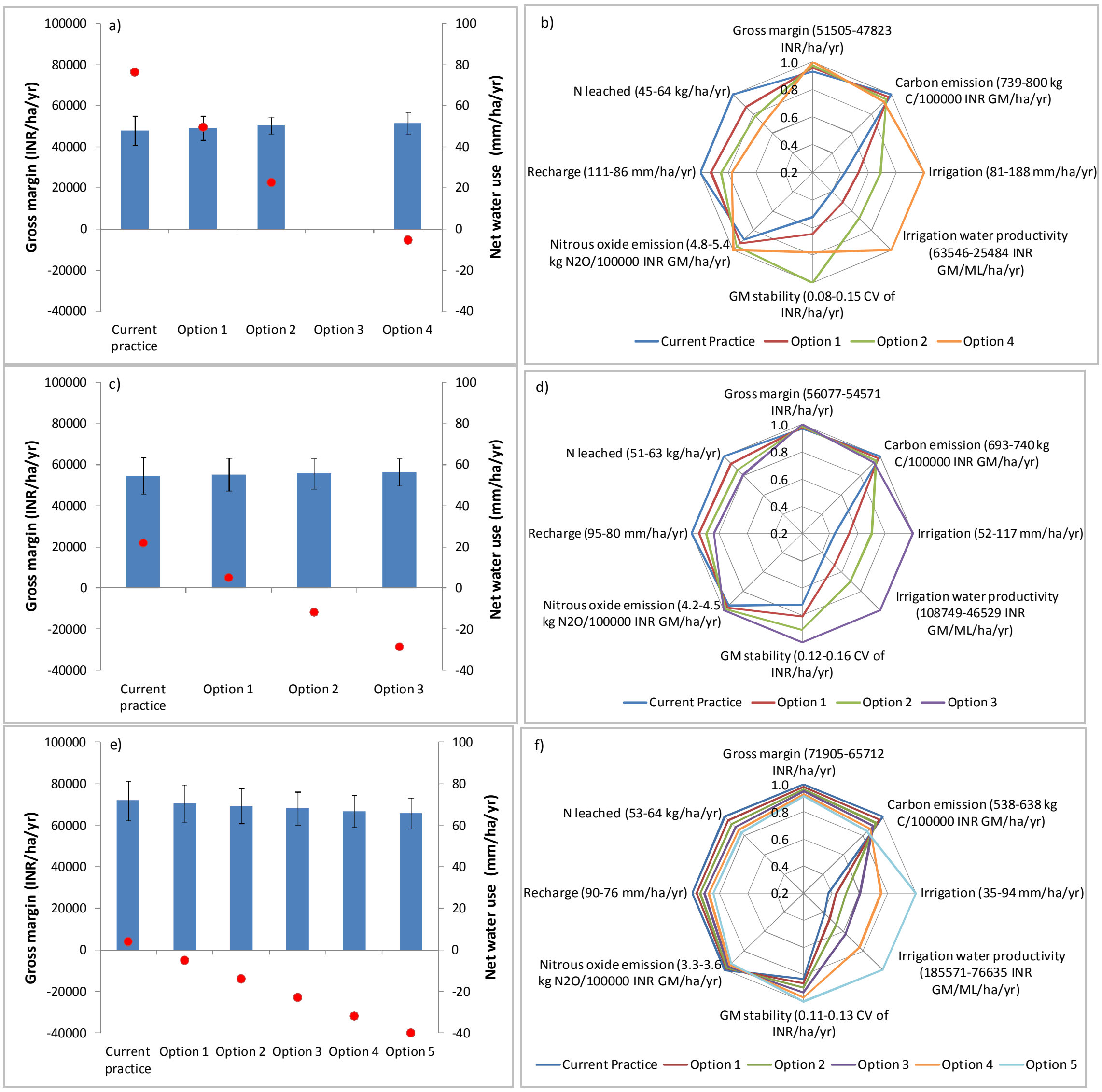


Fig 10. Gross margin (blue bars) and net water use (red dots) for adaptation options used on farms growing rice and maize for a) small farm, c) medium farm and e) large farms at Bairanpally. Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N2O emission, aquifer recharge and N leached for each of the adaptation options on b) small farm, d) medium farm and f) large farms at Bairanpally. Note: option 3 on small farms is not applicable at Bairanpally as there was not enough excess water for unlimited irrigations. Simulation results are for period 1978-2009.

A comparison of the average gross margin and net water use as well as the gross margin, gross margin stability, N_2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for small, medium and large farms growing rice and cotton crops at Gorita are presented in Fig 11.

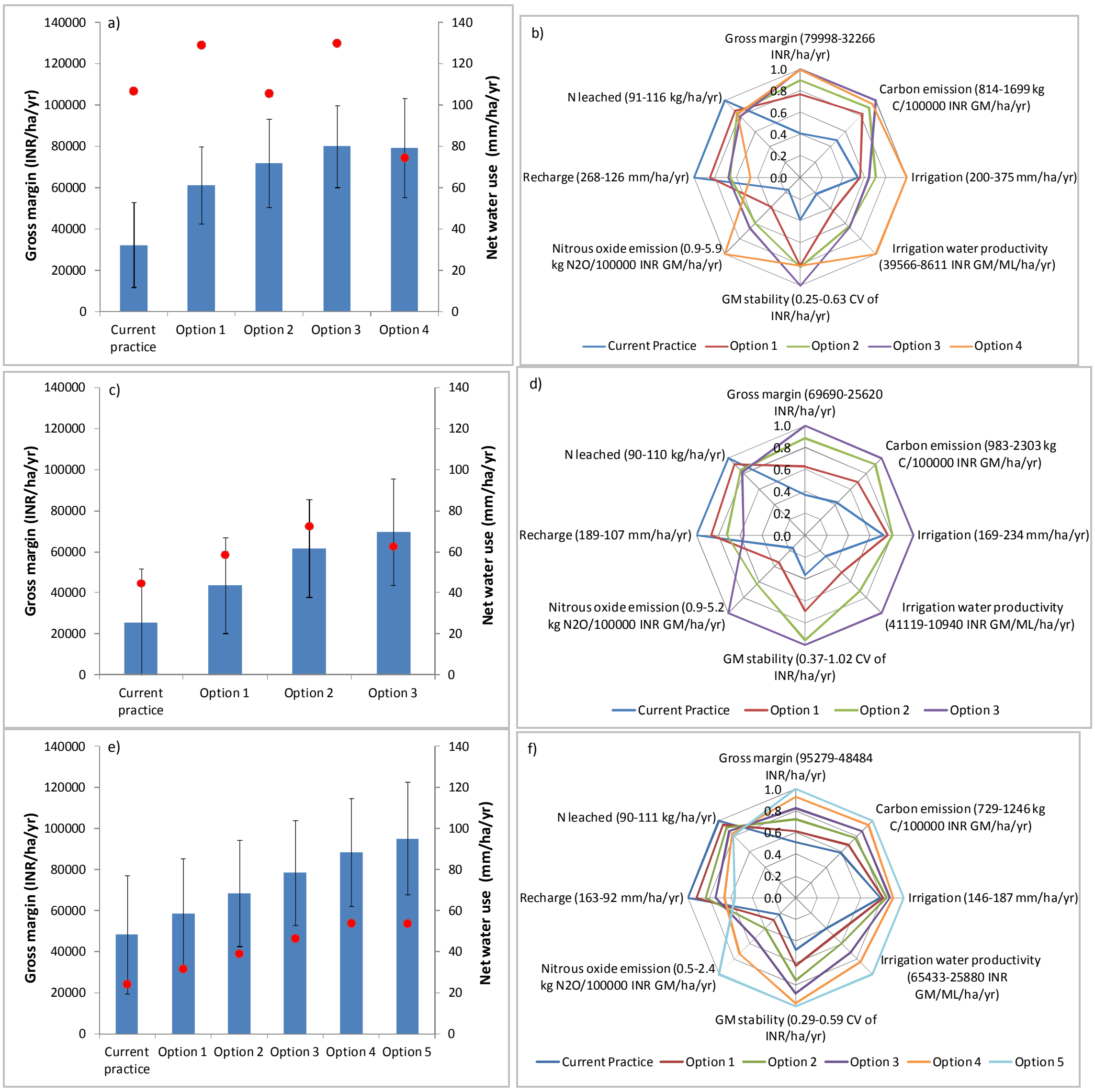


Fig 11. Gross margin (blue bars) and net water use (red dots) for adaptation options used on farms growing rice and cotton for a) small farm, c) medium farm and e) large farms at Gorita. Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N2O emission, aquifer recharge and N leached for each of the adaptation options on b) small farm, d) medium farm and f) large farms at Gorita. Simulation results are for period 1978-2009.

A comparison of the average gross margin and net water use as well as the gross margin, gross margin stability, N_2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for small, medium and large farms growing rice and maize crops at Gorita are presented in Fig 12.

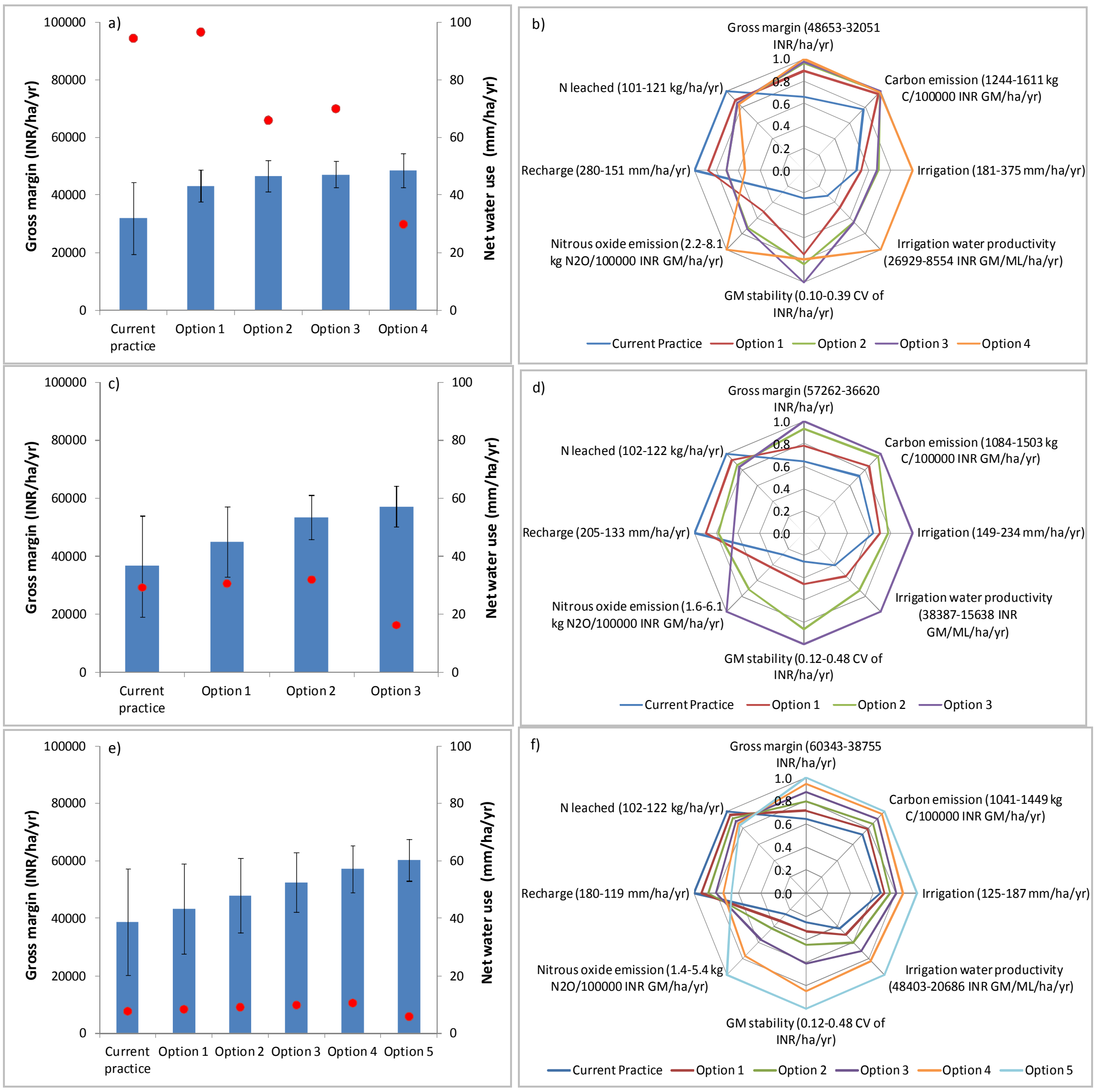


Fig 12. Gross margin (blue bars) and net water use (red dots) for adaptation options used on farms growing rice and maize for a) small farm, c) medium farm and e) large farms at Gorita. Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N2O emission, aquifer recharge and N leached for each of the adaptation options on b) small farm, d) medium farm and f) large farms at Gorita. Simulation results are for period 1978-2009.

A comparison of the average gross margin and net water use as well as the gross margin, gross margin stability, N_2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for small, medium and large farms growing rice and cotton crops at Nemmani are presented in Fig 13.

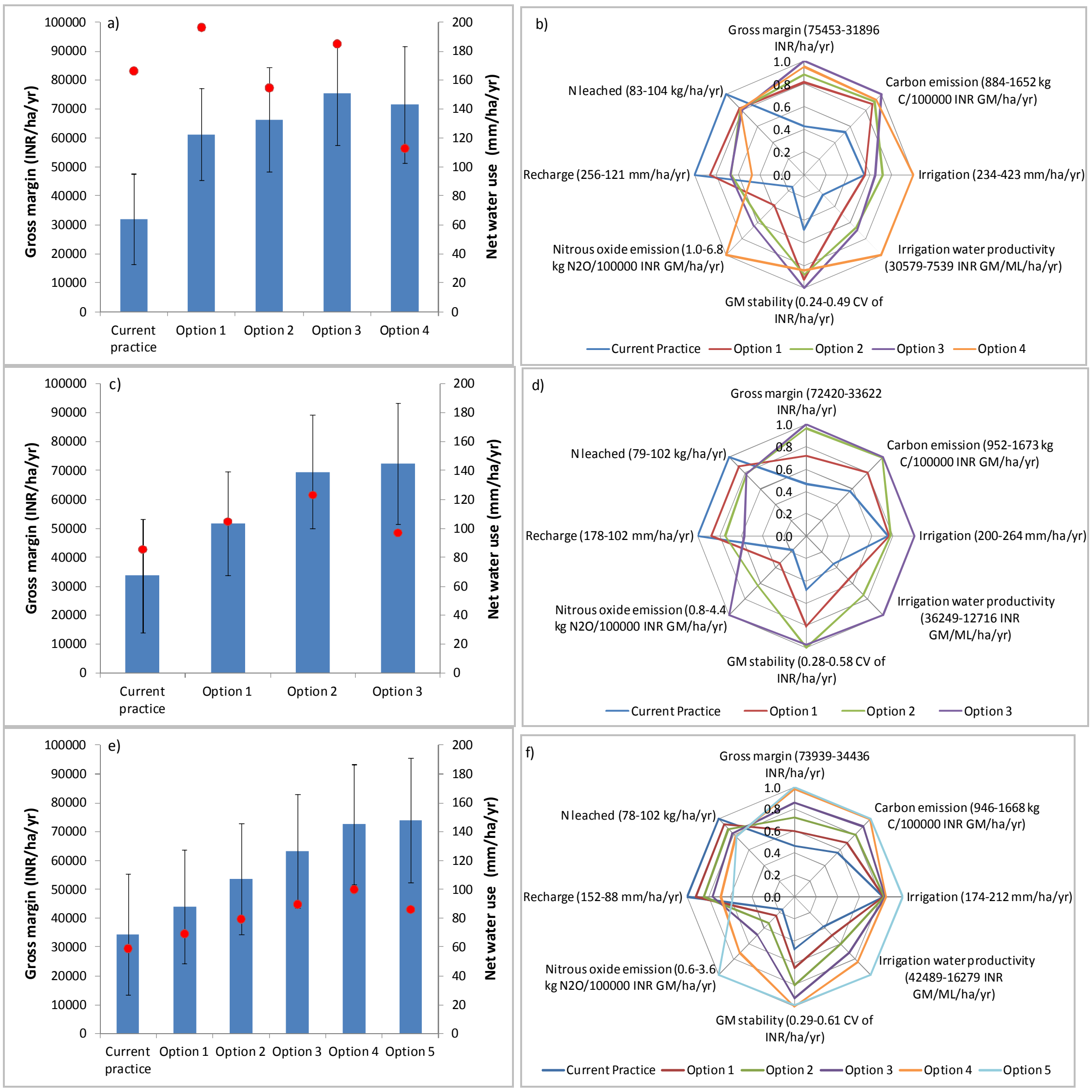


Fig 13. Gross margin (blue bars) and net water use (red dots) for adaptation options used on farms growing rice and cotton for a) small farm, c) medium farm and e) large farms at Nemmani. Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N2O emission, aquifer recharge and N leached for each of the adaptation options on b) small farm, d) medium farm and f) large farms at Nemmani. Simulation results are for period 1978-2009.

A comparison of the average gross margin and net water use as well as the gross margin, gross margin stability, N_2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for small, medium and large farms growing rice and maize crops at Nemmani are presented in Fig 14.

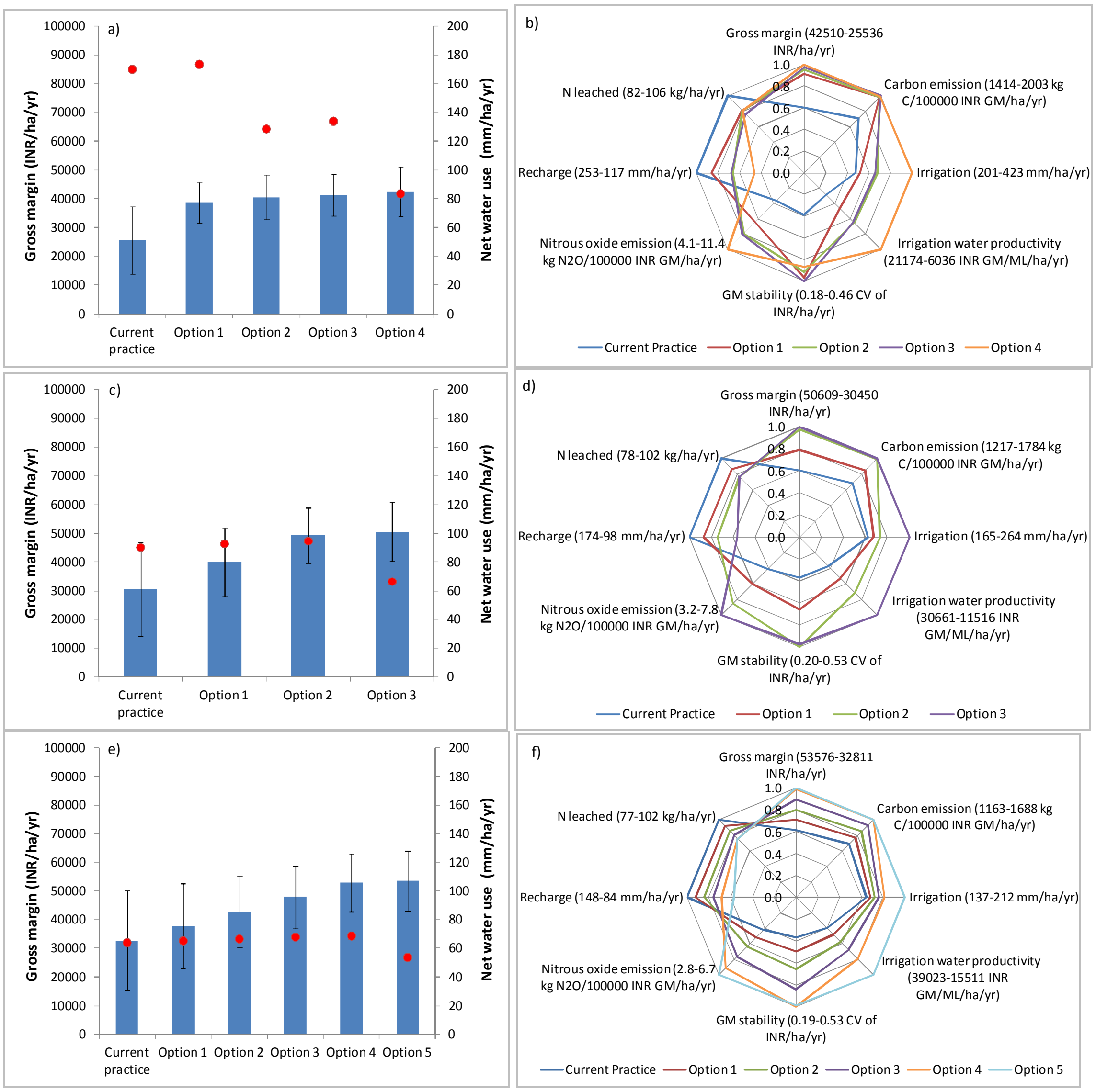


Fig 14. Gross margin (blue bars) and net water use (red dots) for adaptation options used on farms growing rice and maize for a) small farm, c) medium farm and e) large farms at Nemmani. Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N2O emission, aquifer recharge and N leached for each of the adaptation options on b) small farm, d) medium farm and f) large farms at Nemmani. Simulation results are for period 1978-2009.

1. Sowing rules for cotton and maize

A comparison of the effects of sowing rules on the percentage of years in which cotton and maize crops are not sown or in which seedlings fail are presented in Table 8 for future climate ECHAM5 and Table x9 for future climate GFDL CM2.1.

Table 8. The percent of years in which crops are not sown or in which sown crops fail when various sowing rules are applied to cotton and maize crops at Bairanpally, Gorita and Nemmani villages in India (future climate ECHAM5 2021-2040).

Sowing rule	Bairanpally			Gorita			Nemmani		
	Not sown (%)	Cotton fails (%)	Maize fails (%)	Not sown (%)	Cotton fails (%)	Maize fails (%)	Not sown (%)	Cotton fails (%)	Maize fails (%)
IMD 2 day	0.0	20.0	20.0	10.0	16.7	16.7	5.0	15.8	21.1
75mm in 4 days	45.0	0.0	0.0	70.0	0.0	0.0	85.0	0.0	0.0
75mm in 7 days	20.0	0.0	0.0	45.0	0.0	0.0	60.0	0.0	0.0
75mm in 10 days	15.0	0.0	0.0	20.0	0.0	0.0	50.0	0.0	0.0
75mm in 14 days	10.0	0.0	0.0	15.0	5.9	5.9	45.0	0.0	0.0
75mm	10.0	0.0	5.6	0.0	0.0	0.0	15.0	11.8	11.8
50mm in 4 days	5.0	0.0	0.0	30.0	7.1	7.1	45.0	0.0	0.0
50mm in 7 days	5.0	0.0	0.0	10.0	5.6	5.6	30.0	0.0	0.0
50mm in 10 days	5.0	0.0	0.0	5.0	5.3	10.5	20.0	0.0	0.0
50mm in 14 days	5.0	5.3	5.3	0.0	10.0	15.0	15.0	0.0	0.0

50mm	5.0	5.3	5.3	0.0	0.0	0.0	0.0	10.0	10.0
Soil moisture	5.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0

Table 9. The percent of years in which crops are not sown or in which sown crops fail when various sowing rules are applied to cotton and maize crops at Bairanpally, Gorita and Nemmani villages in India (future climate GFDL CM2.1 2021-2040).

Sowing rule	Bairanpally			Gorita			Nemmani		
	Not sown (%)	Cotton fails (%)	Maize fails (%)	Not sown (%)	Cotton fails (%)	Maize fails (%)	Not sown (%)	Cotton fails (%)	Maize fails (%)
IMD 2 day	0.0	35.0	40.0	5.0	31.6	36.8	5.0	21.1	26.3
75mm in 4 days	45.0	0.0	0.0	75.0	0.0	0.0	85.0	0.0	0.0
75mm in 7 days	20.0	0.0	0.0	50.0	0.0	0.0	55.0	0.0	0.0
75mm in 10 days	15.0	0.0	0.0	20.0	6.3	6.3	50.0	0.0	0.0
75mm in 14 days	10.0	0.0	0.0	20.0	6.3	6.3	45.0	0.0	0.0
75mm	10.0	0.0	5.6	0.0	5.0	10.0	15.0	11.8	17.6
50mm in 4 days	5.0	0.0	5.3	30.0	7.1	7.1	45.0	0.0	0.0
50mm in 7 days	5.0	0.0	5.3	15.0	5.9	5.9	40.0	0.0	0.0
50mm in 10 days	5.0	0.0	5.3	10.0	5.6	5.6	25.0	0.0	0.0
50mm in 14 days	5.0	10.5	10.5	0.0	10.0	10.0	20.0	6.3	6.3
50mm	5.0	10.	10.	0.0	5.0	5.0	0.0	10.	10.

		5	5					0	0
Soil moisture	5.0	0.0	5.3	5.0	0.0	0.0	10.0	0.0	0.0

ECHAM5 future climate

At Bairanpally the IMD 2 day sowing rule ensured a sowing opportunity in all years, however, it also resulted in seedling failures in 20% years for both cotton and maize. Of the remaining sowing rules there were four with optimal tradeoffs between sowing opportunity and seedling failure for cotton and maize: 50mm in 4 days, 50mm in 7 days, 50mm in 10 days and the soil moisture rule (Table x8).

At Gorita the IMD 2 day sowing rule resulted in no sowing opportunity in 10% years and also resulted in seedling failures in 16.7% years for cotton and maize. Of the remaining sowing rules there were three which ensured a sowing opportunity and resulted in no seedling failures for cotton and maize: 75mm, 50mm and soil moisture (Table 8).

At Nemmani the IMD 2 day sowing rule resulted in no sowing opportunity in 5% years and also resulted in seedling failures in 15.8% years for cotton and 21.1% years for maize. Of the remaining sowing rules, the two with optimal tradeoffs between sowing opportunity and seedling failure are the 50mm and soil moisture sowing rules for both cotton and maize (Table 8).

GFDL CM2.1 future climate

At Bairanpally the IMD 2 day sowing rule ensured a sowing opportunity in all years, however, it also resulted in seedling failures in 35% years for cotton and 40% years for maize. Of the remaining sowing rules there were four with optimal tradeoffs between sowing opportunity and seedling failure for cotton and maize: 50mm in 4 days, 50mm in 7 days, 50mm in 10 days and the soil moisture rule (Table 9).

At Gorita the IMD 2 day sowing rule resulted in no sowing opportunity in 5% years and also resulted in seedling failures in 31.6% years for cotton and 36.8% years for maize. Of the remaining sowing rules there were three with optimal tradeoffs between sowing opportunity and seedling failure for cotton: 75mm, 50mm and soil moisture. There were two sowing rules with optimal tradeoffs between sowing opportunity and seedling failure for maize: 50mm and soil moisture (Table 9).

At Nemmani the IMD 2 day sowing rule resulted in no sowing opportunity in 5% years and also resulted in seedling failures in 21.1% years for cotton and 26.3% years for maize. Of the remaining sowing rules, the two with optimal tradeoffs between sowing opportunity and seedling failure for both cotton and maize are the 50mm and soil moisture sowing rules (Table 9).

Comparisons of yield and gross margin responses of crops grown using the IMD 2 day sowing rule and the remaining two sowing rules with optimal tradeoffs between sowing opportunity and seedling failure identified for the baseline climate (1978-2009) for each village are presented for the ECHAM5 future climate in Fig 15 for cotton and Fig 16 for maize. The same comparisons for each village using the GFDL CM2.1 future climate are presented in Fig 17 for cotton and Fig 18 for maize.

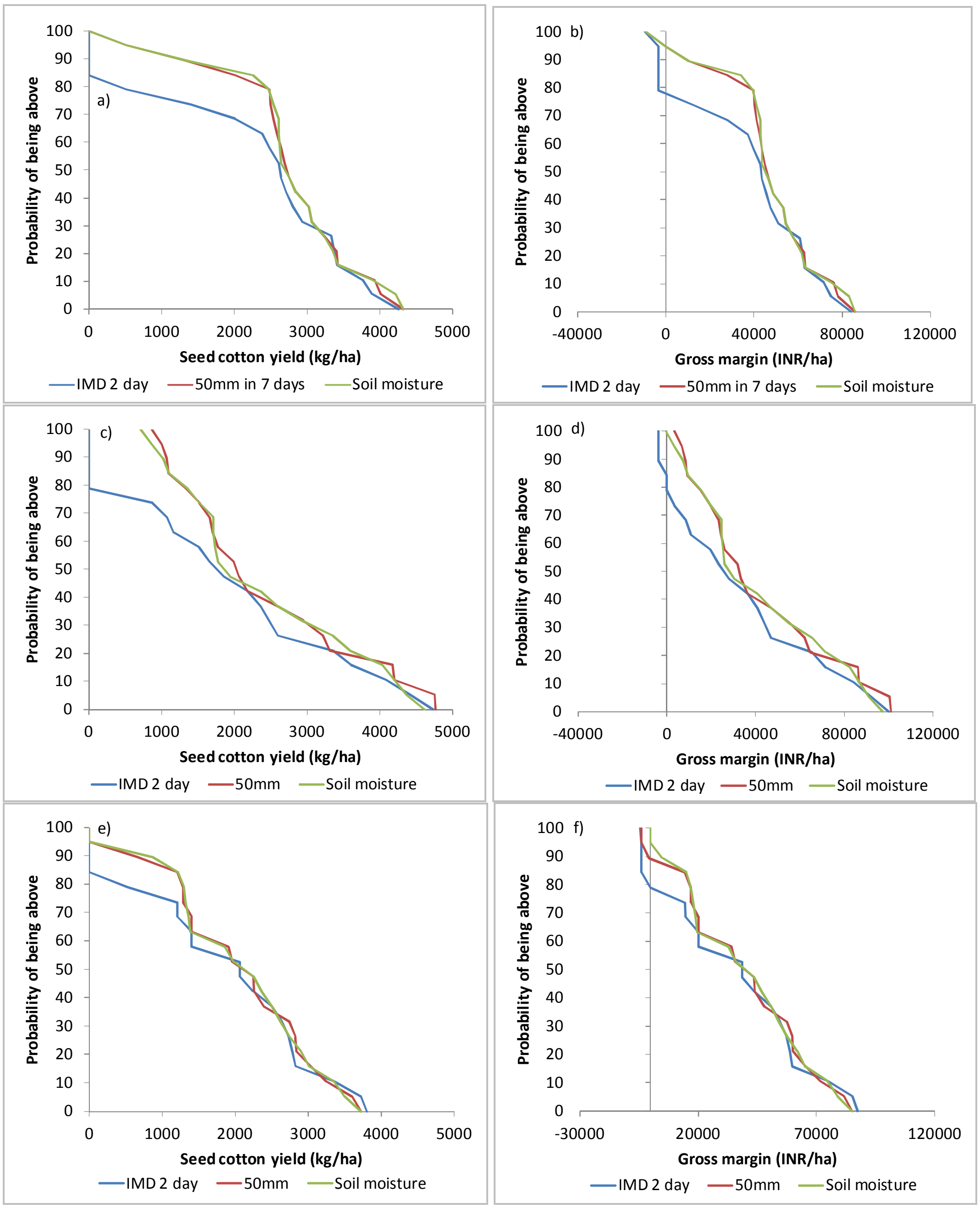


Fig 15. Response of seed cotton yield at a) Bairanpally, c) Gorita and e) Nemmani and gross margin at b) Bairanpally, d) Gorita and f) Nemmani to sowing rule. Simulation results are for future climate ECHAM5 for period 2021-2040 at each village.

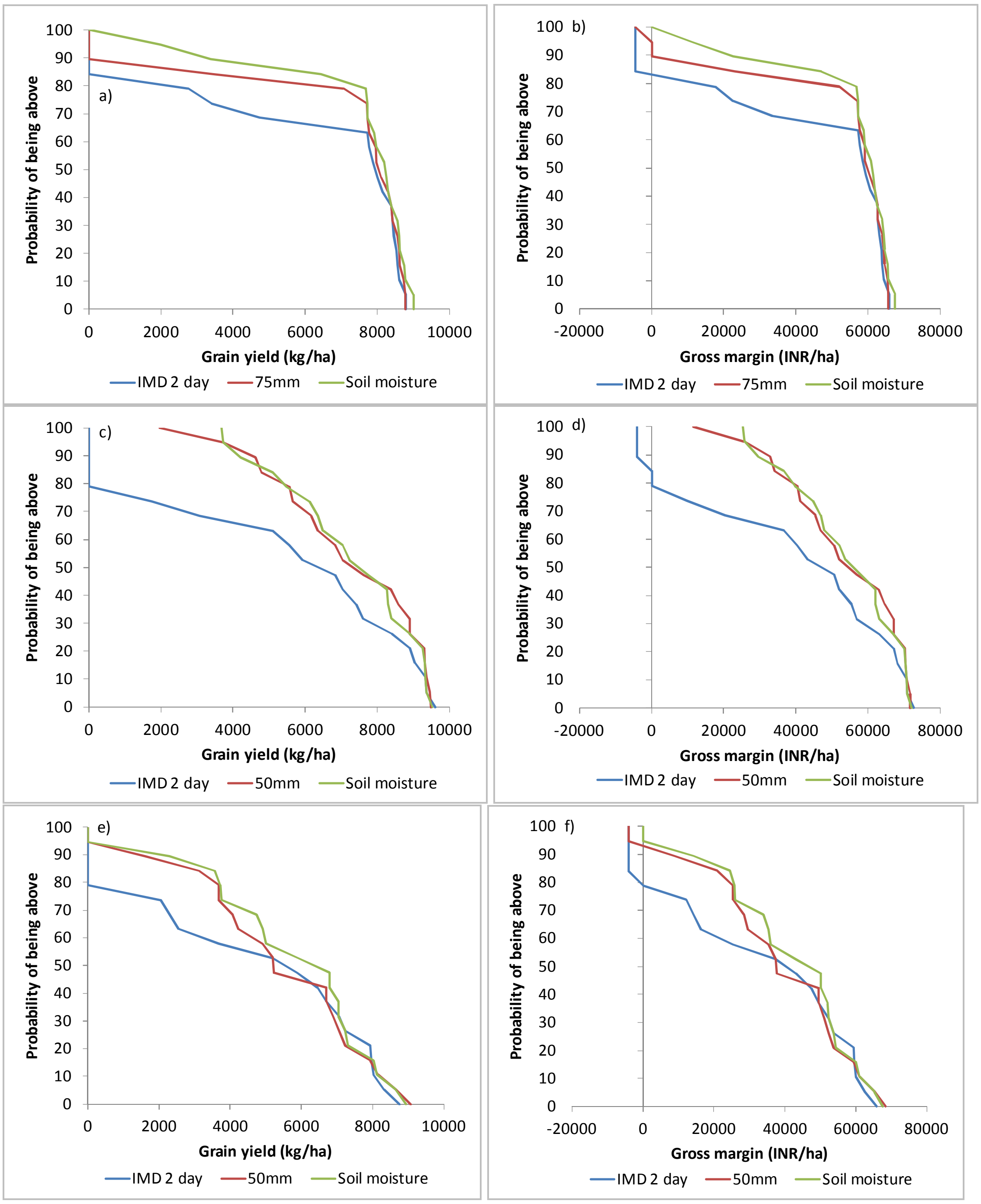


Fig 16. Response of maize grain yield at a) Bairanpally, c) Gorita and e) Nemmani and gross margin at b) Bairanpally, d) Gorita and f) Nemmani to sowing rule. Simulation results are for future climate ECHAM5 for period 2021-2040 at each village.

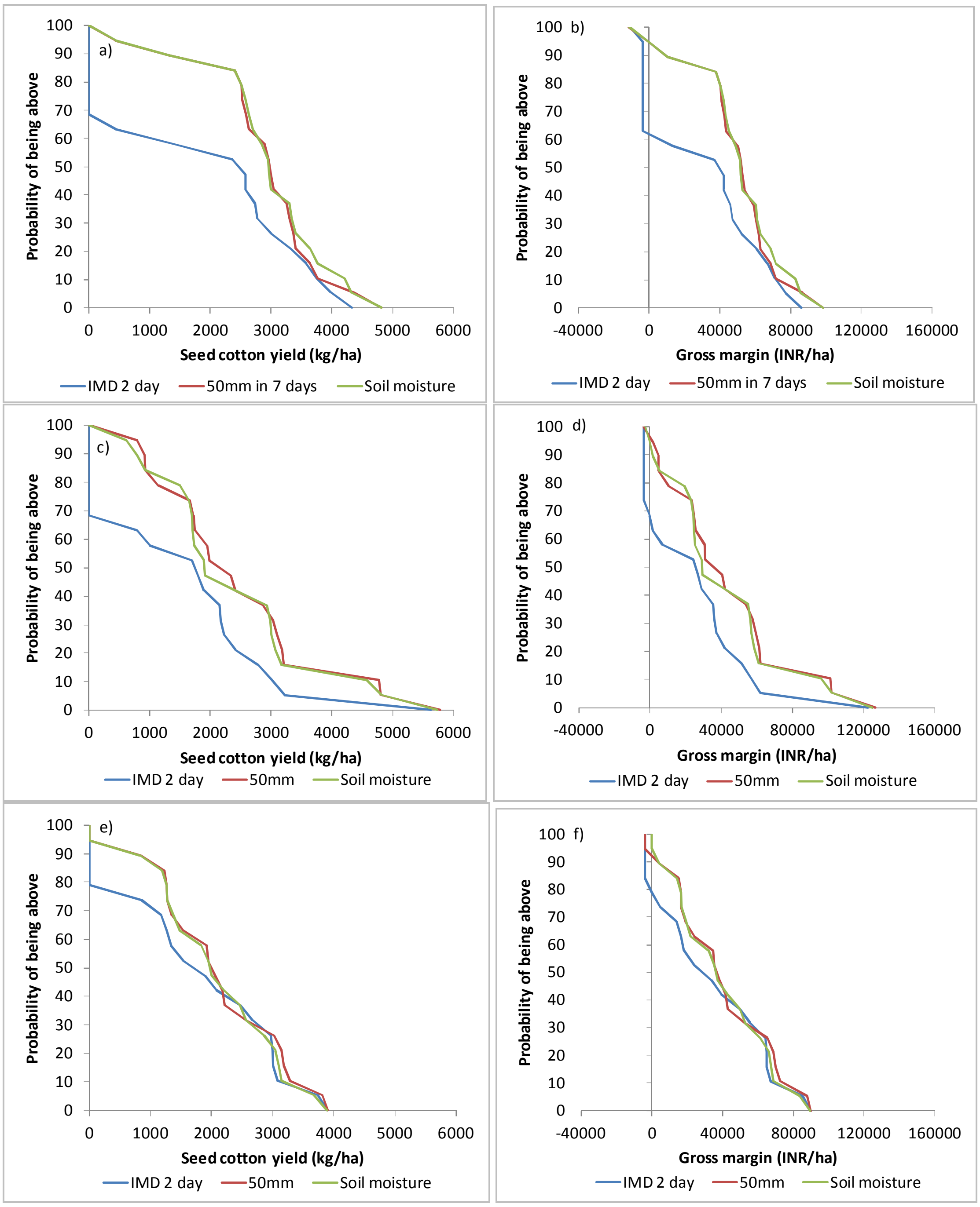


Fig 17. Response of seed cotton yield at a) Bairanpally, c) Gorita and e) Nemmani and gross margin at b) Bairanpally, d) Gorita and f) Nemmani to sowing rule. Simulation results are for future climate GFDL CM2.1 for period 2021-2040 at each village.

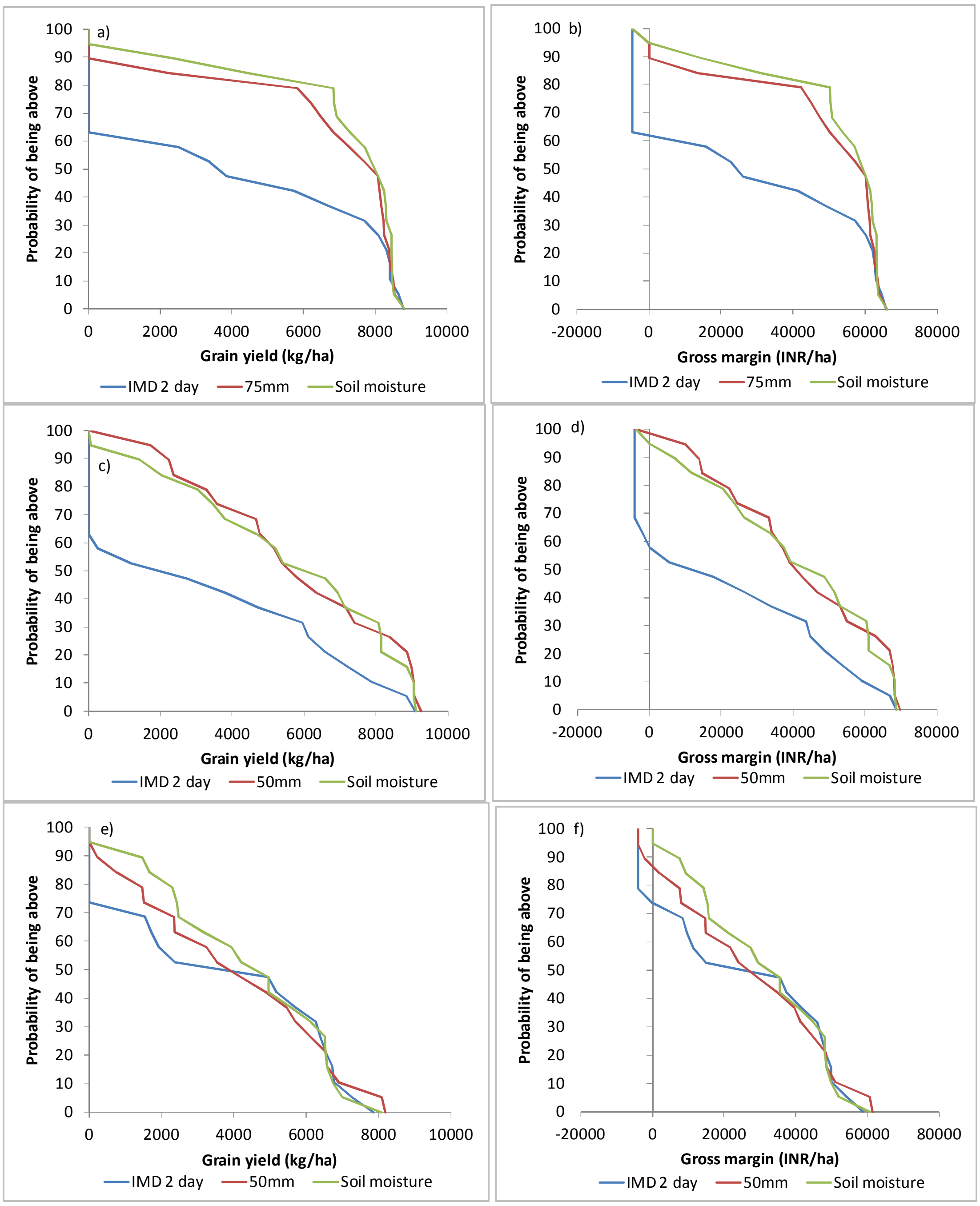


Fig 18. Response of maize grain yield at a) Bairanpally, c) Gorita and e) Nemmani and gross margin at b) Bairanpally, d) Gorita and f) Nemmani to sowing rule. Simulation results are for future climate GFDL CM2.1 for period 2021-2040 at each village.

A comparison of the yield, gross margin, yield stability, gross margin stability, N_2O and C emissions of cotton and maize crops grown using the different sowing rules and baseline climate (1978-2009), ECHAM5 future climate (2021-2040) and GFDL CM2.1 future climate (2021-2040) for Bairanpally are presented in Fig x19, for Gorita in Fig x20 and Nemmani in Fig x21.

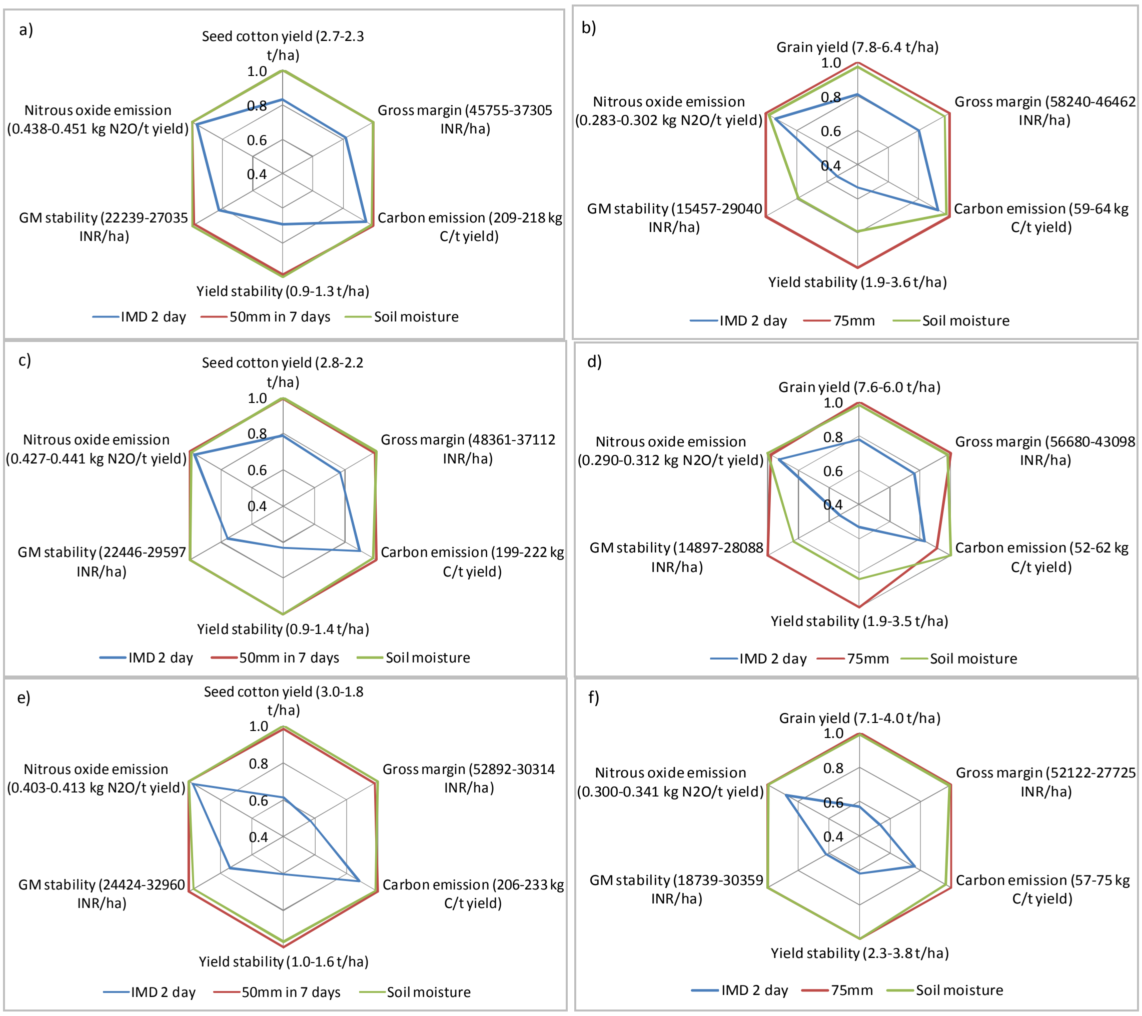


Fig 19. Comparison of yield, gross margin, yield stability, gross margin stability, N_2O and C emissions of crops grown using the IMD 2 day sowing rule and the remaining two sowing rules with optimal tradeoffs between sowing opportunity and seedling failure at Bairanpally for a) cotton using baseline climate (1978-2009), b) maize using baseline climate, c) cotton using ECHAM5 future climate (2021-2040), d) maize using ECHAM5 future climate, e) cotton using GFDL CM2.1 future climate (2021-2040) and f) maize using GFDL CM2.1 future climate.

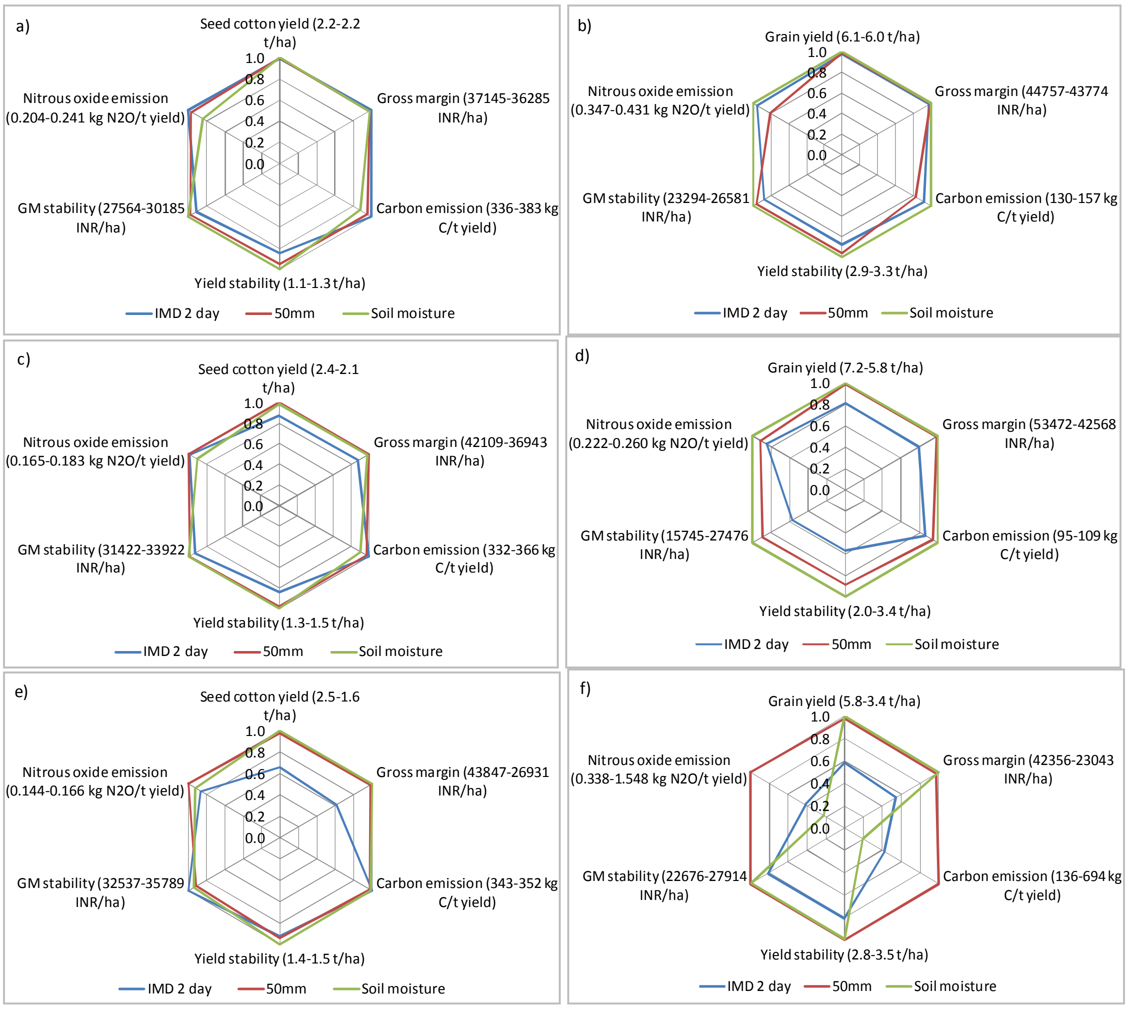


Fig 20. Comparison of yield, gross margin, yield stability, gross margin stability, N_2O and C emissions of crops grown using the IMD 2 day sowing rule and the remaining two sowing rules with optimal tradeoffs between sowing opportunity and seedling failure at Gorita for a) cotton using baseline climate (1978-2009), b) maize using baseline climate, c) cotton using ECHAM5 future climate (2021-2040), d) maize using ECHAM5 future climate, e) cotton using GFDL CM2.1 future climate (2021-2040) and f) maize using GFDL CM2.1 future climate.

Note: the high N_2O and C emissions for the soil moisture sowing rule seen in Fig 20 (f) are caused by a single year (2028) where due to rainfall distribution, maize yield was only 60 kg/ha. As emissions are calculated per t yield this resulted in very large emissions for that year which greatly affects the 20 year average. If 2028 is excluded from the average, the values for N_2O emission would reduce from 1.548 to 0.315 kg N_2O/t yield and C emission would reduce from 694 to 129 kg C/t yield.

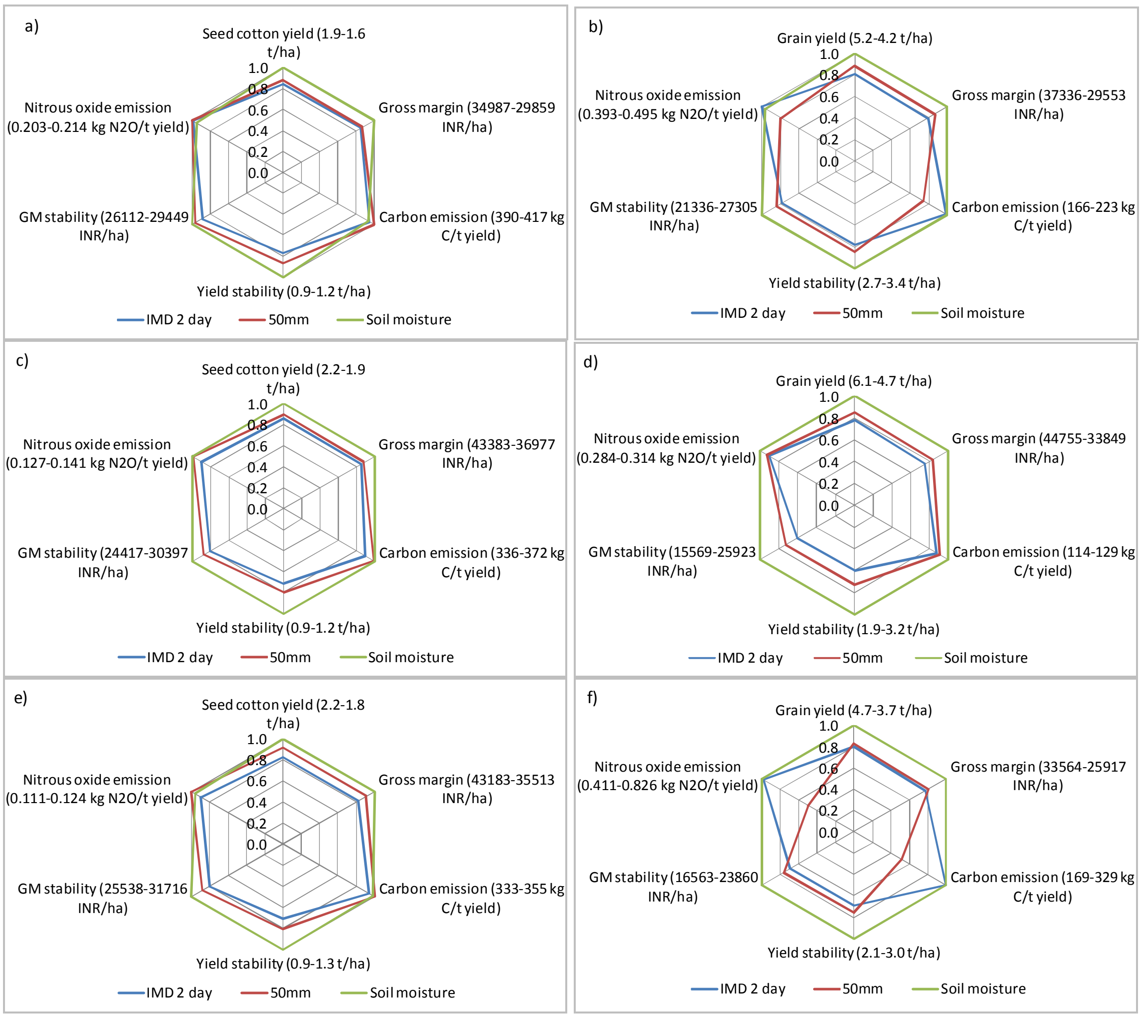


Fig 21. Comparison of yield, gross margin, yield stability, gross margin stability, N_2O and C emissions of crops grown using the IMD 2 day sowing rule and the remaining two sowing rules with optimal tradeoffs between sowing opportunity and seedling failure at Nemmani for a) cotton using baseline climate (1978-2009), b) maize using baseline climate, c) cotton using ECHAM5 future climate (2021-2040), d) maize using ECHAM5 future climate, e) cotton using GFDL CM2.1 future climate (2021-2040) and f) maize using GFDL CM2.1 future climate.

Note: the higher N_2O and C emissions for the 50mm sowing rule seen in Fig 21 (f) are caused by a single year (2039) where due to rainfall distribution, maize yield was only 230 kg/ha. As emissions are calculated per t yield this resulted in very large emissions for that year which greatly affects the 20 year average. If 2039 is excluded from the average, the values for N_2O emission would reduce from 0.826 to 0.480 kg N_2O/t yield and C emission would reduce from 329 to 205 kg C/t yield.

2. Strategic irrigation of rainfed crops

A comparison of the effects of strategic irrigation on yield and gross margin response of crops to IMD 2 day sowing rule and the remaining two sowing rules with optimal tradeoffs between sowing opportunity and seedling failure for each village for future climate ECHAM5 are presented in Fig 22 for cotton and Fig 23 for maize. The same comparisons for each village using the GFDL CM2.1 future climate are presented in Fig 24 for cotton and Fig 25 for maize.

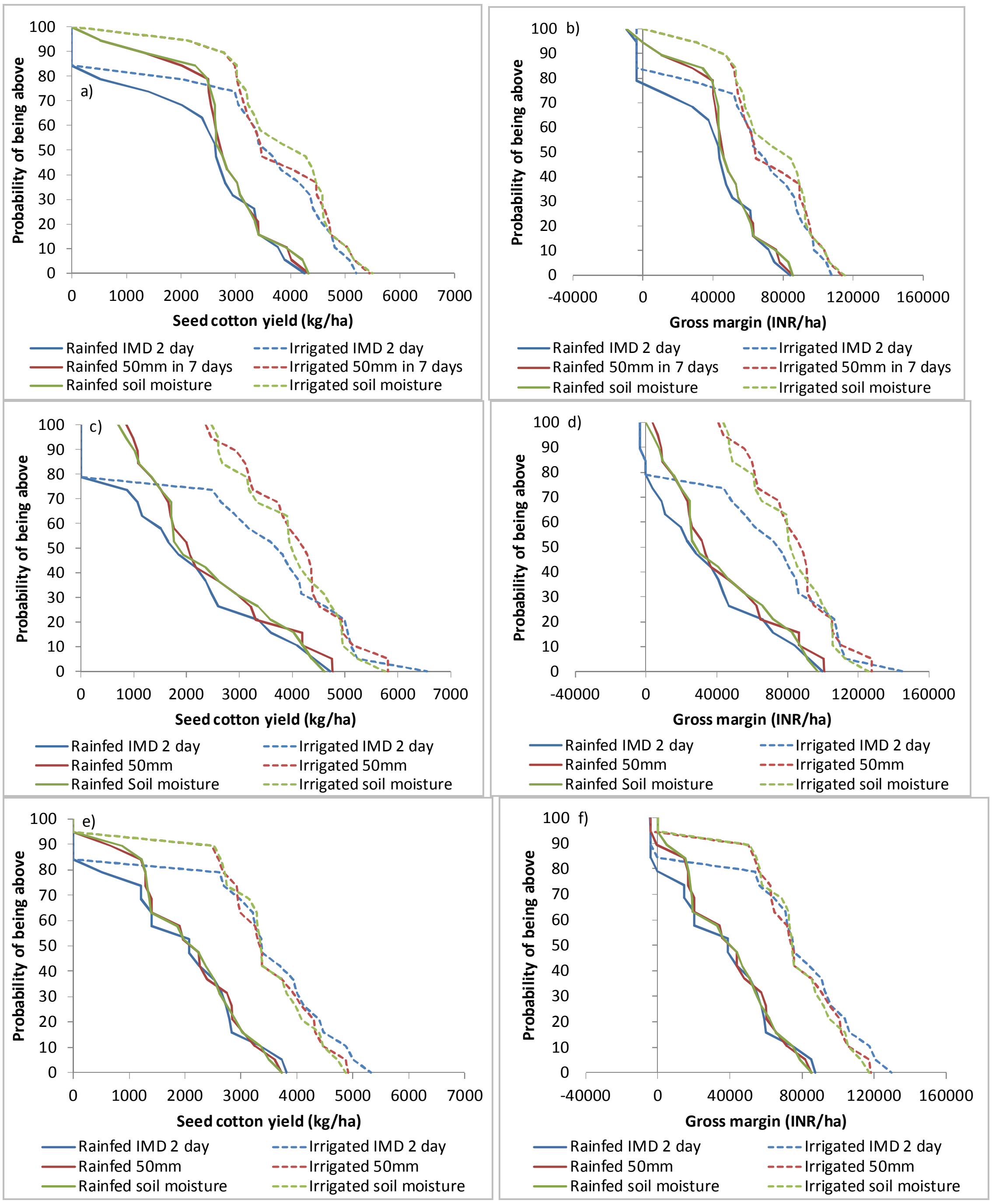


Fig 22. The effect of strategic irrigation on the response of seed cotton yield at a) Bairanpally, c) Gorita and e) Nemmani and gross margin at b) Bairanpally, d) Gorita and f) Nemmani to sowing rule. Simulation results are for future climate ECHAM5 for period 2021-2040 at each village.

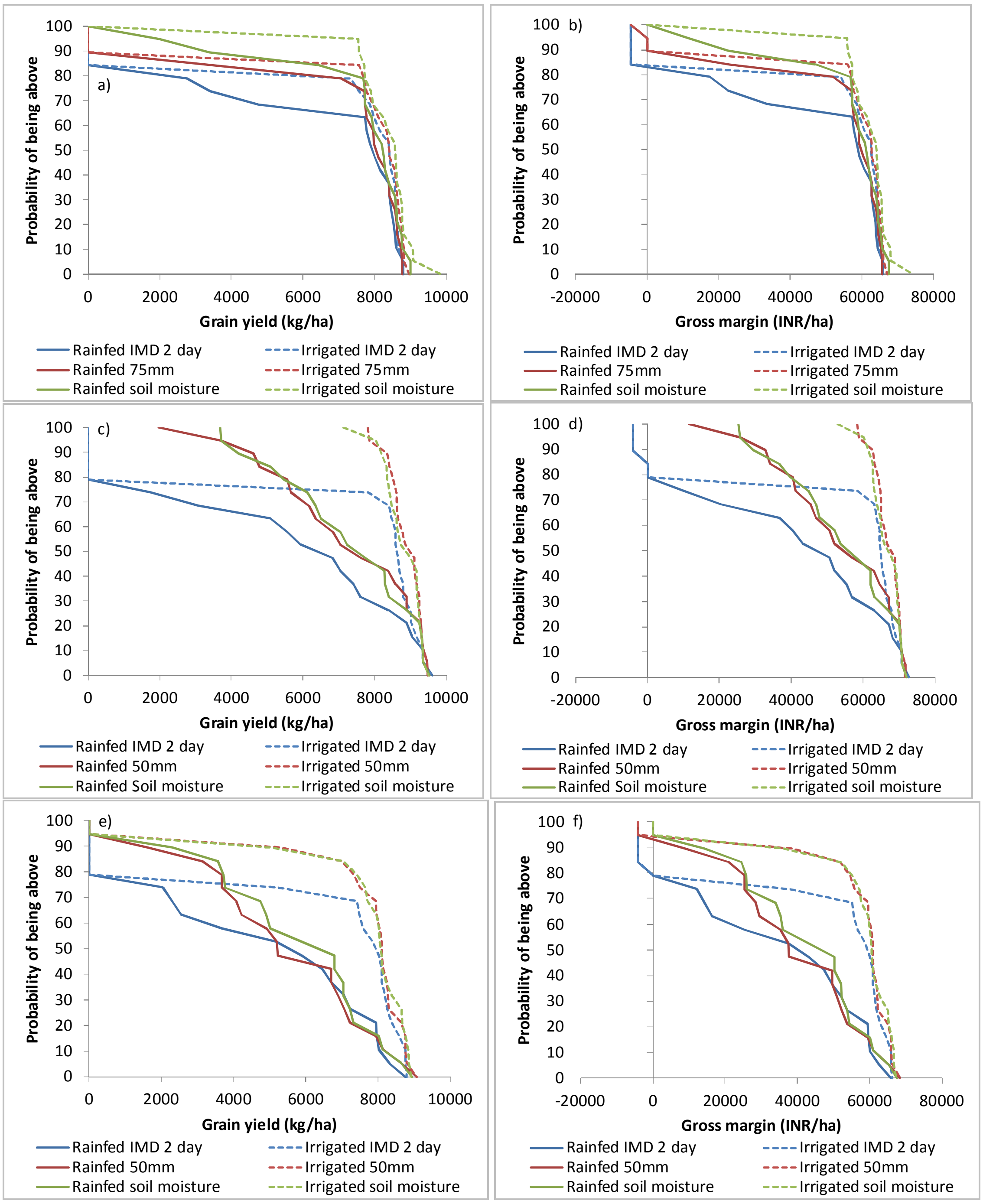


Fig 23. The effect of strategic irrigation on the response of maize grain yield at a) Bairanpally, c) Gorita and e) Nemmani and gross margin at b) Bairanpally, d) Gorita and f) Nemmani to sowing rule. Simulation results are for future climate ECHAM5 for period 2021-2040 at each village.

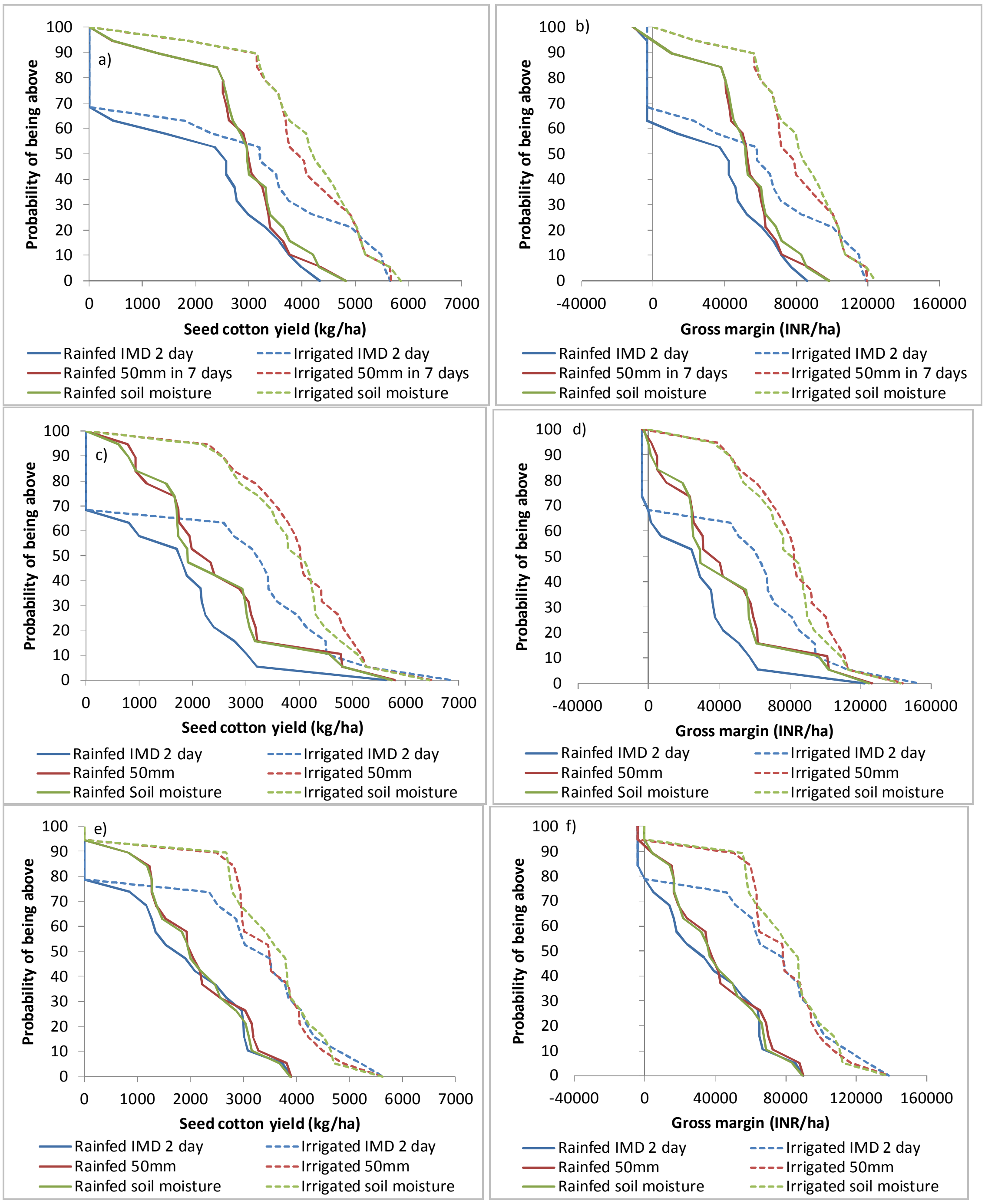


Fig 24. The effect of strategic irrigation on the response of seed cotton yield at a) Bairanpally, c) Gorita and e) Nemmani and gross margin at b) Bairanpally, d) Gorita and f) Nemmani to sowing rule. Simulation results are for future climate GFDL CM2.1 for period 2021-2040 at each village.

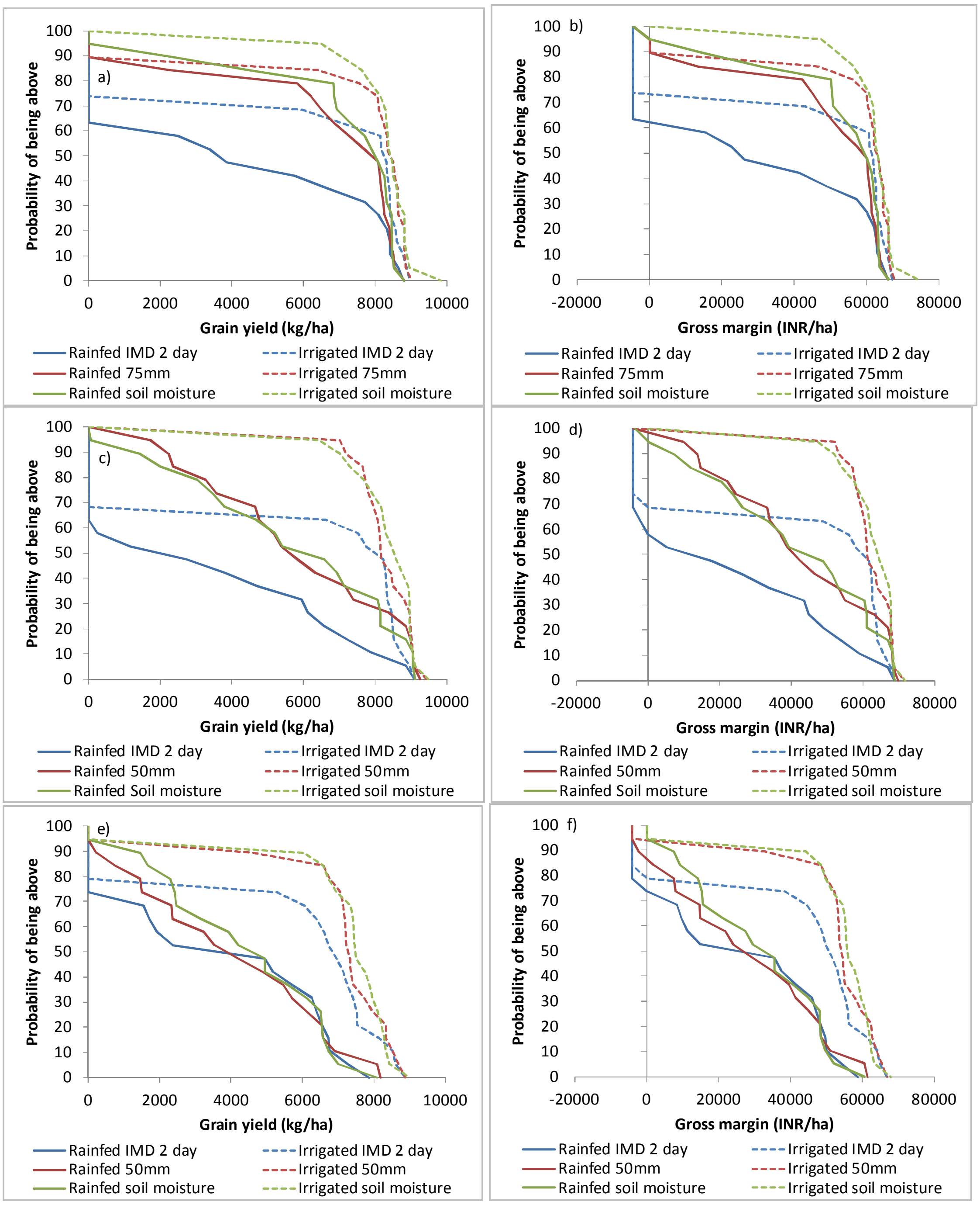


Fig 25. The effect of strategic irrigation on the response of maize grain yield at a) Bairanpally, c) Gorita and e) Nemmani and gross margin at b) Bairanpally, d) Gorita and f) Nemmani to sowing rule. Simulation results are for future climate GFDL CM2.1 for period 2021-2040 at each village.

A comparison of the yield, gross margin, yield stability, gross margin stability, N_2O and C emissions of rainfed and strategically irrigated cotton and maize crops grown using the soil moisture sowing rule for each village and baseline climate (1978-2009), ECHAM5 future climate (2021-2040) and GFDL CM2.1 future climate (2021-2040) for Bairanpally are presented in Fig 26, for Gorita in Fig 27 and for Nemmani in Fig 28.

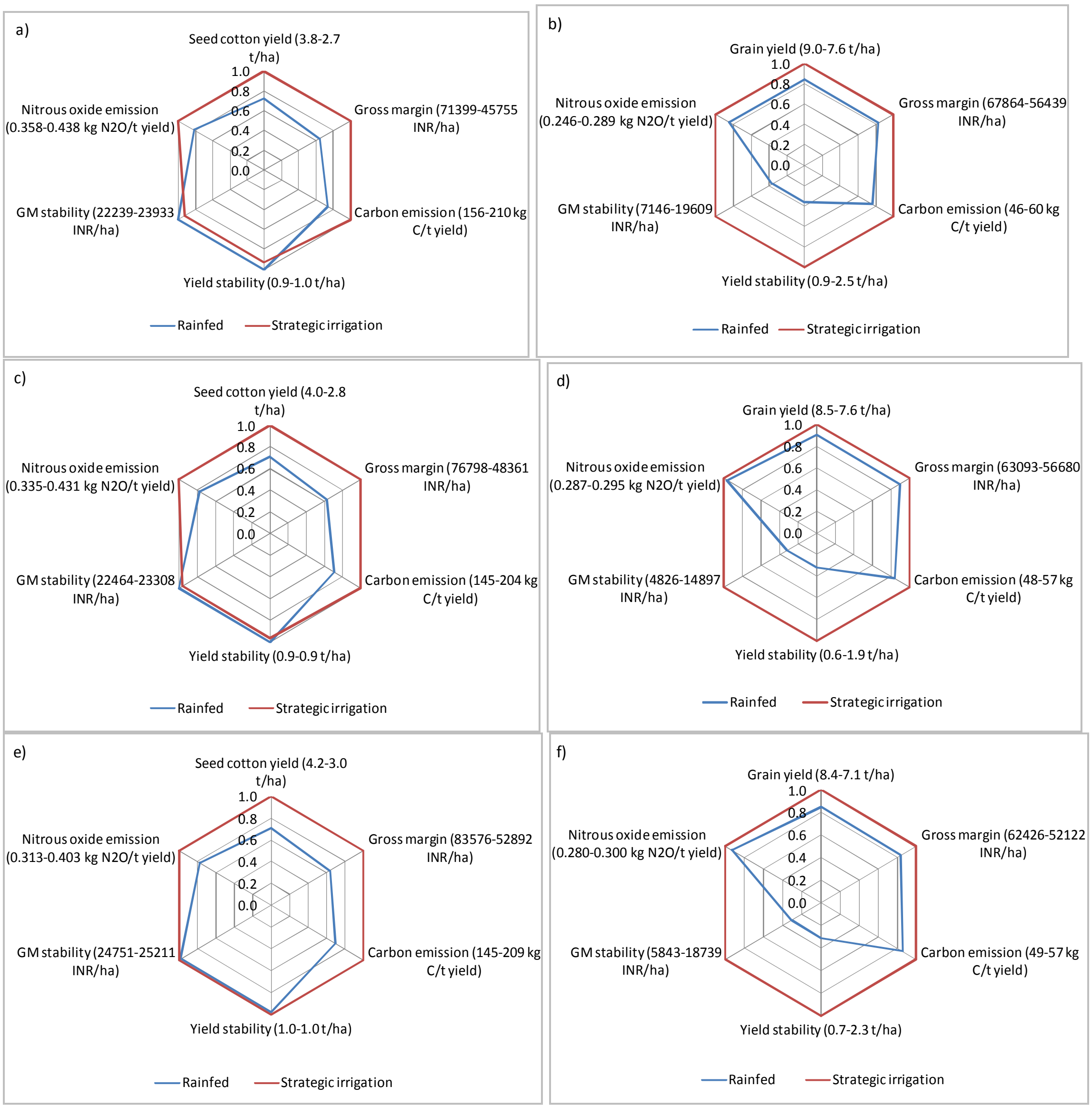


Fig 26. Comparison of yield, gross margin, yield stability, gross margin stability, N_2O and C emissions of rainfed and strategically irrigated crops grown at Bairanpally for a) cotton using baseline climate (1978-2009), b) maize using baseline climate, c) cotton using ECHAM5 future climate (2021-2040), d) maize using ECHAM5 future climate, e) cotton using GFDL CM2.1 future climate (2021-2040) and f) maize using GFDL CM2.1 future climate.

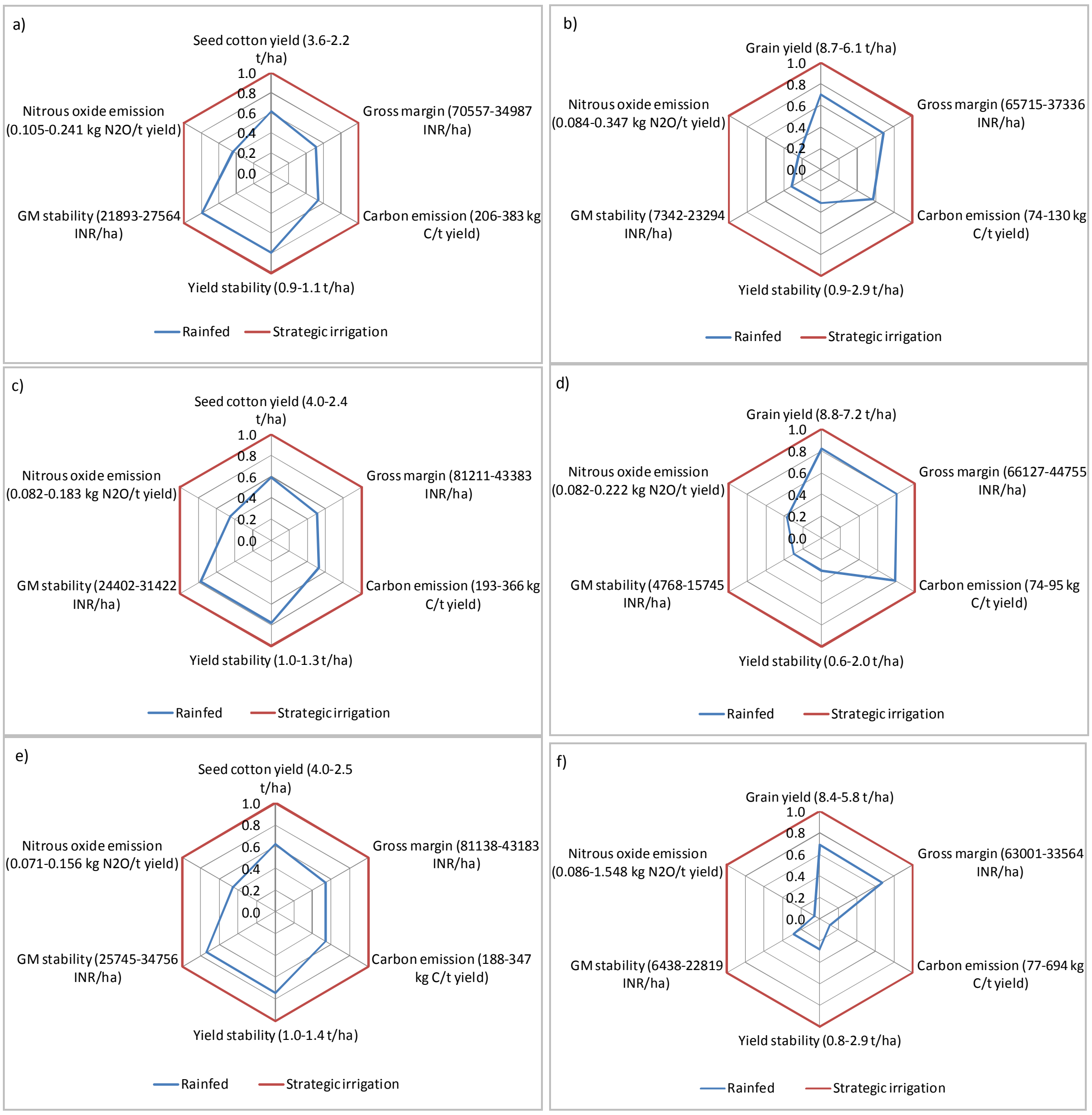


Fig 27. Comparison of yield, gross margin, yield stability, gross margin stability, N_2O and C emissions of rainfed and strategically irrigated crops grown at Gorita for a) cotton using baseline climate (1978-2009), b) maize using baseline climate, c) cotton using ECHAM5 future climate (2021-2040), d) maize using ECHAM5 future climate, e) cotton using GFDL CM2.1 future climate (2021-2040) and f) maize using GFDL CM2.1 future climate.

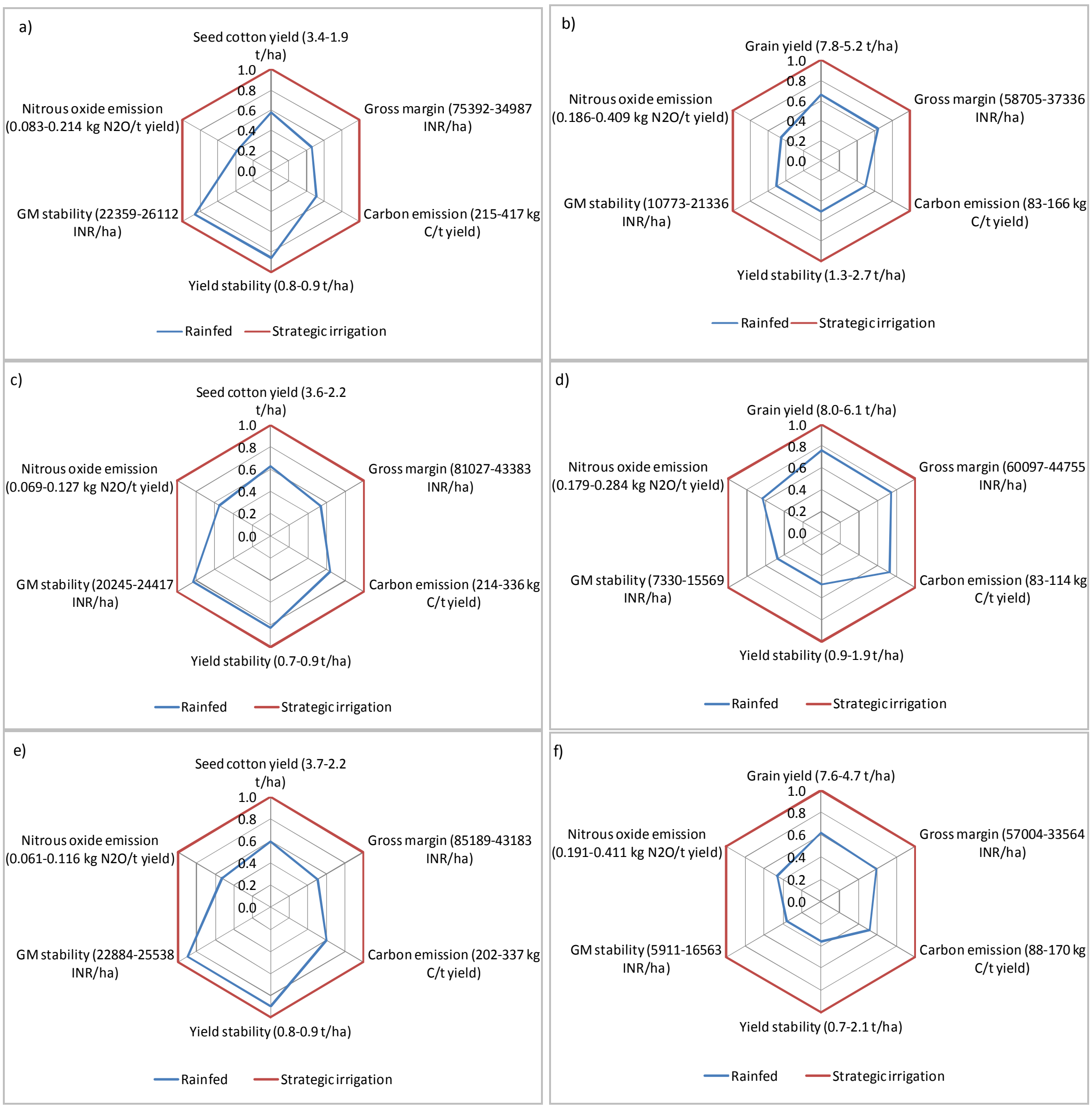


Fig 28. Comparison of yield, gross margin, yield stability, gross margin stability, N_2O and C emissions of rainfed and strategically irrigated crops grown at Nemmani for a) cotton using baseline climate (1978-2009), b) maize using baseline climate, c) cotton using ECHAM5 future climate (2021-2040), d) maize using ECHAM5 future climate, e) cotton using GFDL CM2.1 future climate (2021-2040) and f) maize using GFDL CM2.1 future climate.

3. Reduced irrigation of rice

A comparison of the response of rough rice yield and net water use (irrigation – deep drainage below the root zone) of rice crops grown using the four irrigation rules for each village for future climate (2021-2040) ECHAM5 are presented in Fig 29 and for future climate GFDL CM2.1 are presented Fig 30.

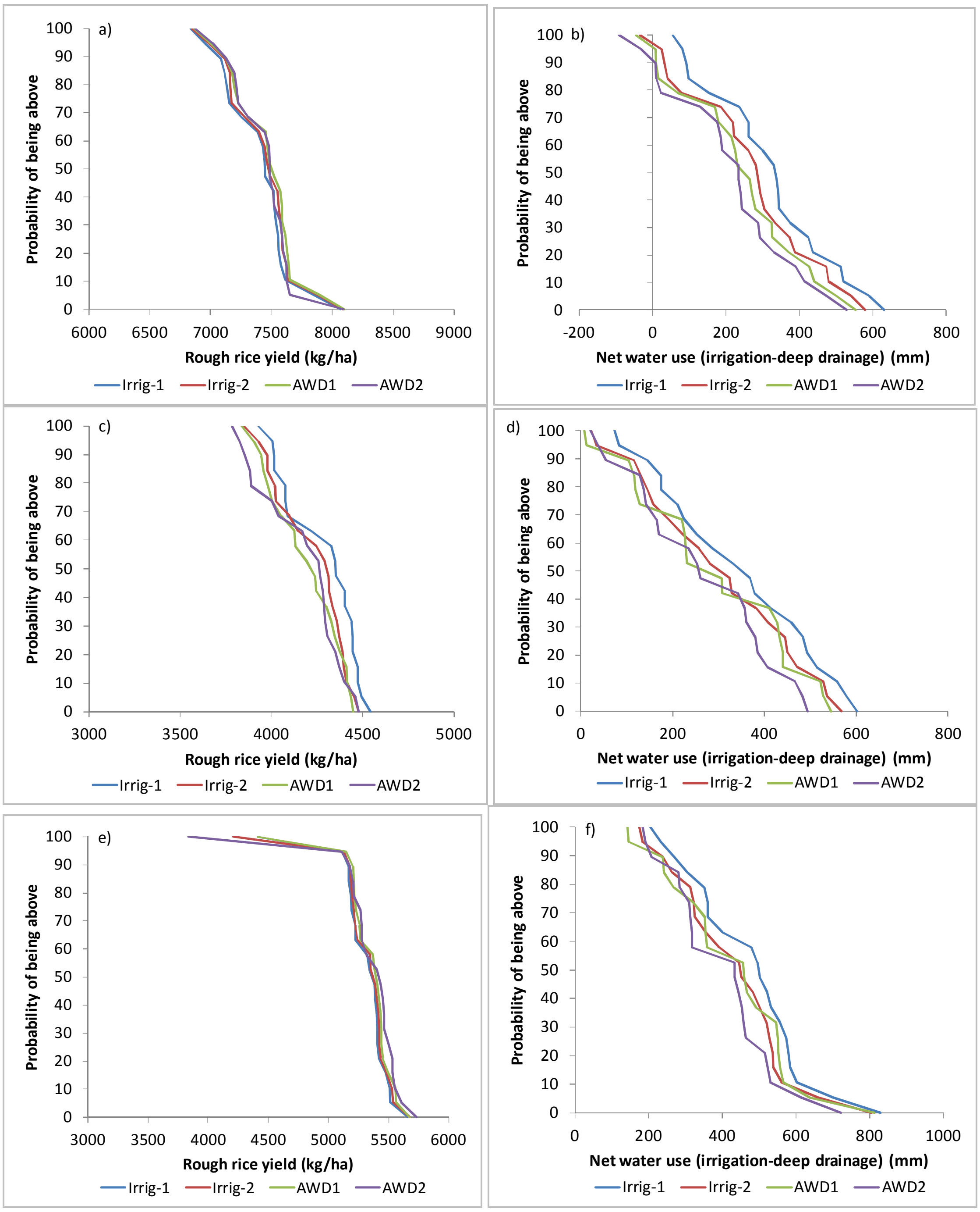


Fig 29. Response of rough rice yield at a) Bairanpally, c) Gorita and e) Nemmani and net water use at b) Bairanpally, d) Gorita and f) Nemmani to irrigation rule. Simulation results are for future climate ECHAM5 for period 2021-2040 at each village.

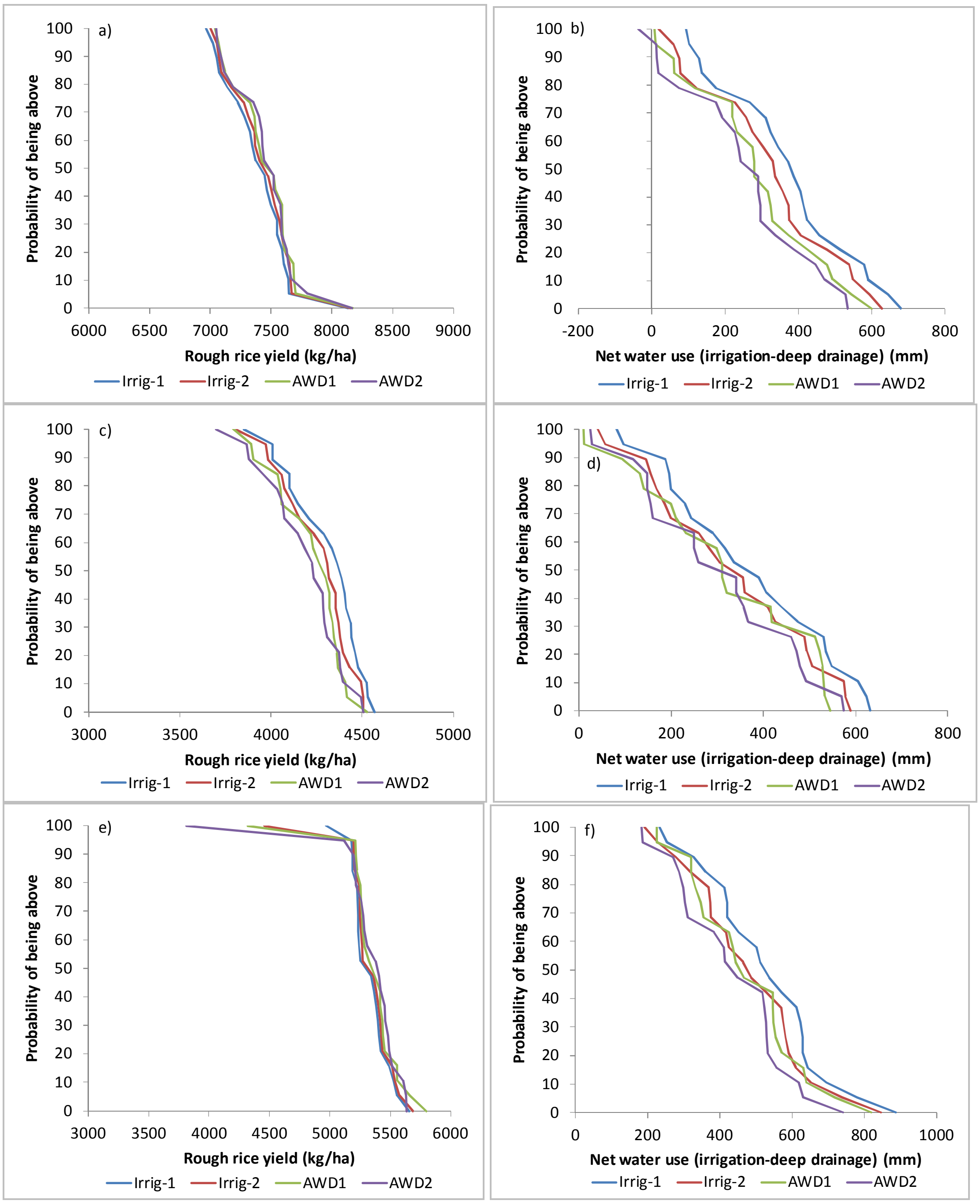


Fig 30. Response of rough rice yield at a) Bairanpally, c) Gorita and e) Nemmani and net water use at b) Bairanpally, d) Gorita and f) Nemmani to irrigation rule. Simulation results are for future climate GFDL CM2.1 for period 2021-2040 at each village.

Comparisons of the yield, gross margin, yield stability, gross margin stability, N_2O and C emissions, irrigation water productivity and net water use of rice crops simulated using the four irrigation rules for each village and baseline climate (1978-2009), ECHAM5 future climate (2021-2040) and GFDL CM2.1 future climate (2021-2040) for Bairanpally are presented in Fig x31, for Gorita in Fig 32 and for Nemmani in Fig 33.

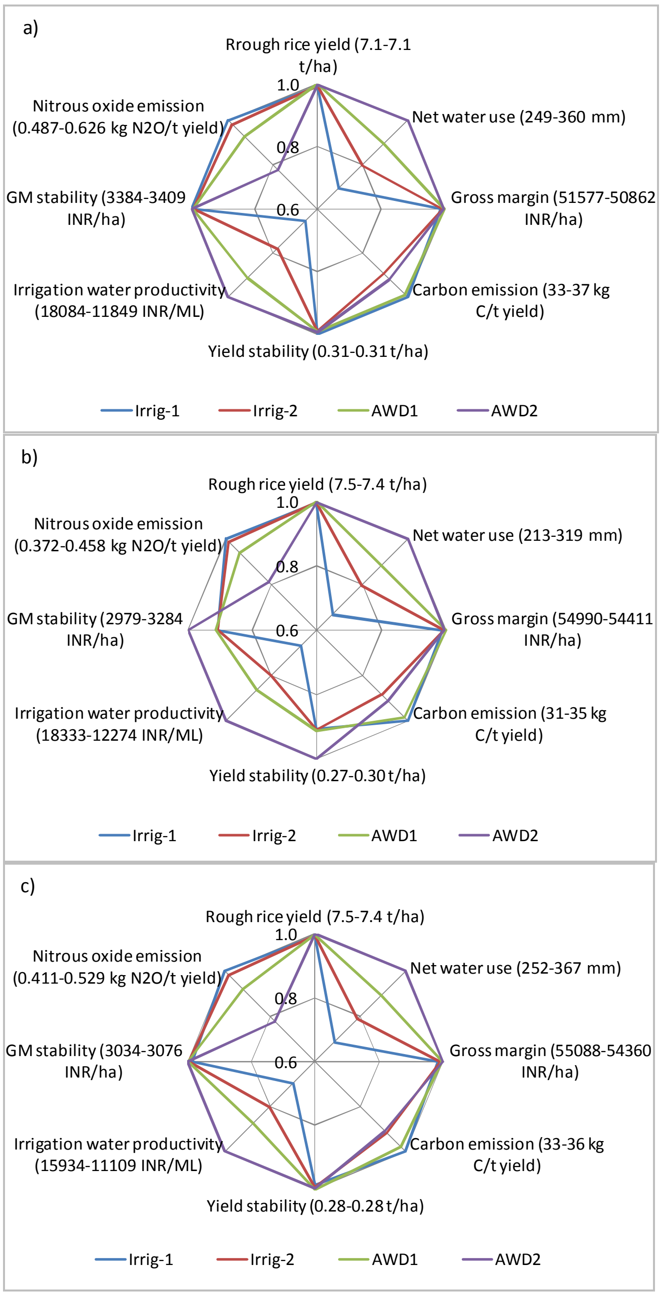


Fig 31. Comparison of yield, gross margin, yield stability, gross margin stability, N_2O and C emissions, irrigation water productivity and net water use of rice crops grown at Bairanpally using a) baseline climate (1978-2009), b) future climate ECHAM5 (2021-2040) and c) future climate GFDL CM2.1 (2021-2040).

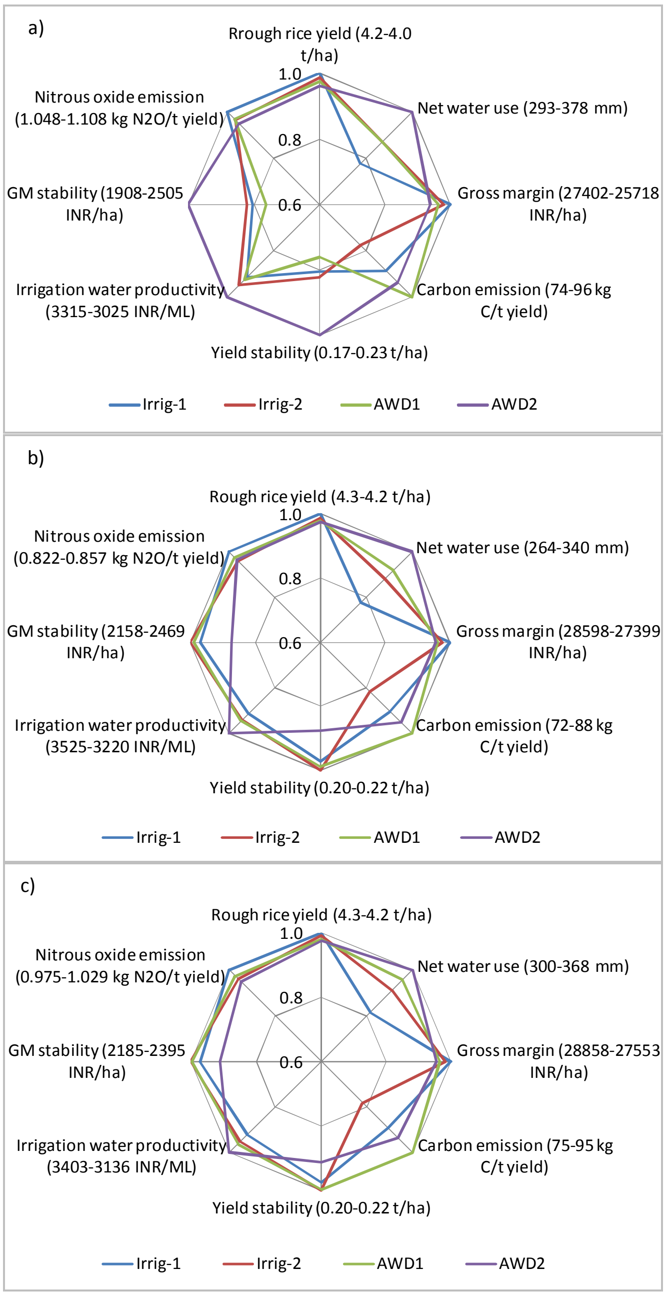


Fig 32. Comparison of yield, gross margin, yield stability, gross margin stability, N_2O and C emissions, irrigation water productivity and net water use of rice crops grown at Gorita using a) baseline climate (1978-2009), b) future climate ECHAM5 (2021-2040) and c) future climate GFDL CM2.1 (2021-2040).

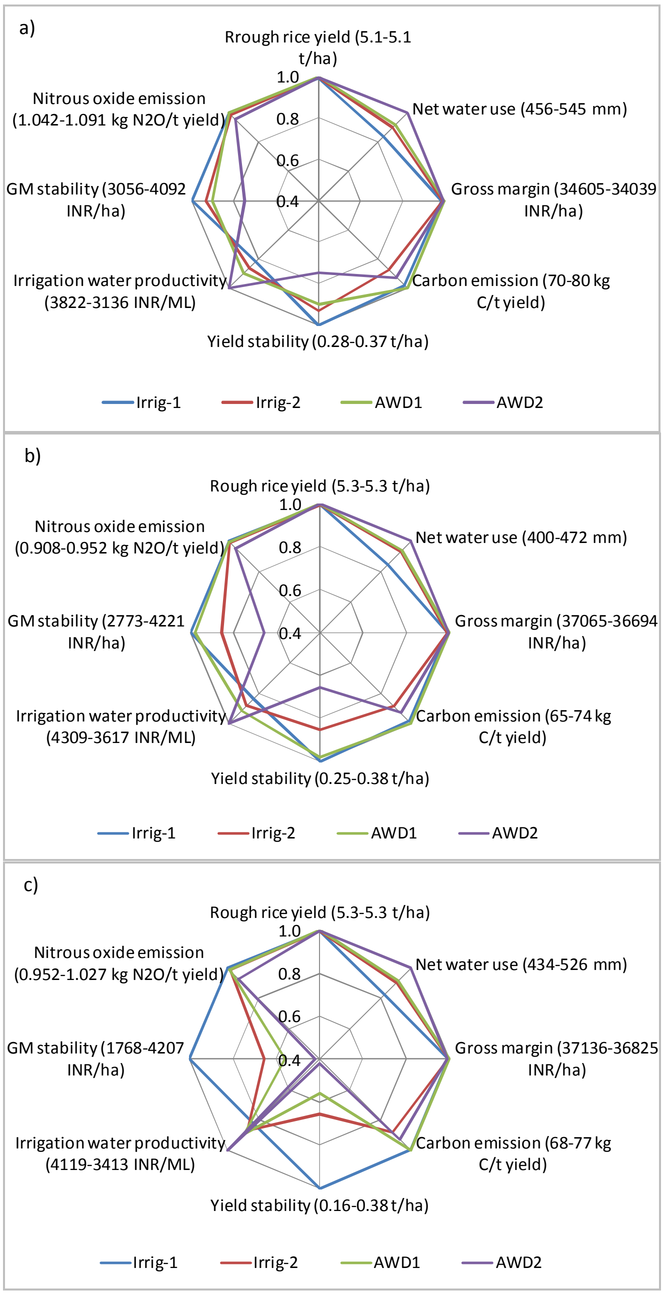


Fig 33. Comparison of yield, gross margin, yield stability, gross margin stability, N_2O and C emissions, irrigation water productivity and net water use of rice crops grown at Nemmani using a) baseline climate (1978-2009), b) future climate ECHAM5 (2021-2040) and c) future climate GFDL CM2.1 (2021-2040).

4. Reduced rice area for strategic irrigation of rainfed crops

Comparisons of the average gross margin and net water use as well as the gross margin, gross margin stability, N_2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for small farms growing rice and cotton crops at Bairanpally using the baseline climate (1978-2009), future climates (2021-2040) ECHAM5 and GFDL CM2.1 are presented in Fig 34.

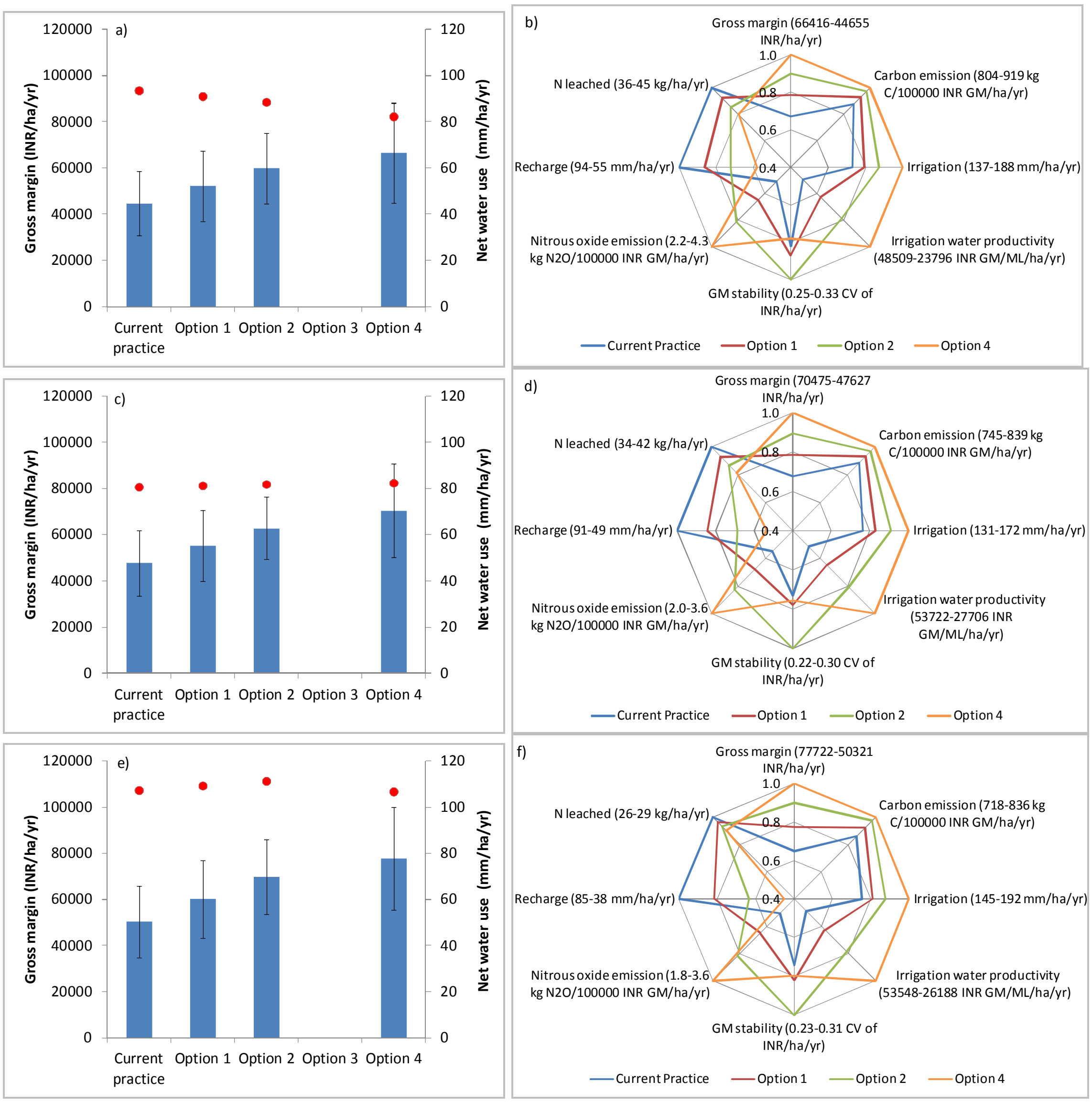


Fig 34. Gross margin (blue bars) and net water use (irrigation – recharge, red dots) for adaptation options used on small farms at Bairanpally growing rice and cotton for a) baseline climate (1978-2009), c) future climate ECHAM5 (2021-2040) and e) future climate GFDL CM2.1 (2021-2040). Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N_2O emission, aquifer recharge and N leached for each of the adaptation options for b) baseline climate, d) future climate ECHAM5 and f) future climate GFDL CM2.1. Note: option 3 on small farms is not applicable at Bairanpally as there was not enough excess water for unlimited irrigations.

Comparison of the average gross margin and net water use as well as the gross margin, gross margin stability, N2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for medium farms growing rice and cotton crops at Bairanpally using the baseline climate (1978-2009), future climates (2021-2040) ECHAM5 and GFDL CM2.1 are presented in Fig x35.

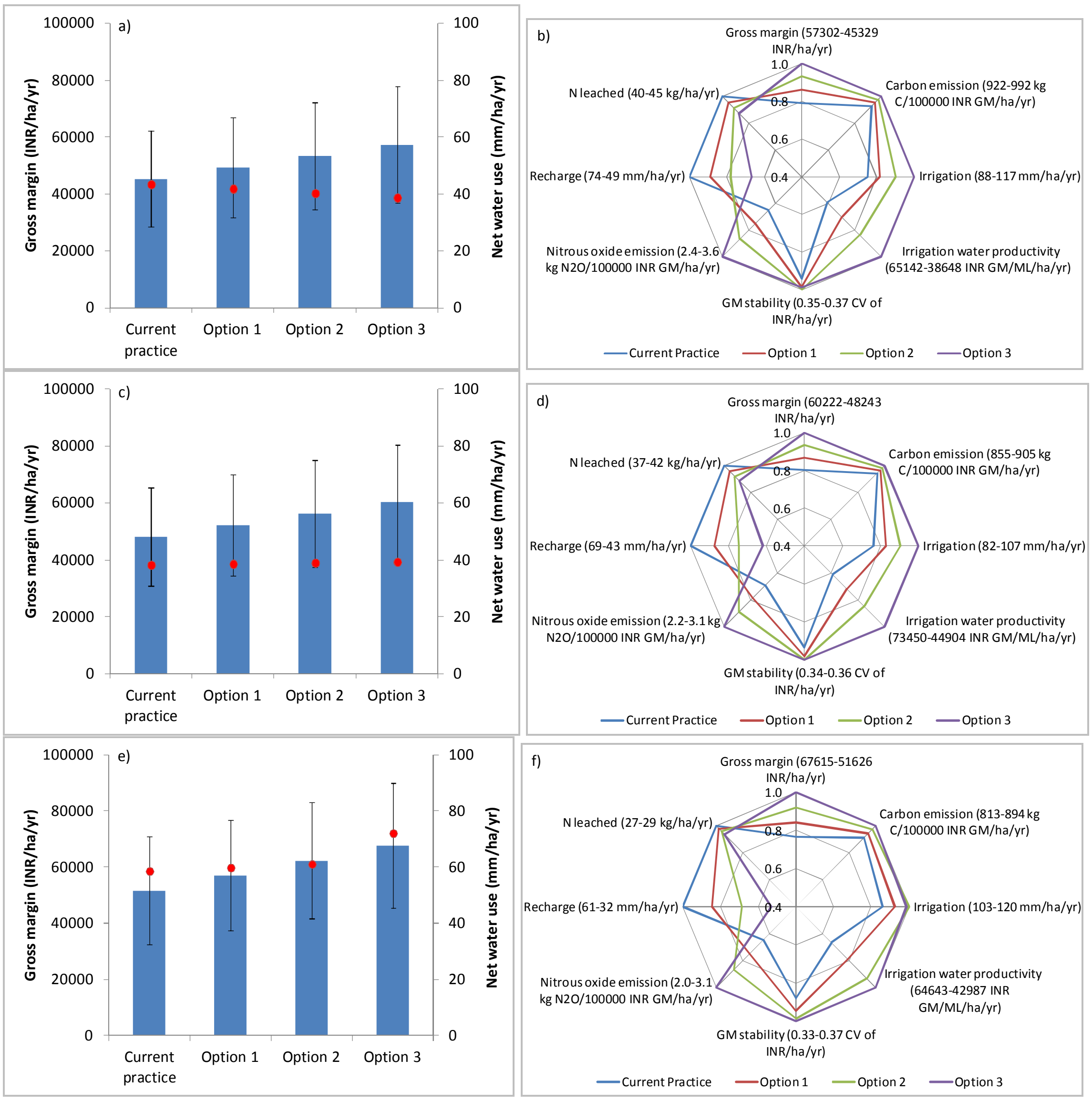


Fig 35. Gross margin (blue bars) and net water use (irrigation – aquifer recharge, red dots) for adaptation options used on medium farms at Bairanpally growing rice and cotton for a) baseline climate (1978-2009), c) future climate ECHAM5 (2021-2040) and e) future climate GFDL CM2.1 (2021-2040). Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N_2O emission, aquifer recharge and N leached for each of the adaptation options for b) baseline climate, d) future climate ECHAM5 and f) future climate GFDL CM2.1.

Comparison of the average gross margin and net water use as well as the gross margin, gross margin stability, N_2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for large farms growing rice and cotton crops at Bairanpally using the baseline climate (1978-2009), future climates (2021-2040) ECHAM5 and GFDL CM2.1 are presented in Fig 36.

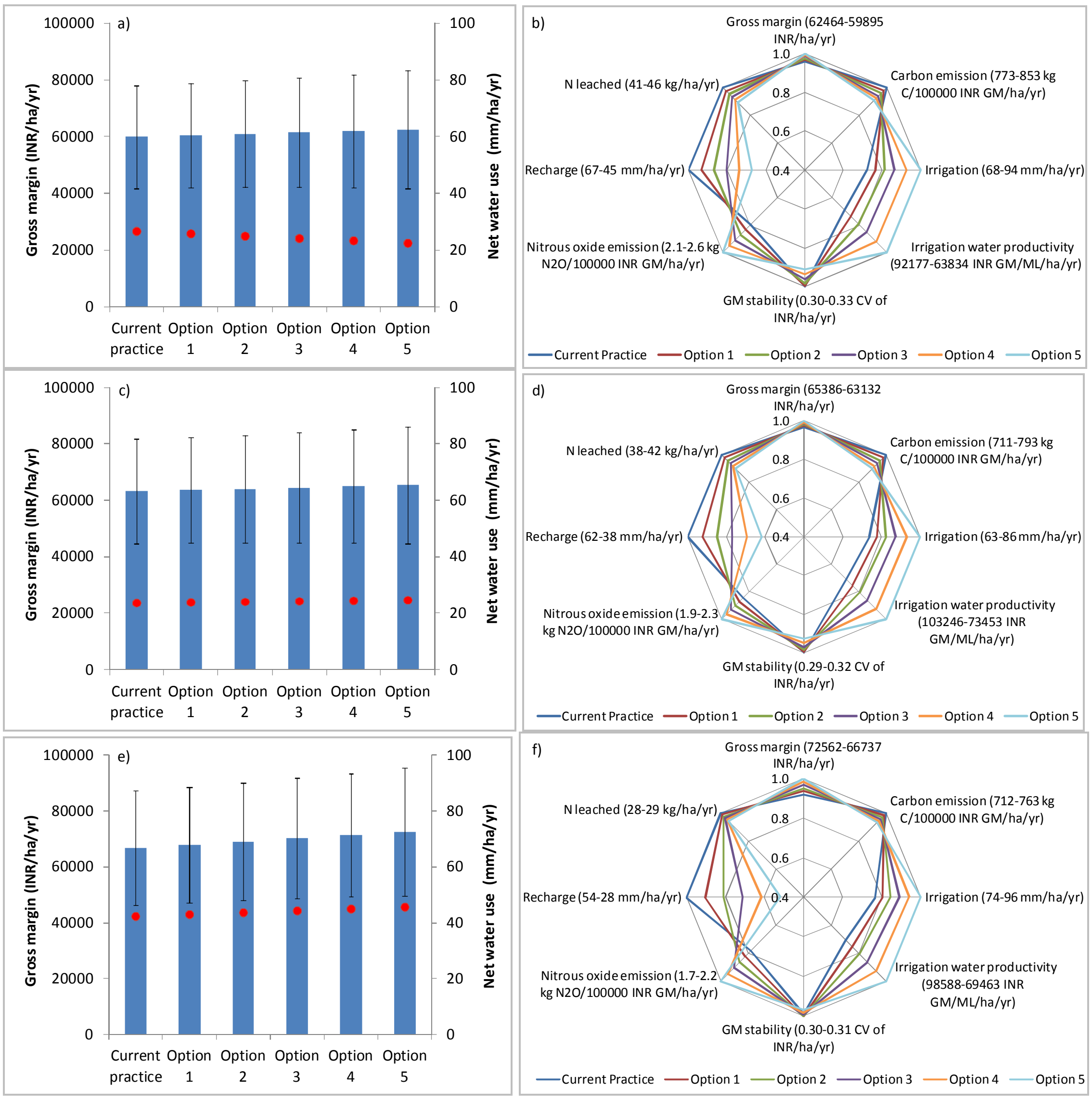


Fig 36. Gross margin (blue bars) and net water use (irrigation – aquifer recharge, red dots) for adaptation options used on large farms at Bairanpally growing rice and cotton for a) baseline climate (1978-2009), c) future climate ECHAM5 (2021-2040) and e) future climate GFDL CM2.1 (2021-2040). Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N_2O emission, aquifer recharge and N leached for each of the adaptation options for b) baseline climate, d) future climate ECHAM5 and f) future climate GFDL CM2.1.

Comparisons of the average gross margin and net water use as well as the gross margin, gross irrigation applied for the different adaptation options for small farms growing rice and maize crops at Bairanpally using the baseline climate (1978-2009), future climates (2021-2040) ECHAM5 and GFDL CM2.1 are presented in Fig 37.

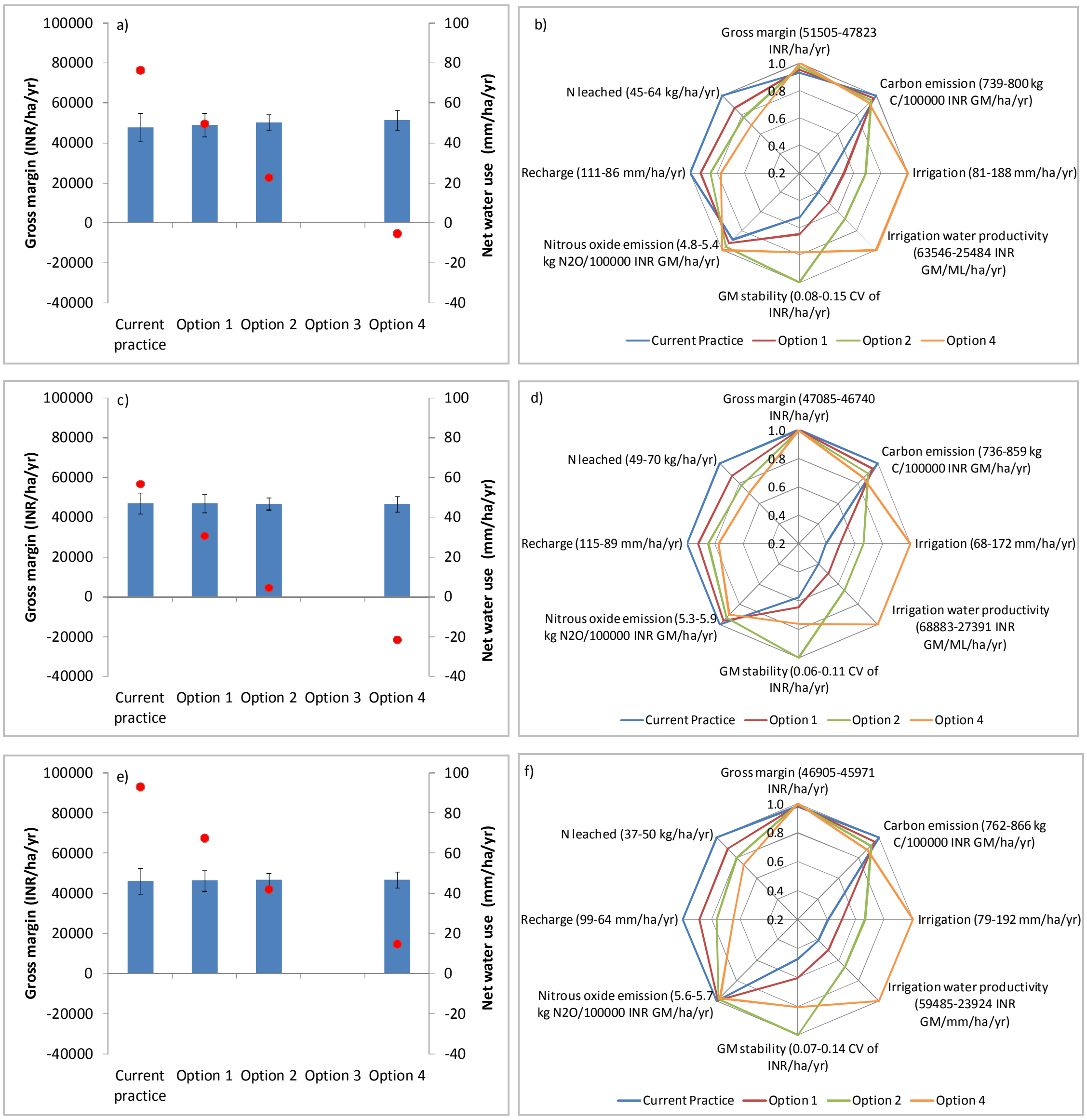


Fig 37. Gross margin (blue bars) and net water use (irrigation – recharge, red dots) for adaptation options used on small farms at Bairanpally growing rice and maize for a) baseline climate (1978-2009), c) future climate ECHAM5 (2021-2040) and e) future climate GFDL CM2.1 (2021-2040). Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N_2O emission, aquifer recharge and N leached for each of the adaptation options for b) baseline climate, d) future climate ECHAM5 and f) future climate GFDL CM2.1. Note: option 3 on small farms is not applicable at Bairanpally as there was not enough excess water for unlimited irrigations.

Comparisons of the average gross margin and net water use as well as the gross margin, gross margin stability, N_2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for medium farms growing rice and maize crops at Bairanpally using the baseline climate (1978-2009), future climates (2021-2040) ECHAM5 and GFDL CM2.1 are presented in Fig x38.

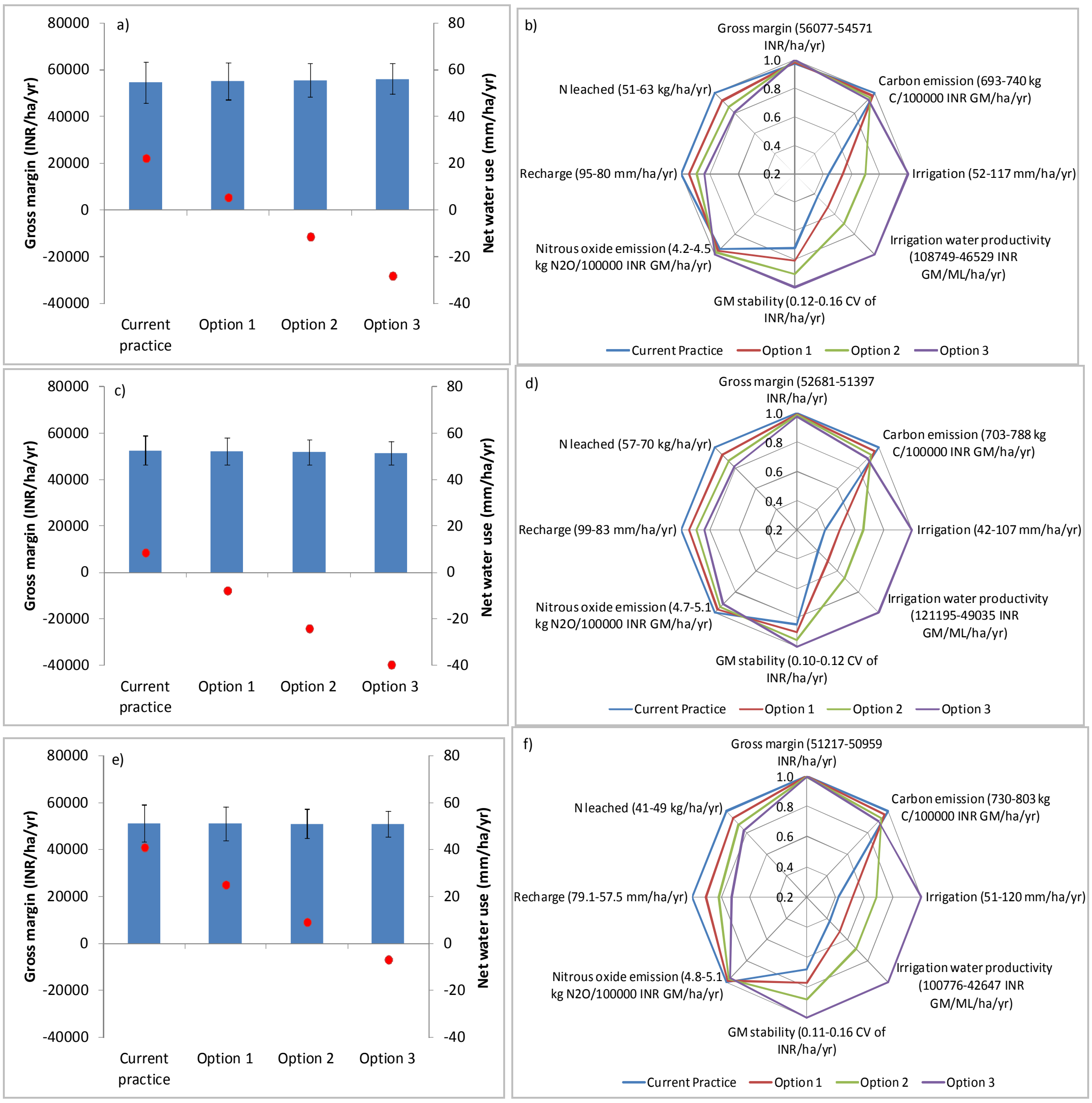


Fig 38. Gross margin (blue bars) and net water use (irrigation – recharge, red dots) for adaptation options used on medium farms at Bairanpally growing rice and maize for a) baseline climate (1978-2009), c) future climate ECHAM5 (2021-2040) and e) future climate GFDL CM2.1 (2021-2040). Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N_2O emission, aquifer recharge and N leached for each of the adaptation options for b) baseline climate, d) future climate ECHAM5 and f) future climate GFDL CM2.1.

Comparisons of the average gross margin and net water use as well as the gross margin, gross margin stability, N_2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for large farms growing rice and maize crops at Bairanpally using the baseline climate (1978-2009), future climates (2021-2040) ECHAM5 and GFDL CM2.1 are presented in Fig 39.

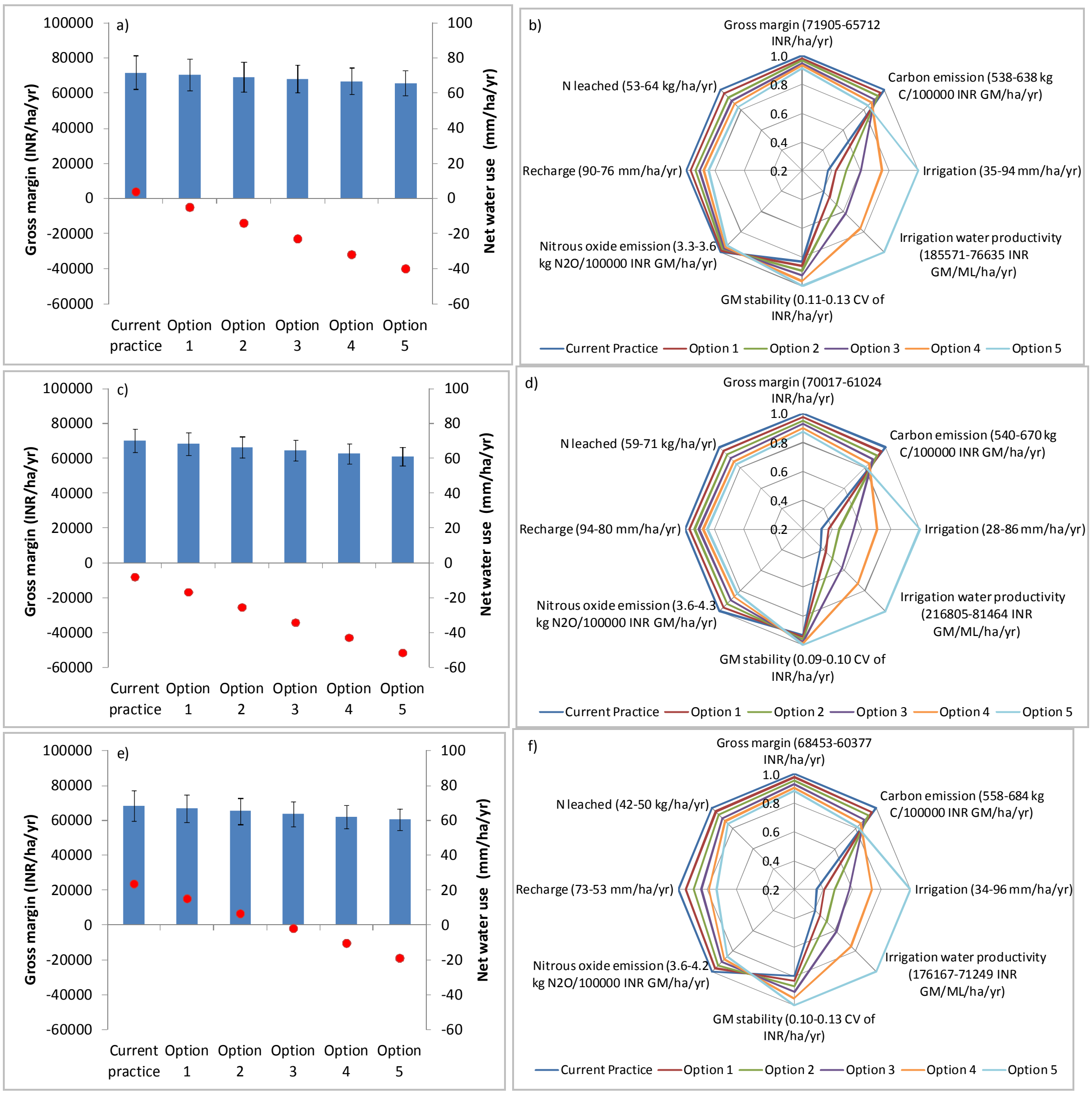


Fig 39. Gross margin (blue bars) and net water use (irrigation – recharge, red dots) for adaptation options used on large farms at Bairanpally growing rice and maize for a) baseline climate (1978-2009), c) future climate ECHAM5 (2021-2040) and e) future climate GFDL CM2.1 (2021-2040). Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N_2O emission, aquifer recharge and N leached for each of the adaptation options for b) baseline climate, d) future climate ECHAM5 and f) future climate GFDL CM2.1.

Comparisons of the average gross margin and net water use as well as the gross margin, gross margin stability, N_2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for small farms growing rice and cotton crops at Gorita using the baseline climate (1978-2009), future climates (2021-2040) ECHAM5 and GFDL CM2.1 are presented in Fig 40.

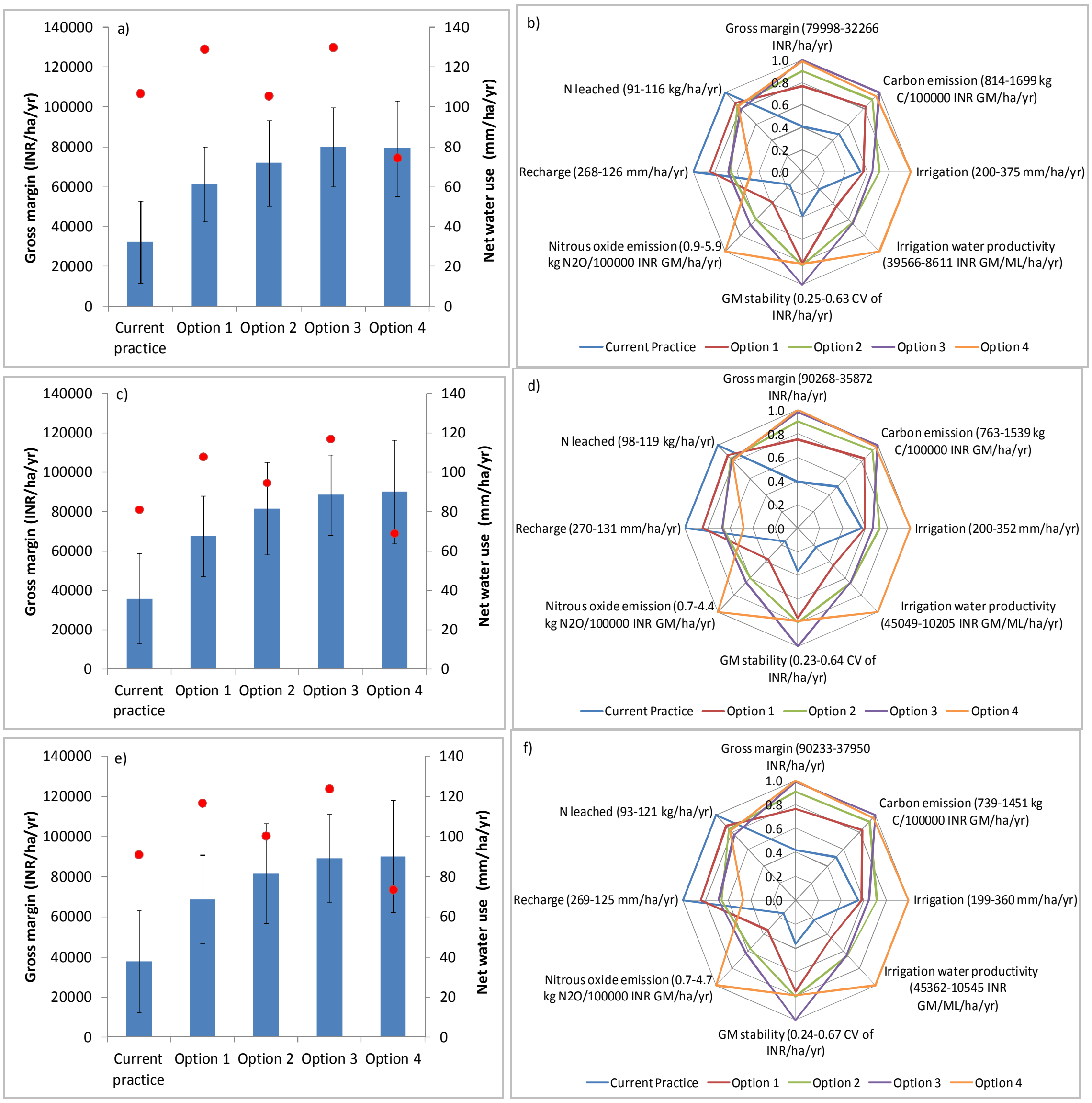


Fig 40. Gross margin (blue bars) and net water use (irrigation – recharge, red dots) for adaptation options used on small farms at Gorita growing rice and cotton for a) baseline climate (1978-2009), c) future climate ECHAM5 (2021-2040) and e) future climate GFDL CM2.1 (2021-2040). Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N_2O emission, aquifer recharge and N leached for each of the adaptation options for b) baseline climate, d) future climate ECHAM5 and f) future climate GFDL CM2.1.

Comparison of the average gross margin and net water use as well as the gross margin, gross margin stability, N_2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for medium farms growing rice and cotton crops at Gorita using the baseline climate (1978-2009), future climates (2021-2040) ECHAM5 and GFDL CM2.1 are presented in Fig 41.

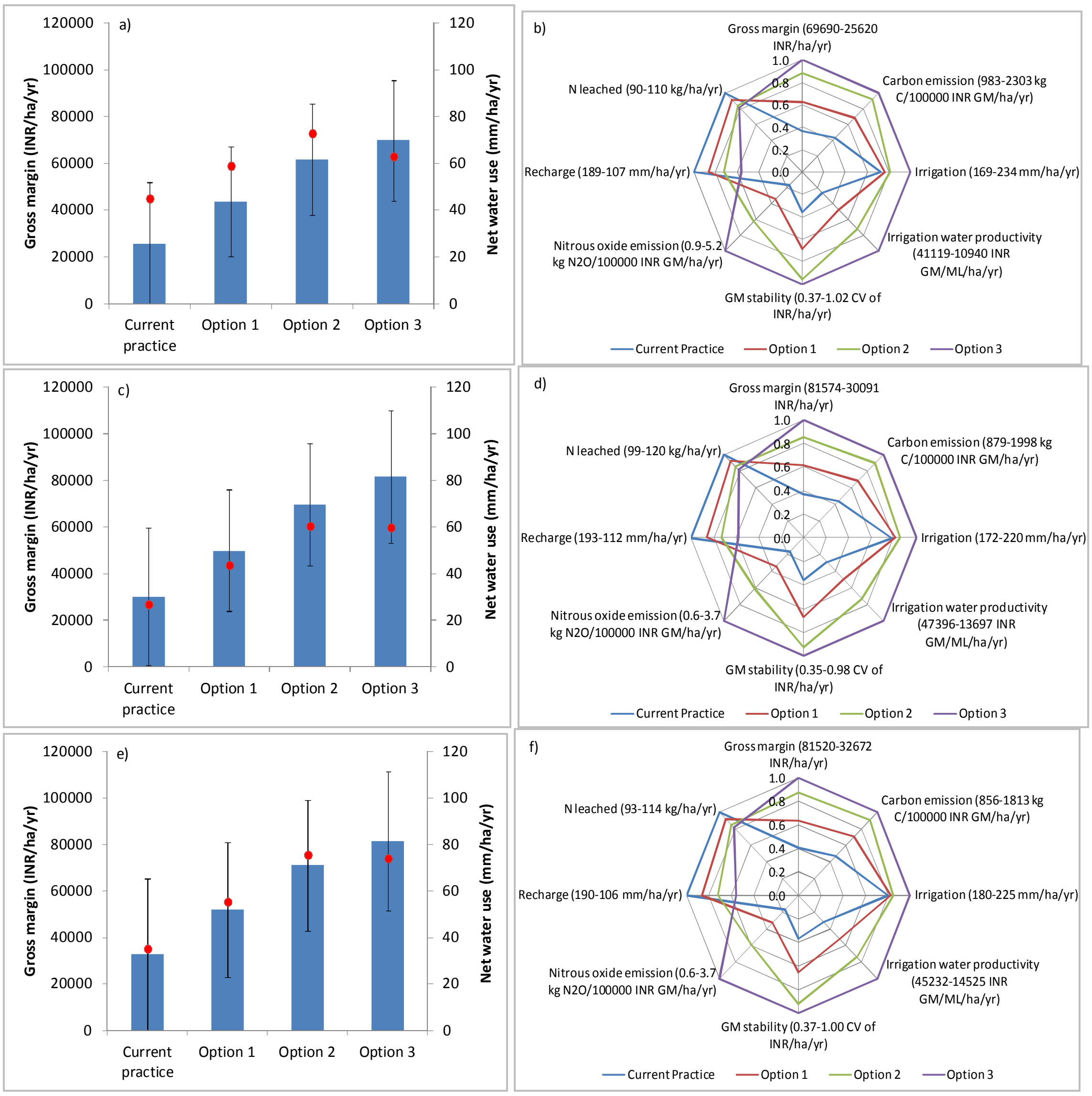


Fig 41. Gross margin (blue bars) and net water use (irrigation – recharge, red dots) for adaptation options used on medium farms at Gorita growing rice and cotton for a) baseline climate (1978-2009), c) future climate ECHAM5 (2021-2040) and e) future climate GFDL CM2.1 (2021-2040). Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N_2O emission, aquifer recharge and N leached for each of the adaptation options for b) baseline climate, d) future climate ECHAM5 and f) future climate GFDL CM2.1.

Comparison of the average gross margin and net water use as well as the gross margin, gross margin stability, N_2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for large farms growing rice and cotton crops at Gorita using the baseline climate (1978-2009), future climates (2021-2040) ECHAM5 and GFDL CM2.1 are presented in Fig 42.

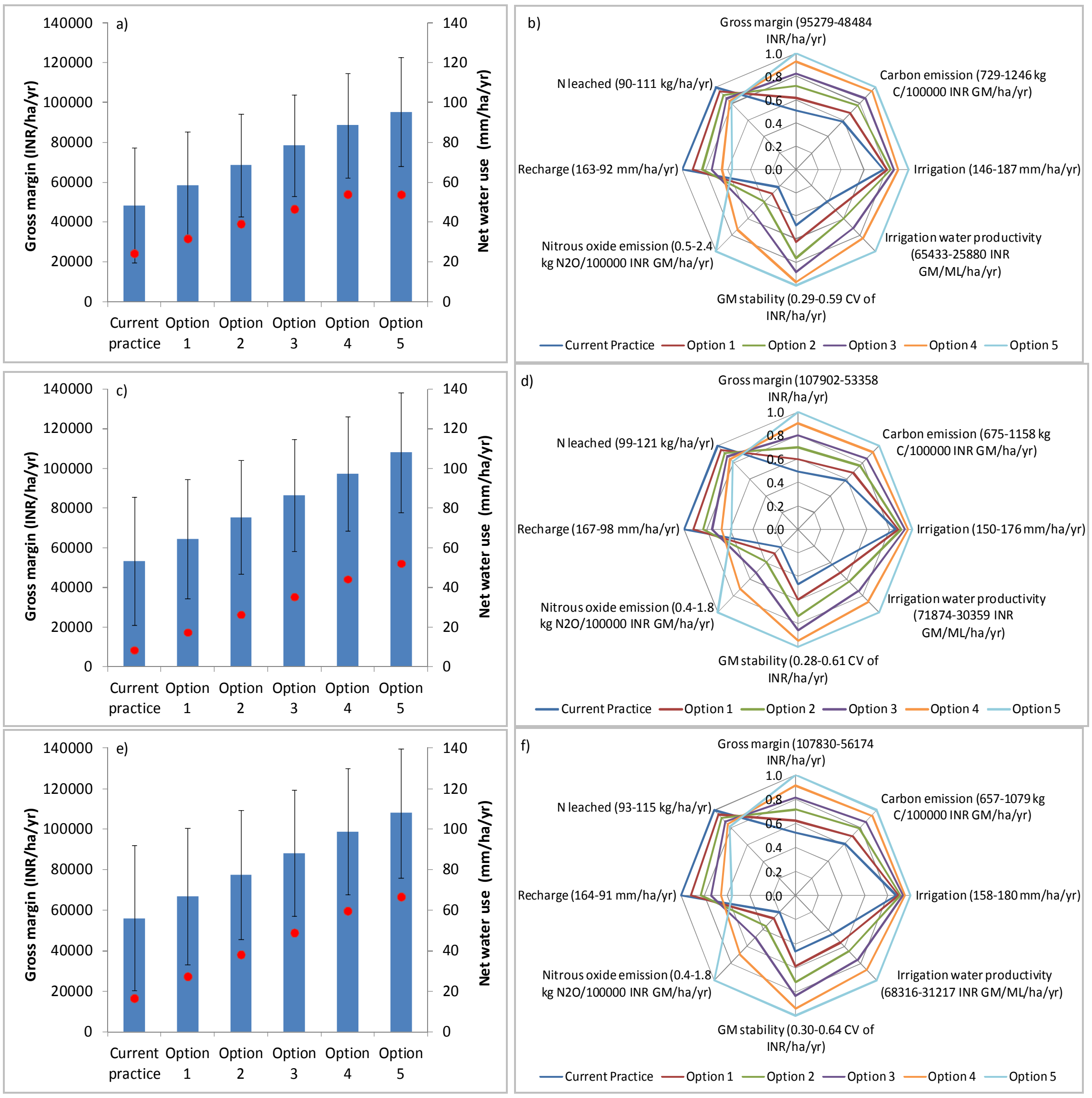


Fig 42. Gross margin (blue bars) and net water use (irrigation – recharge, red dots) for adaptation options used on large farms at Gorita growing rice and cotton for a) baseline climate (1978-2009), c) future climate ECHAM5 (2021-2040) and e) future climate GFDL CM2.1 (2021-2040). Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N_2O emission, aquifer recharge and N leached for each of the adaptation options for b) baseline climate, d) future climate ECHAM5 and f) future climate GFDL CM2.1.

Comparison of the average gross margin and net water use as well as the gross margin, gross margin stability, N_2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for small farms growing rice and maize crops at Gorita using the baseline climate (1978-2009), future climates (2021-2040) ECHAM5 and GFDL CM2.1 are presented in Fig 43.

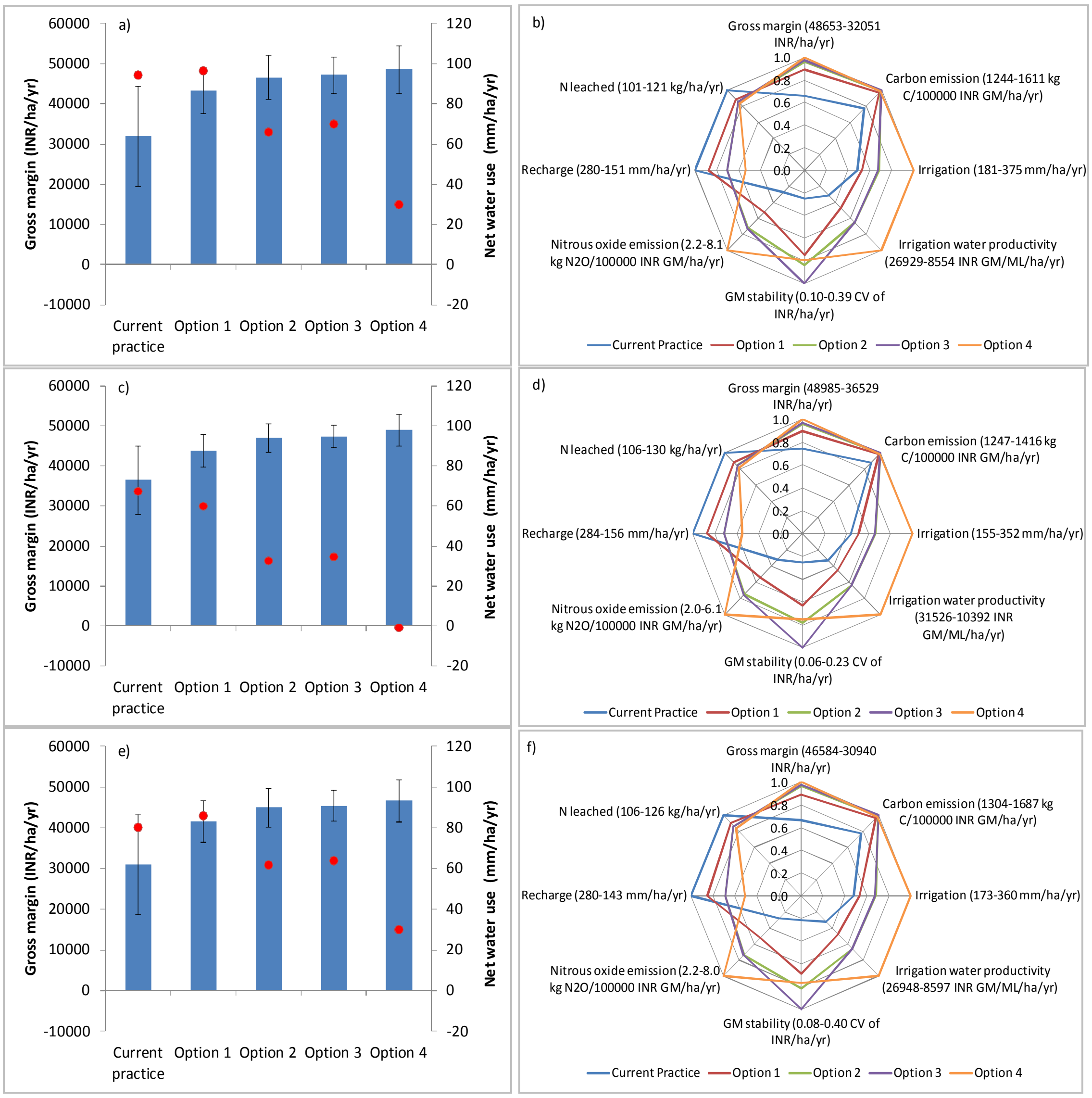


Fig 43. Gross margin (blue bars) and net water use (irrigation – recharge, red dots) for adaptation options used on small farms at Gorita growing rice and maize for a) baseline climate (1978-2009), c) future climate ECHAM5 (2021-2040) and e) future climate GFDL CM2.1 (2021-2040). Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N_2O emission, aquifer recharge and N leached for each of the adaptation options for b) baseline climate, d) future climate ECHAM5 and f) future climate GFDL CM2.1.

Comparison of the average gross margin and net water use as well as the gross margin, gross margin stability, N_2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for medium farms growing rice and maize crops at Gorita using the baseline climate (1978-2009), future climates (2021-2040) ECHAM5 and GFDL CM2.1 are presented in Fig 44.

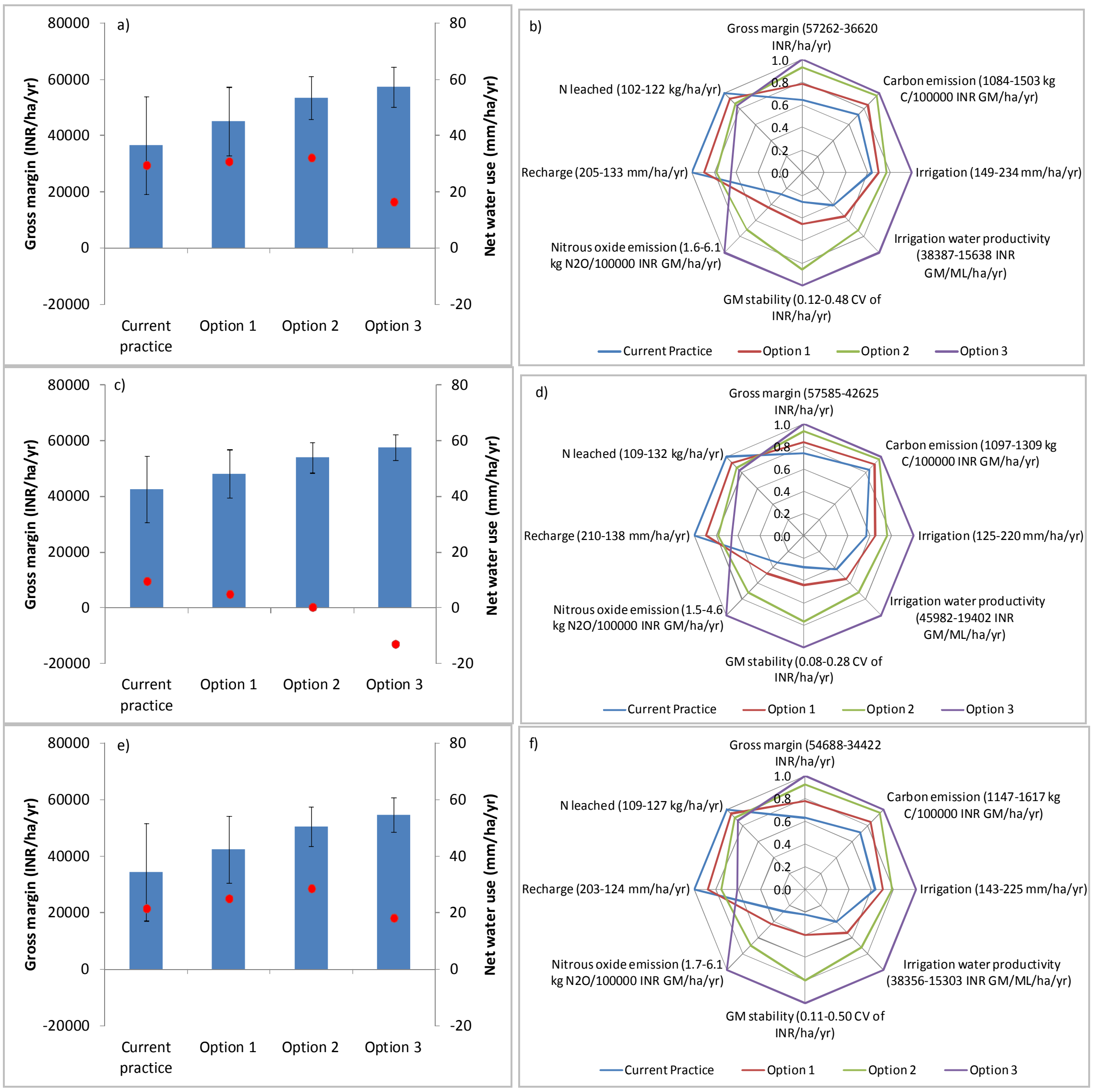


Fig 44. Gross margin (blue bars) and net water use (irrigation – recharge, red dots) for adaptation options used on medium farms at Gorita growing rice and maize for a) baseline climate (1978-2009), c) future climate ECHAM5 (2021-2040) and e) future climate GFDL CM2.1 (2021-2040). Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N_2O emission, aquifer recharge and N leached for each of the adaptation options for b) baseline climate, d) future climate ECHAM5 and f) future climate GFDL CM2.1.

Comparison of the average gross margin and net water use as well as the gross margin, gross margin stability, N_2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for large farms growing rice and maize crops at Gorita using the baseline climate (1978-2009), future climates (2021-2040) ECHAM5 and GFDL CM2.1 are presented in Fig 45.

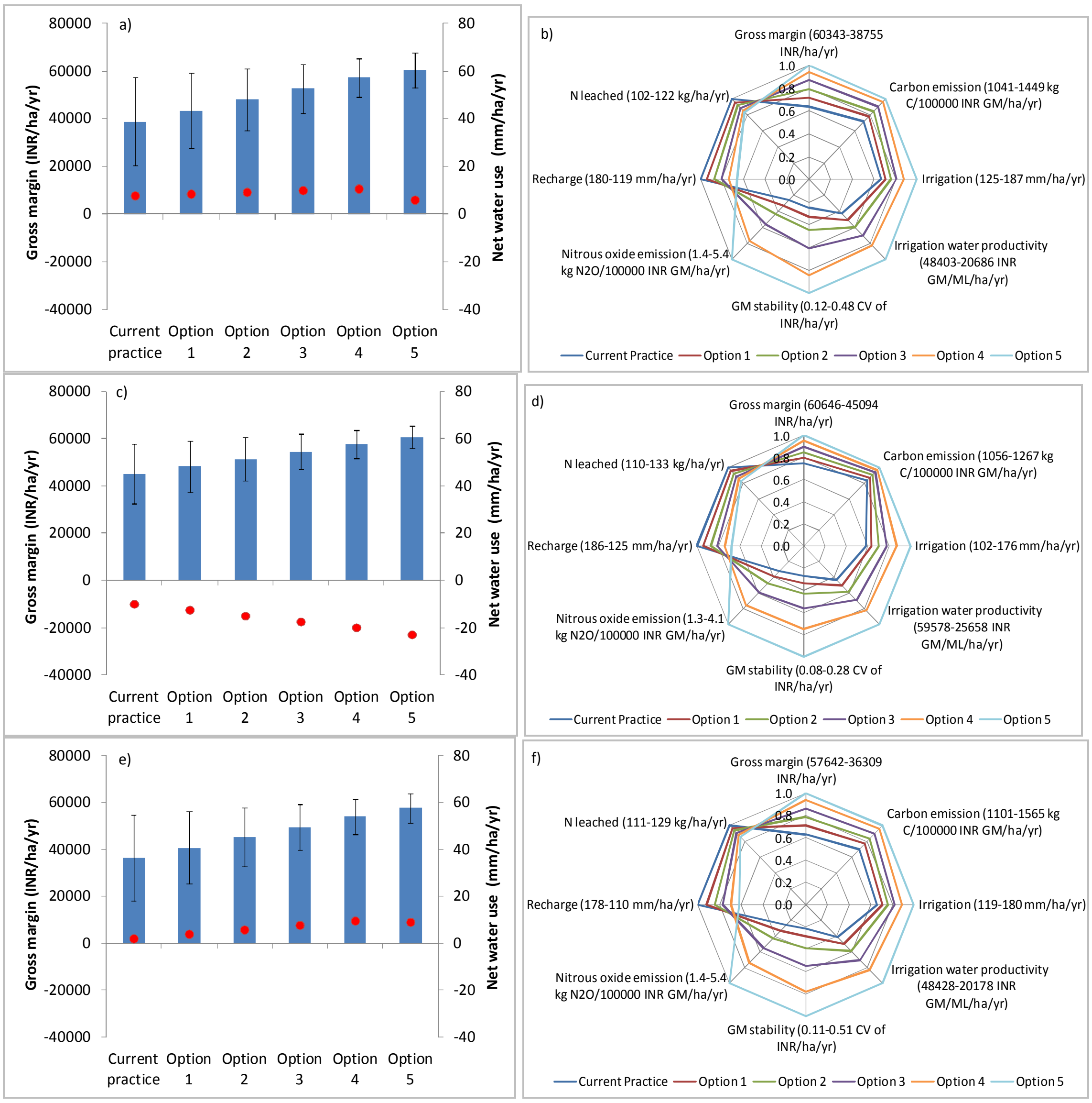


Fig 45. Gross margin (blue bars) and net water use (irrigation – recharge, red dots) for adaptation options used on large farms at Gorita growing rice and maize for a) baseline climate (1978-2009), c) future climate ECHAM5 (2021-2040) and e) future climate GFDL CM2.1 (2021-2040). Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N_2O emission, aquifer recharge and N leached for each of the adaptation options for b) baseline climate, d) future climate ECHAM5 and f) future climate GFDL CM2.1.

Comparison of the average gross margin and net water use as well as the gross margin, gross margin stability, N_2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for small farms growing rice and cotton crops at Nemmani using the baseline climate (1978-2009), future climates (2021-2040) ECHAM5 and GFDL CM2.1 are presented in Fig 46.

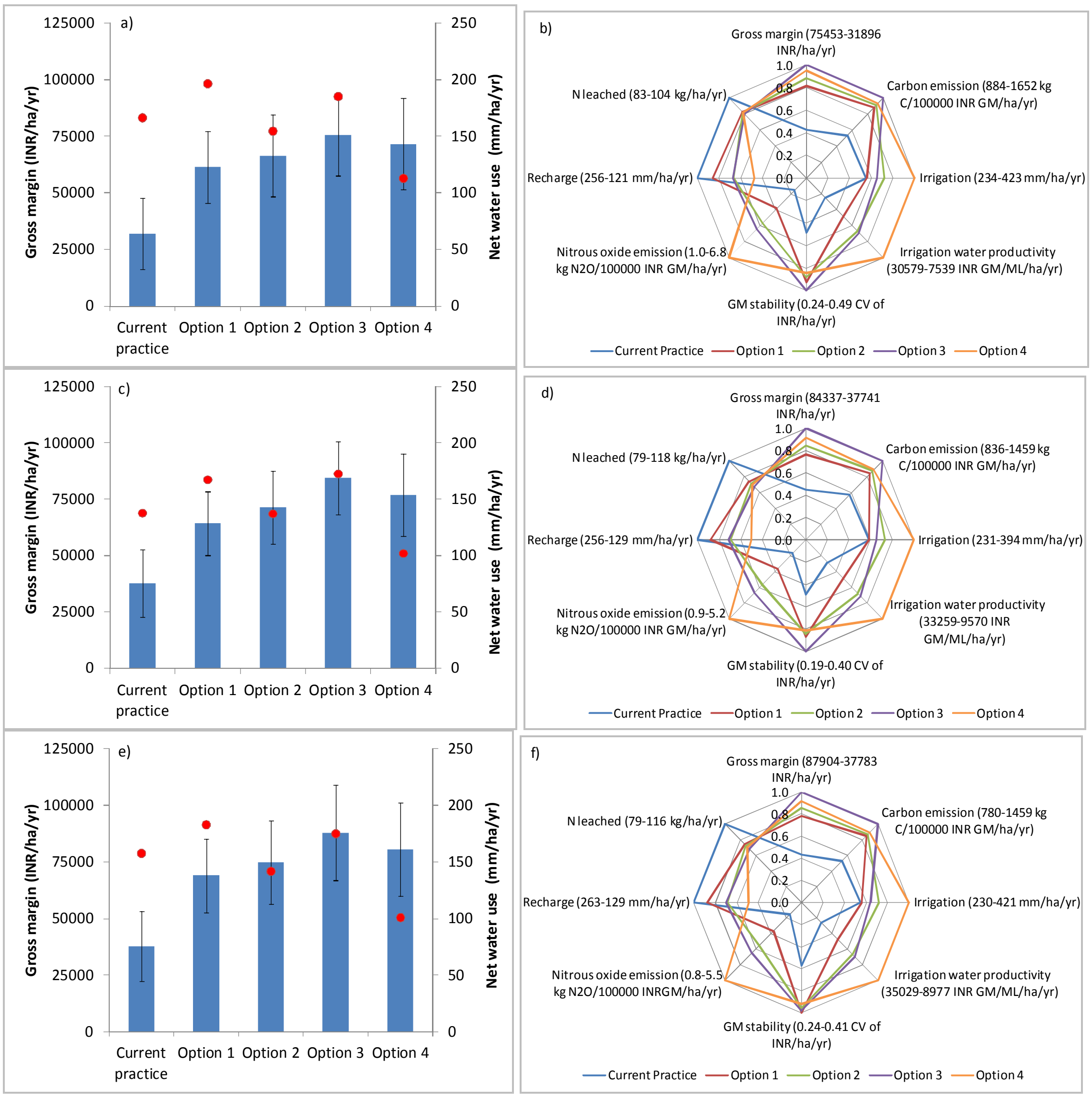


Fig 46. Gross margin (blue bars) and net water use (irrigation – recharge, red dots) for adaptation options used on small farms at Nemmani growing rice and cotton for a) baseline climate (1978-2009), c) future climate ECHAM5 (2021-2040) and e) future climate GFDL CM2.1 (2021-2040). Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N_2O emission, aquifer recharge and N leached for each of the adaptation options for b) baseline climate, d) future climate ECHAM5 and f) future climate GFDL CM2.1.

Comparison of the average gross margin and net water use as well as the gross margin, gross margin stability, N_2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for medium farms growing rice and cotton crops at Nemmani using the baseline climate (1978-2009), future climates (2021-2040) ECHAM5 and GFDL CM2.1 are presented in Fig 47.

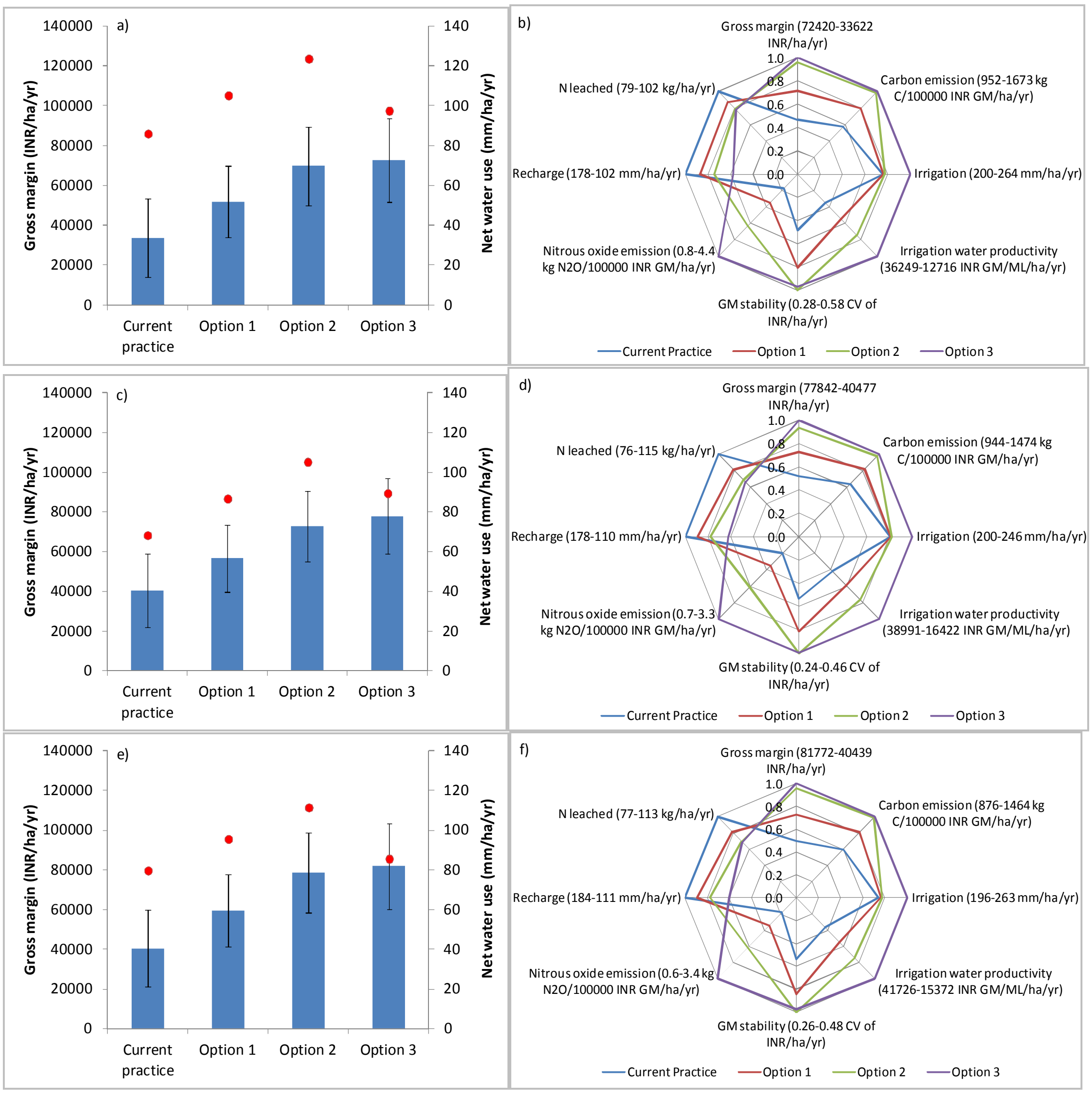


Fig 47. Gross margin (blue bars) and net water use (irrigation – recharge, red dots) for adaptation options used on medium farms at Nemmani growing rice and cotton for a) baseline climate (1978-2009), c) future climate ECHAM5 (2021-2040) and e) future climate GFDL CM2.1 (2021-2040). Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N_2O emission, aquifer recharge and N leached for each of the adaptation options for b) baseline climate, d) future climate ECHAM5 and f) future climate GFDL CM2.1.

Comparison of the average gross margin and net water use as well as the gross margin, gross margin stability, N_2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for large farms growing rice and cotton crops at Nemmani using the baseline climate (1978-2009), future climates (2021-2040) ECHAM5 and GFDL CM2.1 are presented in Fig 48.

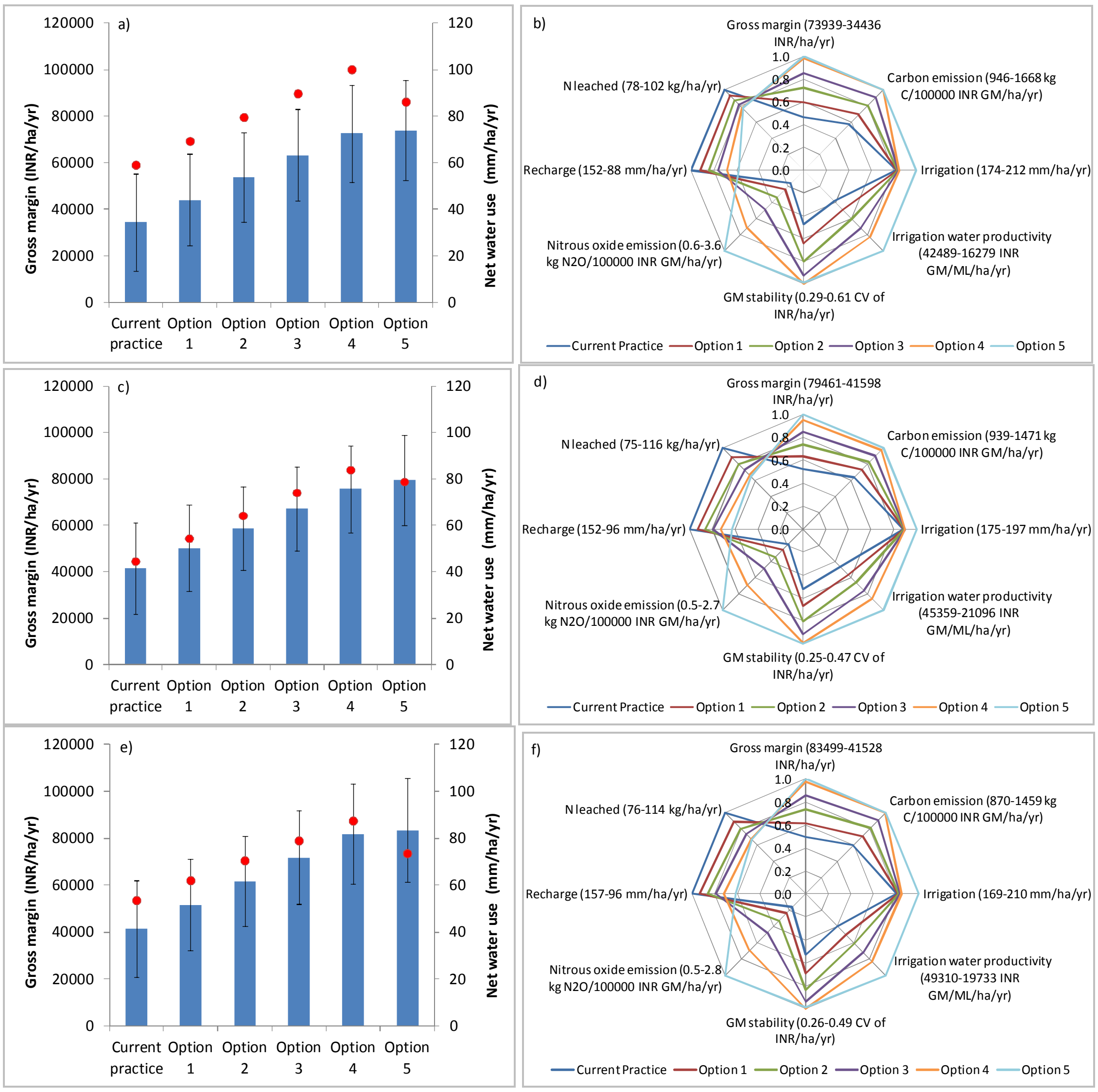


Fig 48. Gross margin (blue bars) and net water use (irrigation – recharge, red dots) for adaptation options used on large farms at Nemmani growing rice and cotton for a) baseline climate (1978-2009), c) future climate ECHAM5 (2021-2040) and e) future climate GFDL CM2.1 (2021-2040). Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N_2O emission, aquifer recharge and N leached for each of the adaptation options for b) baseline climate, d) future climate ECHAM5 and f) future climate GFDL CM2.1.

Comparison of the average gross margin and net water use as well as the gross margin, gross margin stability, N_2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for small farms growing rice and maize crops at Nemmani using the baseline climate (1978-2009), future climates (2021-2040) ECHAM5 and GFDL CM2.1 are presented in Fig 49.

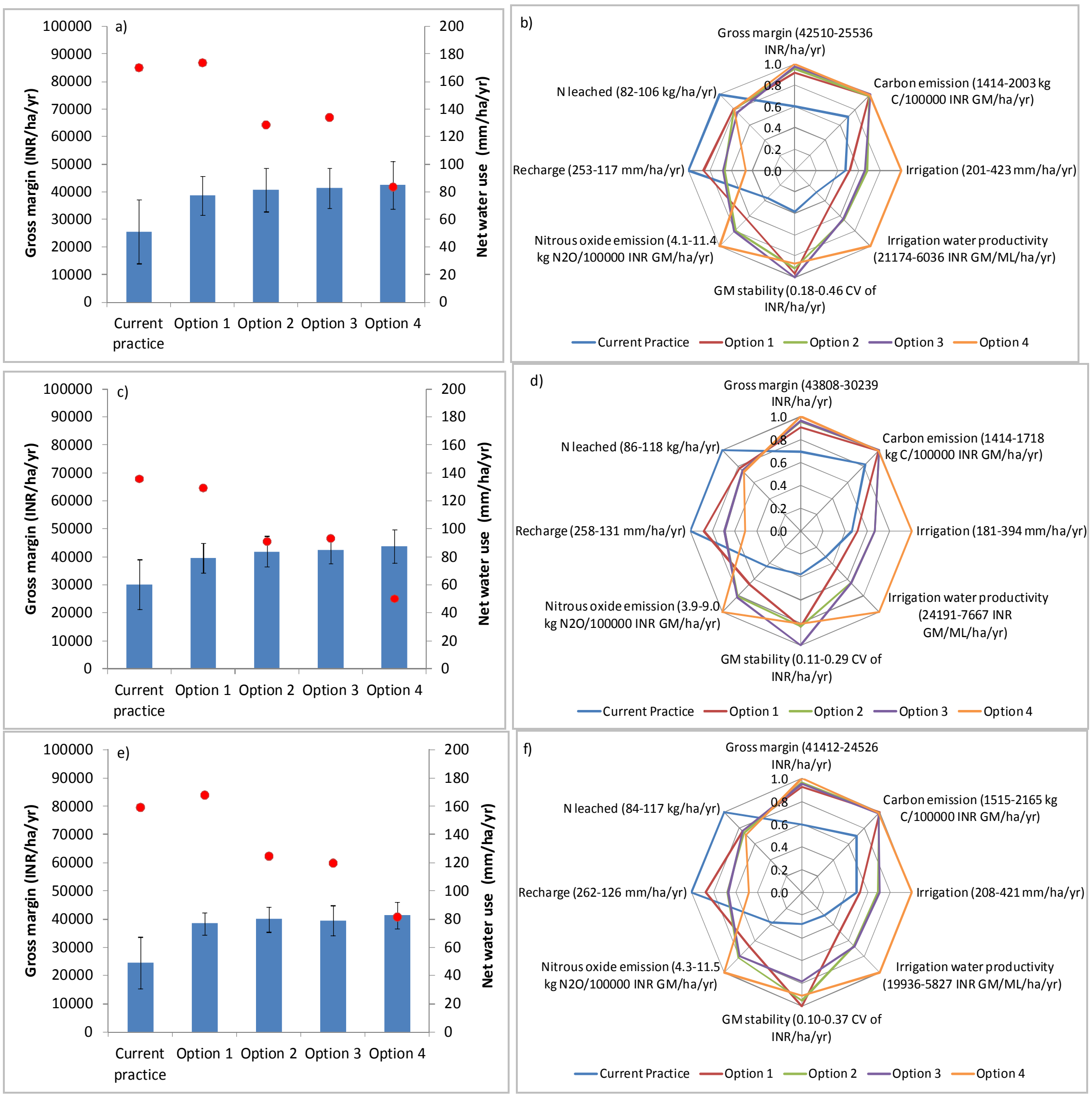


Fig 49. Gross margin (blue bars) and net water use (irrigation – recharge, red dots) for adaptation options used on small farms at Nemmani growing rice and maize for a) baseline climate (1978-2009), c) future climate ECHAM5 (2021-2040) and e) future climate GFDL CM2.1 (2021-2040). Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N_2O emission, aquifer recharge and N leached for each of the adaptation options for b) baseline climate, d) future climate ECHAM5 and f) future climate GFDL CM2.1.

Comparison of the average gross margin and net water use as well as the gross margin, gross margin stability, N_2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for medium farms growing rice and maize crops at Nemmani using the baseline climate (1978-2009), future climates (2021-2040) ECHAM5 and GFDL CM2.1 are presented in Fig 50.

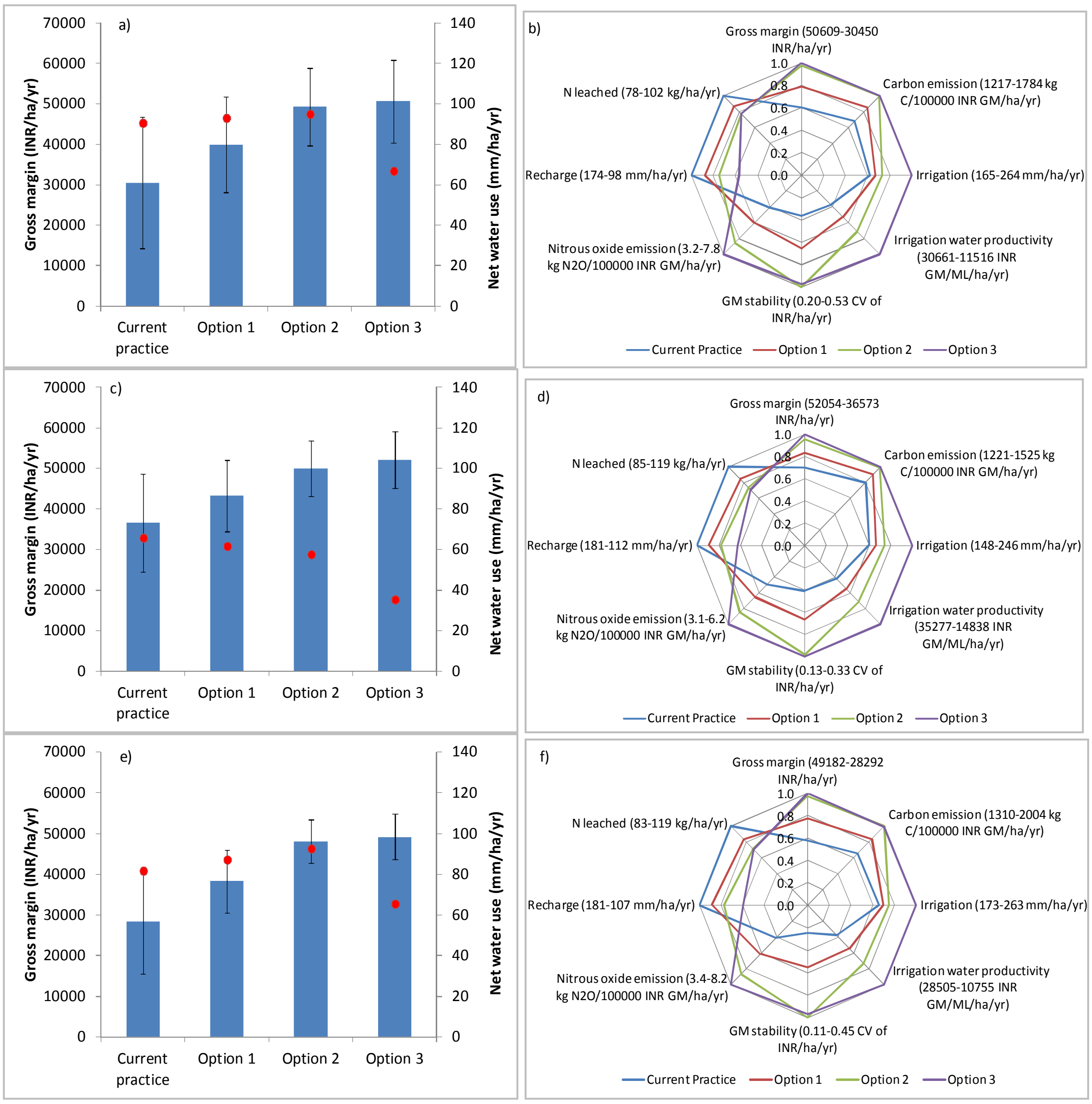


Fig 50. Gross margin (blue bars) and net water use (irrigation – recharge, red dots) for adaptation options used on medium farms at Nemmani growing rice and maize for a) baseline climate (1978-2009), c) future climate ECHAM5 (2021-2040) and e) future climate GFDL CM2.1 (2021-2040). Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N_2O emission, aquifer recharge and N leached for each of the adaptation options for b) baseline climate, d) future climate ECHAM5 and f) future climate GFDL CM2.1.

Comparison of the average gross margin and net water use as well as the gross margin, gross margin stability, N_2O and C emissions, irrigation water productivity, net water use, N leached and irrigation applied for the different adaptation options for large farms growing rice and maize crops at Nemmani using the baseline climate (1978-2009), future climates (2021-2040) ECHAM5 and GFDL CM2.1 are presented in Fig 51.

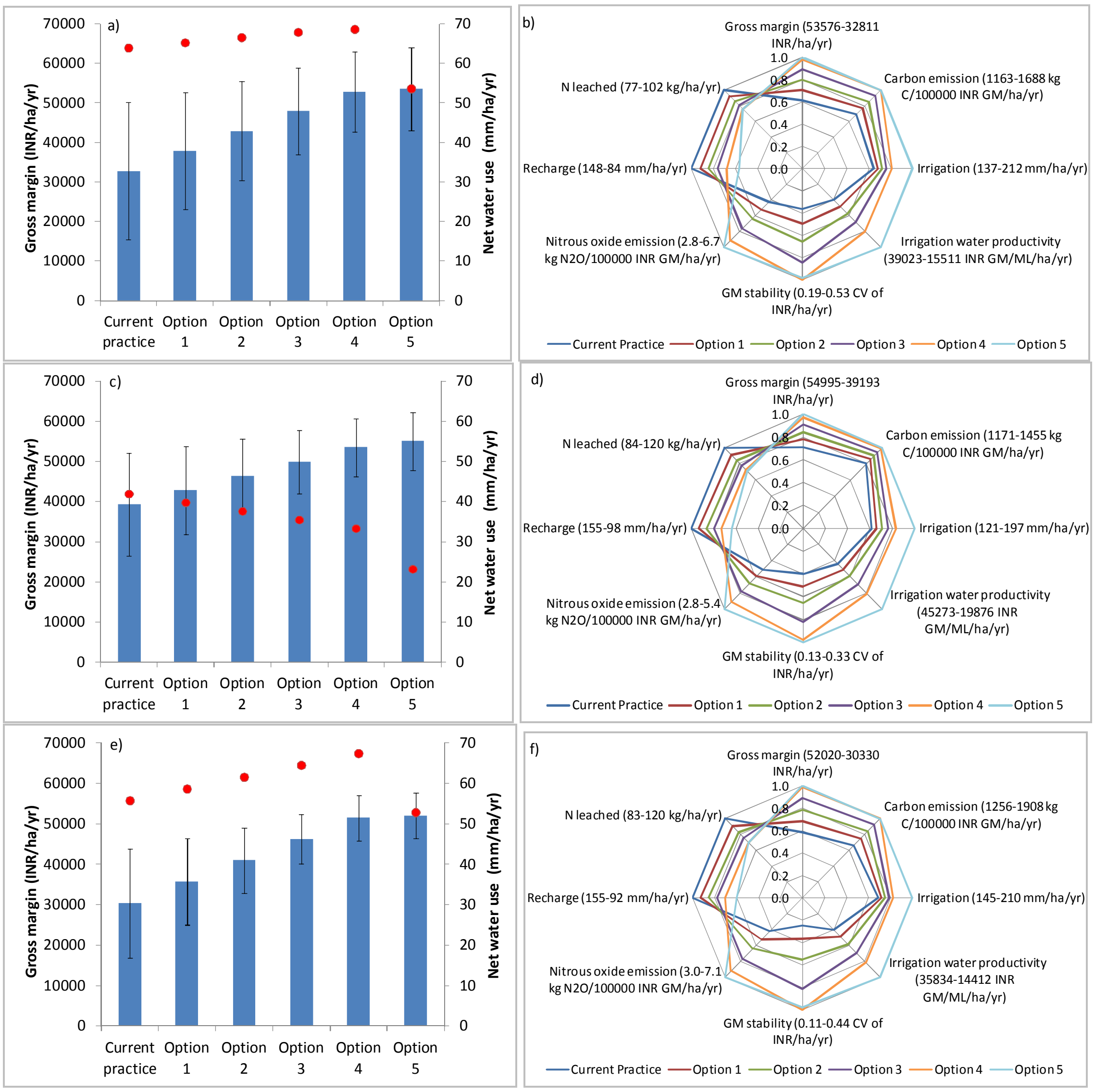


Fig 51. Gross margin (blue bars) and net water use (irrigation – recharge, red dots) for adaptation options used on large farms at Nemmani growing rice and maize for a) baseline climate (1978-2009), c) future climate ECHAM5 (2021-2040) and e) future climate GFDL CM2.1 (2021-2040). Comparison of gross margin, carbon emission, irrigation, irrigation water productivity, GM stability, N_2O emission, aquifer recharge and N leached for each of the adaptation options for b) baseline climate, d) future climate ECHAM5 and f) future climate GFDL CM2.1.

Discussion

Discussion of these results can be found in:

Zvi Hochman, Heidi Horan, D. Raji Reddy, Gade Sreenivas, Chiranjeevi Tallapragada, Ravindra Adusumilli, Don Gaydon, Christian H. Roth (2015a). Smallholder farmers managing climate risk in India: 1. adapting to a variable climate. (To be submitted to Agricultural Systems in Nov 2015)

Zvi Hochman, Heidi Horan, D. Raji Reddy, Gade Sreenivas, Chiranjeevi Tallapragada, Ravindra Adusumilli, Alison Laing, Don Gaydon, Philip Kokic, Christian H. Roth. (2015b). Smallholder farmers managing climate risk in India: 2. Is it climate-smart? (To be submitted to Agricultural Systems in Nov 2015)

5. OVERVIEW OF OTHER ACCA MODELLING

Bangladesh

In the southern saline-affected coastal regions of Bangladesh, earlier maturing wet season (T. Aman) rice crops (or earlier established T. Aman rice crops) allow earlier establishment of the following *rabi* crops (such as cowpea or irrigated boro rice). This resulting earlier second crop establishment is likely to increase the chance of successful harvest before soil salinity levels in the *rabi* season have built up to toxic levels. Earlier establishment of the *rabi* crop will also decrease the likelihood of waterlogging problems from early wet-season rains.

In the first iteration of scenario analyses (2012), the APSIM model has been used to examine the long-term production risk associated with such changed establishment dates, using both historical weather data (1961-2009) and also projected future climate data (2021-2040) using the ECHAM5 and GFDLCM2.1 GCMs to produce local climate predictions using the methods of Kokic et al. (2011).

The scenarios examined were:

- T. Aman sowing dates (day 170 to day 230, at 10 day intervals), particularly examining the effect on T. Aman grain yield. Both a 'local' T. Aman variety and an improved (BR23) variety were simulated.
- For each given T. Aman sowing date, *rabi* season crops were subsequently sown and the average performance and variability in their grain production examined. This provided simulated performance at a range of sowing dates for the following crops:
  - Relay-sown cowpea (established earlier by sowing directly into wet T. Aman stubble)
  - Sequentially-sown cowpea (typical current practice)
  - Sequentially-sown boro rice (typical current practice)

Each of these sowing-date scenarios was simulated using historical climate data for Khulna (1961-2009) and also with projected future climate data (2021-2040). The soil and crop parameterisations were for Parchalna and Laxmikhola (Dacope *upazila)* and Satkhira (Satkhira *upazila*).

Additional scenarios were run to explore the opportunities in intensifying *T. aman* based cropping systems for the non-saline zone, based on data for the Gazipur site (near Dhaka). The scenarios consisted of:

- Scenario 1 Boro rice – Fallow - T.Aman rice (control)
- Scenario 2 Boro rice -T.Aus rice -T.Aman rice
- Scenario 3 Mustard - T.Aus rice - T.Aman rice
- Scenario 4 Maize – Mungbean - T.Aman rice

Each of these sowing-date scenarios was simulated using historical climate data for Khulna (1961-2009) and also with projected future climate data (2020-2040 using both GCMs). The soils and crop parameterisations were for the Gazipur site. Scenario results were compared based on grain yields and gross margins (from an irrigated perspective and also total applied water). Water productivity was defined as profit earned per millimetre of water applied.

A range of scenarios exploring the implications of changed sowing dates and irrigation with different ratios of fresh water : saline water in boro rice cultivation were also performed at Satkhira:

Scenario 1: Boro rice (sown 1-Jan) irrigated with fresh water

Scenario 2: Boro rice (sown 1-Jan) irrigated with a mix of 90% fresh, 10% saline water

Scenario 3: Boro rice (sown 1-Jan) irrigated with a mix of 80% fresh, 20% saline water

Scenarios 4-10: Boro rice (sown 1-Jan) irrigated with a decreasing proportion of fresh, increasing proportion of saline water (ie 70:30, 60:40, 50:50, 40:60 etc)

Scenario 11: Boro rice (sown 1-Jan) irrigated with 100% saline water

This full set of 11 scenarios was then simulated in matrix fashion with a range of sowing dates (six, at fortnightly intervals from 1-Nov), and varietal salt tolerance (four tolerances:- current (BRRI Dhan47, 10%, 20% and 60% increase in tolerance level).

Selected results of the Bangladesh scenario analyses have been presented in Volume 1 of the ACCA Final Report. Also, the majority of results have been or are about to be presented in the following journal papers:

Akhter, S, F Ahmed, I Saiyed, M. Muttaleb, MMR Sarker, AK Chaki, ASMMR Khan, MJ.U. Sarker, MH Ali (2014). Changing irrigation scheduling to increase water productivity of triple rice system in Grey Terrace Soil of Bangladesh. In: Gaydon, DS, I Saiyed and CH Roth (Eds.), 2014: The SAARC-Australia Project – Developing capacity in cropping systems modelling for South Asia. SAARC Agriculture Centre, Dhaka, pp. 35-44.

Gaydon, DS, A Chaki, MR Khan, A Muttaleb, MH Rashid, S Ritu. Intensifying cropping patterns in Bangladesh. I – productivity and risk under current and future climates.
Submitted to *Field Crops Research* or *Agricultural Systems* in January 2016.

Gaydon, DS, A Chaki, MR Khan, A Muttaleb, MH Rashid, S Ritu. Intensifying cropping patterns in Bangladesh. II – adjusting management to enhance future climate performance. Submitted to *Field Crops Research* or *Agricultural Systems* in January 2016.

Gaydon, D.S., A.M. Radanielson, A. K. Chaki, Md. A. Rahman, Md.J. Kabir, A.S.M.M.R. Khan, and C.H. Roth. Options to increase boro rice productivity in salt-affected zones of South-West Bangladesh: I. farmer management options. Submitted to *Agricultural Systems* in December 2015.

Radanielson, AM., DS Gaydon, T Li, O Angeles. Modelling salinity effect on rice growth and yield with ORYZA v3 and APSIM-ORYZA. Submitted to *Ecological Modeling and Software* in April 2015.

Radanielson, A. M., T. Li, A. Ismail. Overview on salinity modelling to define an effective representation of rice crop production under salt affected areas. Submitted to *Field Crops Research.*

Radanielson A. M., O. Angeles, T. Li, A. Ismail. Genotypic variability of rice leaf gas exchange responses to salt stress and effect on whole plant biomass production. Submitted to *Plant Physiology* in October 2015

Radanielson A. M., D.S. Gaydon, Md. M. R. Khan, A. Chaki, Md. A. Rahman, O. Angeles, T. Li, A. Ismail. Options to increase rice productivity in salt-affected zones of South-West Bangladesh: II. varietal improvement options. Submitted to *Agricultural Systems* in September 2015.

Cambodia

The APSIM model was specified for Cambodia and applied in evaluation of the current and potential cropping options, using proximate representative climate data (1978 -2011), as well as local soil and crop data obtained in the on farm experiments. The results of the specification in Cambodia have been presented in:

Poulton, PL, V Touch, N Dalgliesh, V Seng. 2015. Applying APSIM to improved rice varieties in reducing the on farm yield gap in Cambodian lowland rice ecosystems. *Experimental Agriculture* 50:2 264-284

Initial simulations in Cambodia in 2012 were used to evaluate a number of possible planting options with the results reported for (1) direct seeding (using a drum seeder) compared to traditional transplanting and (2) the option of two sequential short duration crops replacing a later maturing traditional variety. The scenarios are listed in Table 10. All simulations with the exception of outcome 8 (drum seed scenario) and outcome 11 (future climate scenario) were evaluated using rainfed conditions without supplementary irrigation.

Table 10. Scenarios studied in the first iteration of modelling (2012)

NO	ESTABLISHMENT DATE NURSERY (TRANSPLANT) SOWING (DRUM)	MANAGEMENT	MATURITY CLASS	VARIETY	IRRIGATION	NITROGEN RATE AND TIMING
1	*First crop:* 1 June, 15 June, 1 July *Second crop:* 1 Sep	Transplant	Medium	Krasang Theap	Rain fed	Zero
2	*First crop:* 1 June, 15 June, 1 July *Second crop:* 1 Sep	Transplant	Medium	Krasang Theap	Rain fed	Transplant: 92kg/ha
3	*First crop:* 25 Apr, 1 May, 8 May, 15 May, 22 May, 30 May, 6 Jun, 13 Jun *Second crop:* 1 Sep, 15 Sep, 22 Sep	Drum seeder	Short	Sen Pidao	Rain fed	Zero
4	*First crop:* 25 Apr, 1 May, 8 May, 15 May, 22 May, 30 May, 6 Jun, 13 Jun *Second crop:* 1 Sep, 15 Sep, 22 Sep	Drum seeder	Short	Sen Pidao	Rain fed	CARDI recommended rate Sowing: 25kg/ha Panicle initiation: 25kg/ha
4	*First crop:* 25 Apr, 1 May, 8 May, 15 May, 22 May, 30 May, 6 Jun, 13 Jun *Second crop:*	Drum seeder	Short	Sen Pidao	Rain fed	FDP rate Sowing: 60kg/ha

NO	ESTABLISHMENT DATE NURSERY (TRANSPLANT) SOWING (DRUM)	MANAGEMENT	MATURITY CLASS	VARIETY	IRRIGATION	NITROGEN RATE AND TIMING
	1 Sep, 15 Sep, 22 Sep					
5	*First crop:* 1 May *Second crop:* 1 Sep	Drum seeder	Short	Sen Pidao	Rain fed 3 X 50 mm irrigations	CARDI rate: 50kg/ha CARDI rate: 50kg/ha + 50kg/ha CARDI rate: 50kg/ha CARDI rate: 50kg/ha + 50/kg/ha
5	*First crop:* 1 May *Second crop:* 1 Sep	Drum seeder ECHAM5 future climate scenario (2021-2040)	Short	Sen Pidao	Rain fed 3 X 50 mm irrigations	CARDI rate: 50kg/ha CARDI rate: 50kg/ha + 50kg/ha CARDI rate: 50kg/ha CARDI rate: 50kg/ha + 50kgha

Following focus group discussions with farmers to verify the initial modelling results and to refine the farmer management rules in APSIM Crop Manager, a second iteration of scenario analyses were carried out. In this case, adaptation strategies targeting a ‘response’ farming approach to the prevailing wet season conditions with the aim of improving efficiency of use of the natural resources, particularly water were evaluated. Response farming assumes that there are a number of ways in which the monsoon period can be used to produce rice, with particular options better suiting particular climatic conditions. Simulated scenarios evaluated the traditional farmer practice with a number of potential adaptation options for a baseline climate period (1978-2011) and for projected future climates (2021-2040).

Scenarios evaluated:

1. Rainfed transplanted, local medium maturation variety established early to mid-wet season with no applied N fertiliser (farmer practice 1).
2. Rainfed transplanted, local medium maturation variety established early to mid-wet season with 20 kg/ha of applied N fertiliser (farmer practice 2).
3. Rainfed transplanted, modern medium maturation variety established early to mid-wet season with 50 kg/ha of applied N fertiliser (adaptation option 1).
4. Rainfed direct seeded, modern medium maturation variety established mid-wet season with 50 kg/ha of applied N fertiliser (adaptation option 2).
5. Rainfed direct seeded, modern short maturation variety established mid-wet season with 50 kg/ha of applied N fertiliser (adaptation option 3).
6. Rainfed direct seeded, modern short maturation variety established early wet season with 50 kg/ha of applied N fertiliser (adaptation option 4).
7. Rainfed double crop sequence of short duration, direct seeded rice sown early (crop 1) and mid-wet season (crop 2) with 50 kg/ha of applied N fertiliser (adaptation option 5).
8. Double crop sequence of short duration, direct seeded rice sown early (crop 1) and mid-wet season (crop 2) with access to supplementary irrigation with 50 kg/ha of applied N fertiliser (adaptation option 6).

Key results of the second iteration Cambodia scenario analyses have been presented in Volume 1 of the ACCA Final Report. The main results are about to be presented in the following journal paper:

Poulton, PL, NP Dalgliesh, V Seng, P Charlesworth, P. Kokic, C.H. Roth. Resilience of Cambodian lowland rice ecosystems systems to future climate uncertainty. For submission to Experimental Agriculture in Dec 2015.

Lao PDR

In the initial scenario analysis in 2012, five different rice cropping simulations were run for both present day (1971-2011) and future (2021-2040):

- Scenario 1: baseline, reflecting recent historical rice cropping practices
- Scenario 2: as scenario 1, but sowing by direct seeding instead of transplanting. The end of the sowing window is shifted 3 weeks earlier, in line with recommended practices
- Scenario 3: as scenario 2, but with a 50 % reduction in seeding rate (45 plants/m^2 instead of 90 plants/m^2)
- Scenario 4: as scenario 1, and with supplementary irrigation if no water remains in the rice bay
- Scenario 5: as scenario 4, with a 100% N fertiliser application (urea fertiliser applied at a rate of 120kg/ha instead of 60kg/ha)

The results of these initial analyses were workshopped with partners in Laos. Farmer feedback was elicited in focus group discussions. Subsequently, we refined APSIM parameterisation for Laos and reran APSIM with a revised set of scenarios reflecting stakeholder feedback.

The scenarios were again run on two soil types: a sandy loam representing lower toposequence positions and a loamy sand representing higher toposequence positions. These soils are representative of low-lying paddies in which rainfed wet season rice is grown in Outhoumphone and Champhone (Sengxua, pers comm.). In both soils there is a puddled hard pan layer in transplanted (PTR) simulations which is less permeable than the comparable layer in direct seeded (DSR) simulations, in which the soil is no longer compacted each year prior to transplanting.

Simulations compared wet season rice production for present day (1971-2011) and two future (2021-2040) climates, representing a wetter milder (GFDLCM) and a harsher, drier (ECHAM) climate.

The standard rice phenology in APSIM-ORYZA was modified to represent an improved variety of Lao glutinous rice, TDK8. TDK8 is common across Savannakhet and is one of the most popular varieties chosen by farmers to use in ACCA project field trials.

The updated baseline simulation represents farmers' risk averse (low input) management practice: a rainfed transplanted TDK8 crop established every wet season. The crop is transplanted the first time water ponds on the soil surface for three consecutive days; the nursery is sown 30 days before transplanting. Small amounts of nitrogen fertiliser (7kg N/ha urea and 0.5t/ha farmyard manure) are incorporated into the soil at sowing.

For each combination of shallow or deep soil and climate (present day or future) the following adaptation options have been examined relative to the baseline:

- Increasing nitrogen fertiliser to the NAFRI-recommended rate of 60kg N/ha (this rate is below that required to maximise yield but considerably higher than the amount currently applied by most farmers);

- Applying supplementary irrigation in the first two months after sowing (ie in the nursery and for the first month after transplanting) in instances where no rainfall or irrigation water has been received in the previous seven consecutive days;
- Switching from transplanting to direct seeding;
- Sowing the direct seeded crop earlier in the wet season (ie into a drier soil) or slightly later (into a wetter soil).

The eight management scenarios examined are summarised in Table 11.

Table 11. Scenarios modelled using APSIM in Lao PDR.

Scenario	Details
T1	PTR, rainfed, low N: this is the baseline scenario
T2	PTR, rainfed, high N
T3	PTR, supplementary irrigation, low N
T4	PTR, supplementary irrigation, high N
T5	DSR, sowing earlier (into a drier soil), low N
T6	DSR, sowing earlier (into a drier soil), high N
T7	DSR, sowing later (into a wetter soil), low N
T8	DSR, sowing earlier (into a wetter soil), high N

Simulation outputs were compared for each adaptation strategy in terms of:

- Yields
- Gross margin (GM), calculated using cost and income data collected from representative case study households
- Yield and GM stability: the standard deviation of yield and GM
- N_2O emission, calculated as kg N_2O per tonne of yield
- C emission, calculated as kg C per tonne of yield.

Results of the second iteration scenario analyses have been presented in Volume 1 of the ACCA Final Report. The main results will also be presented in the following journal paper under preparation:

Laing, A, DS Gaydon, T Inthavong, V Phengvichith, PL Poulton, CH Roth, K Thiravong, G Lacombe, Sipaseuth. Direct seeding of rain fed rice in lowland Lao PDR reduces farmers‟ exposure to climate risks and ameliorates gross margins in poor years. For submission to *Experimental Agriculture* or *Climate and Development* in Dec 2015

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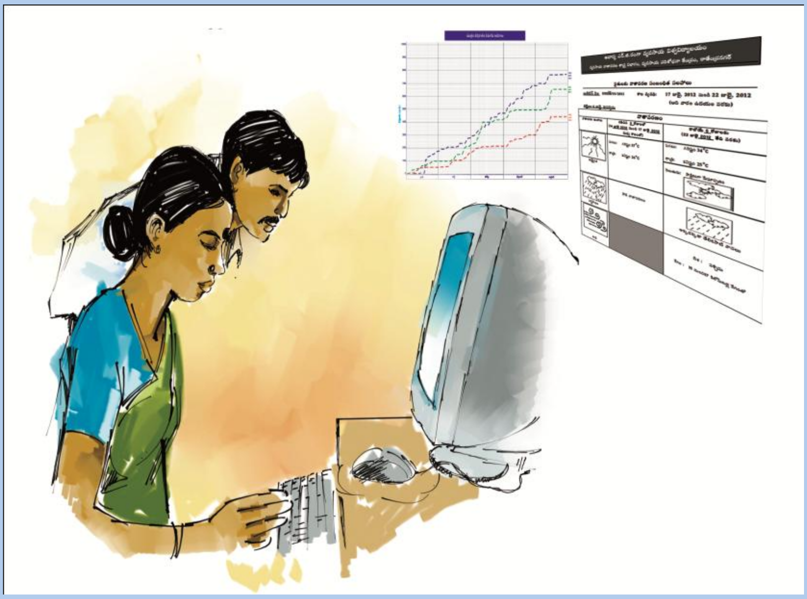
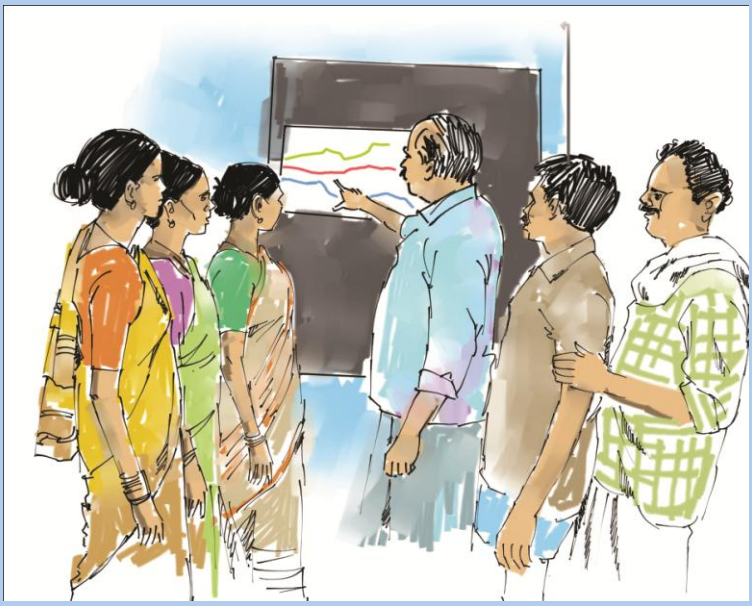
Appendix 6 – WASSAN 2015: Functionality and usage of Climate Information Centres

Report on functionality and usage of Climate Information Centres (CLIC)

WASSAN

Unpublished report.





WASSAN

Report on Functionality and Usage of Climate Information Centres (CLIC)

Developing Multi-Scale Climate Change Adaptation Strategies for Farming Communities in Cambodia, Loa PDR, Bangladesh and India.

CONTENTS

Report on Establishing Climate Information Centres (CLICs)

Report on the Supplementary Services to the Project

Developing Multi-Scale Climate Change Adaptation Strategies for Farming Communities in Cambodia, Loa PDR, Bangladesh and India.

Agreement relating to an ACIAR Project Agreement No LWR/2008/019

"The purpose of this contract is to assist WASSAN in establishing at least 10 Climate Information Centres (CLIC), thus enabling CSIRO to achieve key outcomes under the auspices of the ACIAR-funded "Multi- Scale Climate Change Adaptation Strategies" project.

The purpose of the assignment is as follows:

1. Finalise the development of the CLIC-information system, comprising software that allows access to and displays: agro-met advisories produced by other project partners, the rainfall visualisation tool and other static information of relevance to farmer decision making (e.g. pest and disease information). The computer based information is to be complemented by non-computer based information comprising posters, rainfall charts and other pictorial material to be posted in the CLICs.
2. Develop training modules for CLIC facilitators and orientation modules for farmers. The modules will be developed in consultation with other partners as required, in particular Dr. Sreenivas from ANGRAU and Dr Chiranjeevi Tallapragada from LNRMI.
3. Select, appoint and train 32 village-based CLIC facilitators. Training will be carried out in close liaison with Dr. Sreenivas, ANGRAU.
4. Ongoing monitoring of performance of CLICs and provision of support to CLIC facilitators as required. This entails CLIC facilitators maintaining a daily diary of activities and participants for each CLIC. A monthly summary of these diaries is to be provided to CSIRO via WASSAN.

The deliverables of the assignment are:

1. Functional CLIC – information software system. Beta version by 15 June 2014. Test-runs and continuous refinement over the kharif season 2014 (July – Oct 2014). Final version of the information software system
2. Training modules for the CLIC facilitators
3. Orientation modules on CLIC for farmers
4. At least 32 facilitators trained on CLICs using the modules developed
5. At least 10 CLICs operational and fully functional

REPORT ON THE ASSIGNMENT

Development of CLIC - Information System

The software is now in full-shape and the final version is now deployed in the CLICs. The *beta version* was deployed earlier and feedback was taken from a cross-section of users – the CLIC operators, farmers, development professionals etc. The system is designed as flexible so as to enable incorporation of more modules, information, videos, pictures and text.

Software Platform:

CLIC is the output of a complex idea as a web-application/software with an easy user interface providing for multiple-types of navigation. It runs in browser as an offline application. This application was developed using various web-technology includes PHP 5.4 (Codeigniter), JQUERY 1.8 and it's different libraries, Bootstrap (Design), MYSQL (database), Apache etc.

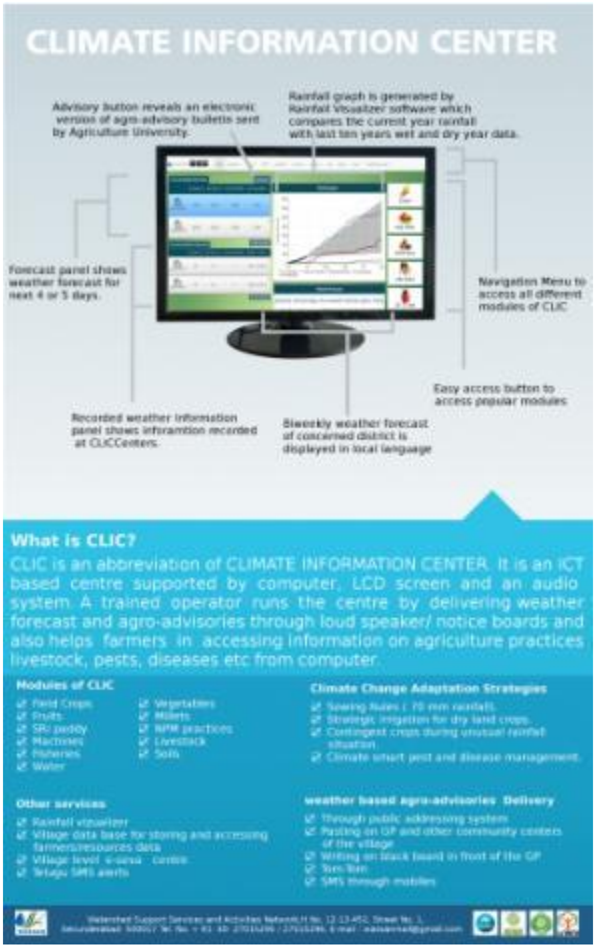
This CLIC application includes various multi-media modules on agriculture, livestock, covering 30+ diseases, 17+ crop modules –on field crops, vegetables, millet, fruits and information on 60+ pests with details on their life cycles, crop specific symptoms and control measures (without and with using pesticides) , 30+ machine information, SRI rice, Soils, Fisheries, films on agriculture, interactive advisory and forecast information and local actual weather data storage with option to export data in various formats. Most of the information is presented in multiple slides contains image gallery, audio, video gallery and illustration and it is fully dynamic; the operator can update, edit, delete content/information on the fly.

All the information provided in the CLIC-Info system is in Telugu, the local language –including the films. We have purchased the crop-films from ANGRAU / PJTS Agriculture University and *Vyavasaya Panchamgam* (Almanac of Agriculture) published by the university and used them in some of the modules. Most of the content is sourced from the information library / communication material developed by WASSAN and from the internet. Enormous amount of work from a team went into content building in local language and to build visual content as such resources are not available in general.

The software is prepared for off-line browsing. The heavy multi-media content with poor connectivity will be a bottleneck if it is online. The CLIC software is a web-application making it easy to migrate into an online resource if resources are available. At present, the updates have to be manual (through CD).

The interface of software is developed keeping in view of a farmer walking into CLIC with a question and it is for the CLIC facilitator to ask few questions to the farmer and navigate easily to the specific information module within 5 minutes time – play the video, read out the content, show the visuals and provide the required information to the farmer. For e.g., if the agro-advisory forecasts a pest – all that the facilitator needs is to identify the crop and identify the pest (by name or by visual along with the farmer). It is not expected that the facilitator is a subject matter expert; s/he only have to navigate to the specific module/ web pages to find information and read out/ play the media files there. The attempt is to provide required knowledge about the problem rather than merely providing input-prescriptions.

The 2 sample posters below developed for an exhibition provides a glimpse of CLIC-Information system.



Developing Training Modules for CLIC Facilitators

The Climate Information Centre is facilitated by a person from the host-village selected through a process involving Gram Panchayat.

- **Selection of CLIC operators:**

<u>Operators' selection was done based on the following criteria:</u>

Should be native of the village, has agriculture background in the family, higher secondary school to graduation is educational qualification, preferably having familiarity in working with computers. Preference was given to women in the recruitment.

Profiles of CLIC Operators		
Total number of Operators		15
1	Number of females	8
2	Graduates with sciences background	3
3	Graduates with other background	9
4	Post graduate	1
5	10th Class	2

The message of recruitment of the CLIC operators was passed on through the Gram Panchayats and applications were invited. The interviews were conducted by WASSAN team (to avoid any political influence in the selection).

Appointment letters were issued by the Gram Panchayats with conditionalities. There are two major differences between the processes followed earlier in ACCA and these CLICs in Ranga Reddy district; a) younger people who are not practicing farmers are chosen b) the appointment was by the Gram Panchayats and watershed committee which has a much wider base than the farmers' club.

It is still to be seen whether a practicing farmer or an educated youth in the village (who takes this up as a full-time employment) will serve better the purpose.

Preparation of Training Modules and Organizing Trainings for CLIC Facilitators

After selection of the candidates, WASSAN has organised an induction program for CLIC operators in the Parigi regional office. Training needs assessment was conducted to know the level of skills and knowledge of the operators in Agriculture and their familiarity with computers. Based on the assessment, training modules were prepared for operators in the areas of imparting basic computer operational skills, orientation on agriculture and operational methodology of CLIC.

Computer training program was organised for three days in the Parigi office in Ranga Reddy District. The module is mainly intended to give basic skills of operating a computer, file management, basics of MS-Office, web-browsing and operating the CLIC-Information system. This also included familiarising the participants on hardware. Technical Training program was organized for three days at ACRC of Agriculture University, Hyderabad.

Based on these experiences an ***Training module for the CLIC Operators*** is developed (*Annexure - 1*).

Preparation of Orientation Module and Organizing Orientation Events for Farmers

Keeping priority of Farmer orientation on CLIC's agenda, the following events were facilitated to motivate farmers in the village to use CLIC services.

1) Tom-Tom; announcement in village in the regular system of Gram Panchayat
2) Announcement during school prayers
3) CLIC is an agenda point in Community /SHG meetings
4) Pamphlets distribution
5) House to House campaign; operators were asked to meet each household, explain about CLIC and distribute a pamphlet.

6) Night shows for films on CLIC-information system
7) Farmers orientation in CLIC centre

Small and marginal, rainfed farmers from each village were targeted for all orientation programs. To intimate the news that the CLIC centre is being operated in their village, the tom-tom method was selected where the officially designated person the village goes around announcing the event. CLIC operators also have visited schools and made arrangements to include the CLIC centre as news item in the prayer time. School children are target group who can pass the message to their farmer- parents. In another event the farmer group was oriented in the scheduled meetings of community meetings and Self Help Groups. CLIC operator was assigned to attend the meeting and give brief orientation on the CLICs. WASSAN has published a pamphlet in local language to create awareness on CLIC and to attract the farmers to CLIC centres. Same pamphlets were utilized to educate farmers in a house to house orientation program. CLIC operators have visited every house in the village, interacted with family members, cordially shared their concerns, informed about CLIC services, how they can utilize and come out of farming as well as weather disasters. Operators have also collected some basic data from farmer family which is useful during the sessions at CLIC centres. Night shows with video films have been undergoing in CLIC villages. These shows, as audio visual media, are attracting more number of farmers and thus become prime activity to create orientation on CLICs. During other days, CLIC operators used CLIC centre to educate on climate, forecast, and agro advisories through CLIC software or sometimes by using mike set.

CLIC's Computer and Multimedia Systems Maintenance

Strategically all CLIC centres were set up in the Gram Panchayat offices , except in few villages like Roopkhanpet, Dornalapally, Sultanpoor, Baspally where the GP facility is not accessible for farmers or not favourable for CLIC systems. The following facilities were considered for setting up CLIC centre.

- Individual room with security
- Electricity connection
- Receptivity of internet signal
- Prime location in the village

All the centres were provided with a computer, a large-TV (32"), an UPS, a audio-set with mike, and posters.

Handing over CLIC Centres to Gram Panchayat (GP)

Orientation meetings with GP and Sarpanches: One to one meeting with GP board members and sarpanches was carried out in all villages since 27th June, 2014 onwards.

A one day workshop was organised with Presidents of the Gram Panchayatswas organized on 30th July, 2014 at Parigi office. The agenda was i) Role of GP & sarpanches ii) Services of CLIC iii) Awareness building programs in villages iv) business models v) fund raising vi) monitoring of CLIC vii) handing over of CLICs to GP

This is followed up by WASSAN signing an MOU with the Gram Panchayat for the management and monitoring of CLIC centres. Further GPs have taken declaration from CLIC operators that they will abide by the roles and responsibilities set by GP and WASSAN. All GPs have handed over a possession letter stating that they have received material from WASSAN to manage the CLICs. They also stated that they take sole responsibility for any damage and theft of any material. They protect all materials and assets of

CLIC .It was also agreed that GPs will pay the salaries of operators after the project period. They will work closely with WASSAN for fundraising for post-project maintenance of CLIC.

At present WASSAN has trained 33 CLIC facilitators, recruited 13 operators and three operators have moved out due to various reasons.

Operationalizing CLICs

There are in total 13 new CLIC centres established in two Mandals of Ranga Reddy district and one centre established in Daulatabad Mandal of Mahabubnagar district. These are in addition to the 3 centres established as a part of ACCA program. The CLIC Centres established.

S.No.	Village Name	Mandal
1	Naskal	Parigi
2	Sultanpoor	Parigi
3	Roopkhanpet	Parigi
4	Rangampally	Parigi
5	Chiguralpally	Parigi
6	Gudur	Doma
7	Shivareddypally	Doma
8	Dongayenkeypally	Doma
9	Muthkoor	Doma
10	Doma	Doma
11	Dornalpally	Doma
12	Baspally	Doma
13	Timmareddypalli	Daulatabad (Mahabunagar district)

CLIC operators are assigned to open the CLIC centres both in the morning and evening. The timings of CLIC are set to match with free available time of farmers in the village. The timings are; 7.00 am -9.00 am and 6.00 pm to 8.00 pm.

Regular activities in the CLIC centre are; receiving bulletins from WASSAN through mail and/or SMS, writing on black board in front of the GP, pasting bulletins in major community centres, announcing bulletin through mike set and engaging time with farmers.

Operators maintain following records in the CLIC centre; rainfall data book, farmers log-book, operators' attendance register and diary. Rainfall register contains following data; rainfall (mm), rainy day, rainfall monthly, rainy days monthly, rainfall since June, Rainy days since June. The farmers log book contains; date, farmer name with cell number, time of visit, issues with farmers, knowledge shared by operator, assistance taken from other sources, issues resolved after visit.

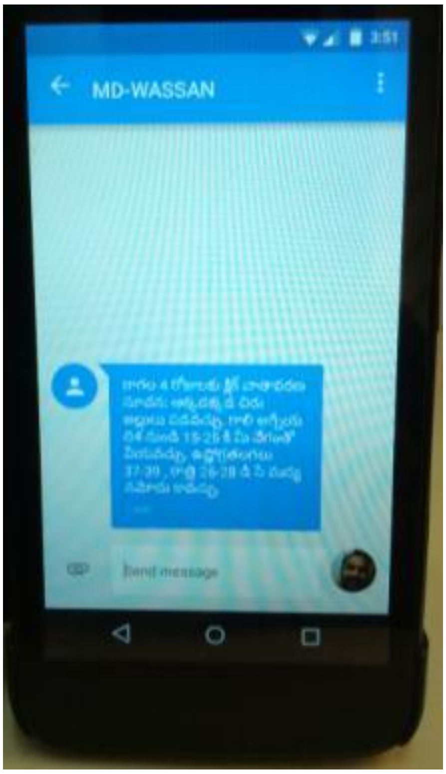
Operator attendance register consist following information; date, morning time , evening time, activities, signature.

Rainfall Visualiser is regularly updated in the CLIC centre both on the computer and on the wall poster. The rainfall visualizer sheet pasted on the wall depicts the cumulative rainfall and the current rainfall.

Usually farmers visit the CLIC centre with issues such as pest problems or diseases; the weather bulletins are heard every day (mike-announcements). Operators browse through pages and arrive at solutions. Sometimes they also refer to the handbook of farmers published by agriculture university (Vyavasaya Panchamgam). In emergency cases they call subject matter specialists in WASSAN.

CLIC Monitoring committee was constituted with the President of the Gram Panchayat as chair and Watershed committee as members. Salaries of CLIC operators are paid after a letter of recommendation reviewing the work of the Operator for the month is submitted by the President. WASSAN release salaries after verifying monthly report of the operator with the President's signature. This is to ensure the CLIC operators accountability towards the Gram Panchayat.

Bulk SMS services to Farmers



Weather forecast bulletins are sent through Tel ugu SMS services to selected farmers having the mobile phones. WASSAN purchased the bulk-SMS services from a firm. The program coordinator sends the SMS after receiving the advisories. This is also to establish a mobile communication with the farmers.

Other Activities of CLICs

CLIC operators are also actively involved in other activities in the village such as Farmer Field Schools (FFSs) on Low Carbon Farming programs, measuring ground water , crop water budgeting and also, have gone through drinking water quality analysis trainings in watershed program

Few reflections from the farmers' visit to CLICs
• Mr. Elchaali Chandriah from Rangampally village has visited CLIC several times who has asked about new generation pesticides with commercial names. CLIC discourages recommendation of any commercial brands of pesticides and fertilizers or other inputs. We provides only technical names of agro inputs .
• Mr. K. Bhaskar Reddy from Rangampally village is interested in seed production activity. Considering his demand WASSAN has initiated module on seed production.
• Many farmers complain that they are not able to receive bulletins as CLIC centre is located at the outskirts of the village that they are in. They requested to shift it to prime locality of the village.
• Mr. Gunjari Narsimhulu from Naskal village has viewed machines in CLIC centre. Now he would like to get some useful machines from govt. Sources.

• Mr. Kanne Kishtiah from Naskal village is interested in daily weather bulletins. Due to technical problems in his mobile he unable to get forecast through SMS.
• Mr.Dastiah from Naskal village is not happy with loud speaker which is not covering entire village. He want see one or two loud speakers in other parts of the village.
• Mr. Sampali Venkatiah from Muthkoor village has requested to supply seed that are shown on CLIC site.
• Mr. Mantri Chandriah from Baspally village has visited CLIC centre, after watching videos on CLIC he requested to supply pesticides and fertilizers to farmers. Their main concern non-availability of inputs in the village.
• Mr. AnanthaReddy from Shivareddypally would like to take up own seed production activity.
• Mr. Pandariah from Shivareddypally village would like run custom hiring centre.
• Mr.Venkat Reddy from Gudur village has requested to add more crops to the CLIC software, particularly Turmeric. WASSAN has considered this request , stated adding more crops to the site.
• Mr. A. NarayanReddy from Gudur village has visited CLIC centre several times, started referring agriculture handbook for clarification on pests and diseases.

<u>The following are the most frequently asked questions by farmers when they visit CLICs:</u>

- Pests of paddy
- Seeds of Cotton
- Pesticides of Cotton
- Diseases of cattle
- Machines useful for their crops, availability, price , subsidy , eligibility
- Possibility of vegetable cultivation in the village

Non-availability of the pesticides recommended in CLIC-modules (taken from the recommendations of the Agriculture University) is pointed out frequently as an issue. This is arising because of newer chemicals/ formulations in the market which are not updated in the university's literature.

Monthly Review Meetings of CLIC Operators

These meetings are organised centrally to review the work of the previous months. The action points / reflections are taken up into planning for the next month. The monthly meetings are minuted and the records are available with WASSAN.

External Fund Raising and Strategies for Sustenance

Finding avenues for sustaining CLICs post-project is one of the major concerns.

WASSAN team along with sarpanch representatives has met the district collector for the continuity of CLIC centres. Sarpanches have requested to link with government programs and manage the CLIC centres with government funds. The district Collector has gone through the CLIC modules and impressed by its applications. AS he suggested we have met the Joint Director of Agriculture, the Dist Panchayath Officer, the director DWMA for integration of their schemes and activities. This did not go any further.
Another avenue is to raise funds through Corporate Social Responsibility. This is now being attempted. The potential for integrating CLICs with upcoming E-panchayatin Telangana state is also one avenue for sustainability. Efforts are being made by WASSAN to scale up CLIC centres in other watershed districts funded by NABARD.

It is becoming clear from the experience that CLIC can't sustain on its own as the climate information is now provided through multiple sources, including CLICs; payment for such services will not come by. The learning and popular demand is to integrate business with CLICs. Farmers from Naskal village are taken to Daulatabad Mandal where WASSAN integrated business with CLICs. WASSAN is attempting at promoting farmers producer organisations in the watershed villages and federate them. This is an attempt for the watersheds to move into post-project phase and into business. This is one perceived pathway for CLICs' integration with business and sustainability.

A poster on Sowing Rule has been developed and distributed widely across the state. This poster was released by Dr. M.S. Swaminathan, Executive Director (MSSRF) and Dr. Ayyappan, Director (ICAR) in a high-profile meeting of ICAR.

Annexure - 1: CLIC Training Module

Developed by WASSAN

With inputs from LNRMI, PJTSAU and CSIRO

Supported by ACIAR

Developing Multiscale Climate Change Adaptation Strategies for Farming Communities in Cambodia, Lao PDR, Bangladesh and India

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Training Module for CLIC Facilitators

About the Module:

The 3 days basic training module is meant for the trainers training CLIC facilitators. It orients them on the topics - Agromet Advisories, rainfall measurement, rainfall visualization, understanding of sowing rules and critical irrigation.

The module also orients the operators on navigating the CLIC information system, ways of narrowing down to specific information required for farmers who visit the Center and teaches them the basic protocols of interfacing with and entertaining farmers when they visit the CLIC.

Prerequisites:

The CLIC operators must have gone through Module-1 which is basic training on computers. They must also have working knowledge of web-browsing and operating videos and reasonably fast on computer typing. This is normally done by sending the CLIC facilitators to a standard computer orientation course.

The participants must have basic familiarity with English language – at least able to read and comprehend very simple words and sentences in computer.

Training Module on Climate Information Centres (CLICs)

Participants: Selected Facilitators for CLIC centres

- **Climate Information Center:** The concept of CLIC evolved in the ACCA project supported by ACIAR. The center essentially receives the agromet advisories, adds value in terms of local measurements of rainfall and in preparing a 'rainfall visualiser' for on-season tracking of the actual rainfall vis-à-vis the previous years and the forecasts.

  While the agromet advisories provide forecasts of pests and diseases and advises on the operations, CLIC helps farmers to be better prepared by providing required knowledge through the CLIC information system. All required information is expected to be available to farmers through CLICs in local language and in the form of visuals and videos to the extent possible.

- **CLIC Facilitators:** Each CLIC is managed by a facilitator chosen by the Gram Panchayat. These people will be available in the CLICs in the morning and in the evening times to meet and explain to the farmers who visit them. They also are responsible for local rainfall measurement.

- **Training module:** This module attempts to improve knowledge, skills and attitude of the facilitators operating CLICs.

  - ✓ **Improves Knowledge on:** Basic understanding of climate variability, its impact on agriculture, forecasts, agro-met advisories, and functionality of the Center. It provides an overview and appreciation of different modules, importance of the themes to farmers and other such understanding.
  - ✓ **Enhances *skills*** in rainfall measurement, preparing the rainfall-visualiser, inputting the data from advisories into CLIC software, navigating and retrieving the information as quickly as possible, analyse, understand and share the information with farmers/users and visitors.

- ✓ ***Develop better attitude*** towards their role and appreciate farmers approaching the Center, encourage farmers to better use the resource and be accessible to the farmers, be patient and friendly and cordial.

- **Objectives**: By the end of the training programme the CLIC facilitators would be able to
  - ✓ Explain climate variability (at the on-set of monsoons, mid and late season drought spells) and their potential impact in agriculture
  - ✓ Appreciate the need for and the purpose of Climate Information Centers (CLICs)
    - a. List the functions and services of CLIC
    - b. Explain the process of functioning of CLIC including institutional system
  - ✓ Explain the role of CLIC facilitator
    - c. Read, analyse, understand, prepare and explain agro-met advisories and weather data.
    - d. Taking local rainfall measurement and maintaining the database
    - e. Explain the basic features of software and hardware part in CLIC
    - f. Analyse and explain rainfall visualizer
  - ✓ Understand and explain the Agro-met Advisories.
  - ✓ Familiar with the CLICs software and have navigation skills to seek information from the CLICs information system.
    - g. Understand the farmers requirement / questions / purpose well
    - h. Able to navigate the CLIC software to retrieve information quickly
    - i. Maintain good rapport with other stakeholders in the process
  - ✓ To be able to explain the basic rules/ practices of managing climate variability with respect to the important crops in the area with a focus on :

Session- 1: Introducing the Learning Program

Registration, Introduction, Pretest and objectives of the training, introducing the schedule to participants

- ✓ **Duration:** 1 hour 30 min
- ✓ **Objectives:** By the end of the session the participants know each other and would be able to explain objectives of the training program. And, the trainer is able to understand the basic skill levels of the participants relevant to the subject.
- ✓ **Tools required**: none
- ✓ **Resource Materials for display/Use by Facilitator/Resource Person:** List of objectives written on the chart& the broad schedule of the program
- ✓ **Resource Material to distribute:** Schedule of the program (Annexure 1)
- ✓ **Methodology:** Each objective carries a different methodology

1) **Registration of the participants:** collect basic details of the participants. Let the participants feel that they are welcome to the training programme. Include the columns the data on i) if they are involving in agriculture operations at home ii)

2) **Introduction & Ice breaking:** Use participatory games for the purpose; the purpose is to make the participant comfortable, mix with others and be in a learning environment.

3) Introduce the training management team and the procedures (facilities, logistics documentation etc.)

4) **Pre-Test:** The purpose is to assess the basic understanding of the participants on the theme. Use the Pre-Test Form in Annexure 2 for the purpose. The Pre-Test form has three components to provide an assessment of the participants level with respect to i) skill levels with computers ii) familiarity with agriculture iii) understanding of weather. This helps in evaluation of the effectiveness of the program and also, of the base level of the participants.

5) **Objectives of the training programme:**

   a. **Objectives:** Start with compiling participants' expectations of the program using flash cards and present the objectives of the training program with any modifications, if necessary. (see Page 1 for objectives.

b. **Introduce the schedule:** Draft schedule is enclosed at Annexure-1. Give this as a hand out after making any changes.

Note: It is very important to introduce the resource person to the participants before start of the session. Give the brief note of the credentials of the resource person.

- ✓ **Learning outcome:** Trainers will understand the existing knowledge on climate, weather bulletins, local agriculture practices and identification of pests and diseases.

Session- 2: Basics of Weather, Rainfall Measurement and Rainfall Visualizer

- ✓ **Duration :** 1 hour 30 min

- ✓ **Objectives:** By the end of the session the participants would be able to

1. Measure rainfall and understand about temperature, wind speeds (those mentioned in the weather forecasting) and understand their units of measurement.
2. Prepare daily rainfall and cumulative rainfall graphs.
3. Identify drought spells and their duration
4. Explain rainfall visualiser

- ✓ **Resource Material required:** rain gauge, flat tray whose area is measurable, one liter water bottle, Daily rainfall data of 4 years of any location, graph papers and pencils and Rainfall visualizer chart

- ✓ **Handouts:** on installing and using rain-gauge - A two page note on rainfall, rainfall visualizer and drought spells.

- ✓ **Method:** Explanation and Practice session – hands-on measurement of rainfall and preparation of graphs from the sample data.

- ✓ **Methodology& Content:**

Measurements:

1. Introduce measurements of water (liter, cu.m, cu.ft, acre-ft, ha-m). Take a flat tray whose area is measureable (square / rectangle). Pour a liter of water in it and measure the depth. Ask them to measure the depth of water. Show the calculations. Repeat the experiment with half liter of water. Relate these measurements to the areas and volume (ha.m or ac.ft).

It is important that the CLIC facilitators have good knowledge of water and rainfall as these are required at any places (in rainfall measurement, irrigation measurements etc.).

Using Rain-gauge:

2. Demonstrate usage of rain-gauze with precautions of places where it should be set up and where it should not. Show some photographs of existing rain-gauze stations.

3. Give the hand out and make them read the do's and don'ts of installation and measurement of rainfall.

Preparation of Graphs:

This is to be done in groups of 3 persons; it helps them to support each other in their learning.

4. Give the daily rainfall data sheet
5. Ask them to calculate the cumulative rainfall in the rainfall data sheet
6. Give the participants graph sheets.
7. Explain what is a line graph and what is a bar-graph, scale and plotting on a graph.
8. Ask them to plot the daily rainfall (bar graph) and cumulative rainfall (line graph) on the graph sheets.
9. After completion of the exercise, make corrections

Identifying Drought Spells:

1. Relate the cumulative rainfall graph with the daily rainfall graph
2. Initiate discussion around the key question : what is the difference between flat cumulative rainfall graph and flat stretches of the curve? Generate discussion and explain the concept of drought spells and their lengths.
3. Generate discussion around implications of the drought spells.

Key points for Re-cap &Summarizing the session:

1. Rainfall measurements (mm, cm) and volume measurements
2. Measuring rainfall using rain-gauge
3. Key points in preparing the daily and cumulative rainfall graphs.
4. Summarize the discussion around drought spells.

Session- 3: Familiarize with Agro-met Advisories

- ✓ **Duration:** 3 hours
- ✓ **Objectives:** The participants are able to explain the agro-met advisories and are aware of the process / source of its preparation.
- ✓ **Resource Material required:** Copies of the Agro-met Advisory, weather forecast pages in news papers
- ✓ **Handouts:** copies of the posters
- ✓ **Method:** Invited lecture and group discussion
- ✓ **Methodology & Content:**

1. **Group discussion:** give the weather forecast page in the news papers and ask the participants to quickly brainstorm with 3 other persons around on what is weather forecasting and how it is made. This is for getting them prepared to receive the information.

2. **Invited Lecture:**

   a. Invite a scientist from ACRC (PJTSAU) for a guest lecture. The following topics are to be covered at a basic / introductory level :

      i. Explain the terms, Climate, Weather, Monsoons, rainfall
      ii. Explain about Indian Monsoon system.
      iii. Brief on weather forecasts and the institutional system (introduce IMD).
      iv. Explain what is weather forecasting with an emphasis on the probability-nature of such forecasts.
      v. Introduce the forecast levels (that at present the forecasts are available at only district level).
      vi. Explain the differences between the weather forecasts in TV / News papers and those in the Agro-met Advisories.

      … open discussion and Break …

   b. 2nd part of the invited lecture (ACRC, PJTSAU) deals with the Agro-Met advisories.

      i. Explain about pest lifecycles and their relation to climatic conditions with an example.

ii. Explain about the system of preparation of Agro-Met advisories (who, how, frequency, levels etc.).
iii. Emphasis in this lecture must be on the life cycles of pests and diseases and their relation with weather.

3. **Group Discussion on Agro-met Advisories:** Participants are formed into groups and each one is given one agro-met advisory (preferably of different seasons). The task for the group is to clearly explain all aspects of the agro-met advisory. The trainer (preferably along with the resource person from ACRC) will provide any clarifications required. Emphasis must be on understanding the probability nature of the forecast and advisory and that the level at which they are prepared.

4. **Role-Play:** Invite 3 volunteers from the participants to play the role of CLIC facilitators; rest of them will enact as farmers. Let each volunteer take an advisory and explain it to the group of farmers. Trainer must carefully look at the interpretation and the correctness of messages.

5. **Give the handout** – a copy of the agro-advisory to each of the participants.

6. Summarise the session and provide the contact details of ACRC, introduce their website and also IMD website. This is also a good occasion for the CLIC facilitators to get introduced to the invited guest from ACRC.

Key points for Re-cap &Summarizing the session:

1. The process of weather forecasts and the institutions involved
2. The probability nature of the weather forecasts
3. The nature of agro-met advisories and pest forecasts & control measures need to be clubbed with local observations and knowledge.

Session- 4: How to Use Agro-Met Advisories?

- ✓ **Duration:** 2 hours
- ✓ **Objectives:** After this session the CLIC facilitators will be able to explain the use of agromet advisories and safe sowing rules
- ✓ **Resource Material required:** ACCA Posters, Safe Sowing Rule poster

- ✓ **Handouts:** ACCA Posters, Safe Sowing Rule poster – A4 size hand-out.

- ✓ **Method:** Group work

- ✓ **Methodology & Content:**

1. Group work on usage of agro-met advisories

    Key Question: What are the different ways in which we can use the weather forecasting and agro-met advisories?
    Let there be discussion in groups and presentation of the conclusions.

    Facilitate the following conclusions:
    - Scheduling input application (seed, fertilisers and pesticides)
    - Determine the sowing and harvesting time
    - Take measures in pest and disease control
    - Any others that the participants may come up with.

2. Group discussion on risks in sowing and arriving at safe sowing rule:

    Key Questions:

    - When do farmers sow seed? What are the measures they use to take the decision on sowing?
    - What are the risks and losses involved at the sowing time? Let the participants also assess the investment farmer looses if s/he has to do repeat sowing.

    If the participants are from farming background, the discussion will be rich. If not, find out the persons from within the participants as key respondents and form groups around them.

    After initial discussion give them the poster on safe-sowing rule. Ask them to brainstorm again and present their conclusions. Then explain the usage of rainfall visualizer to identify the cumulative rainfall for safe-sowing.

Key points for Recap and Summary of the Session:

- The two parts in the agro-met bulletin are a) weather forecasts and b) forecast and recommendations on probable pests and diseases.

- The weather forests are used for scheduling input use (fertilizer and pest control) and in determining sowing and harvesting times.

- Emphasise on the safe-sowing rule;

    - Farmer must wait till the soil has adequate moisture for seed germination and establishment.
    - Best is for farmer to wait till the cumulative rainfall in the last consecutive 7 days (week) 50 to 75 mm which will be announced by the CLIC center.

Session- 5: Communicating the Agro-Advisories

- ✓ **Duration:** 2 hours

- ✓ **Objectives:** After this session the CLIC facilitators will be able to know her/his responsibilities and methods of ensuring that the information in the agro-advisories reach all the farmers.

- ✓ **Resource Material required:** Sample agro-advisories.

- ✓ **Handouts:** ACCA Brochure.

- ✓ **Method:** Organise the participants into cafeteria type of sitting. Let participants be there in groups and facilitate the session. Conclusions from each set of key questions for the group becomes input for the next task.

- ✓ **Methodology & Content:**

1. Group brainstorming and listing and evaluating the methods:
    a. **Question 1: List Methods:** In this brainstorming exercise, the group task is to list various ways of communicating the weather forecasts to farmers (with particular emphasis on reaching out to Schedule Caste farmers and women, illiterate/ and farmers in distant hamlets).
    b. **Question 2: Assess Methods:** Once the listing of strategies is complete, ask the groups to work on positives and negatives of each option and priority rank each option from the point of view of reaching out to the marginal groups.
    c. **Question 3: What is needed and how to operationalize each method?**
    Discuss do's and don'ts of each method.

Key points for Re-cap &Summarizing the session:

a. Consolidate the group's listing and assessment of the methods at one place. List the methods from the experiences of ACCA program:

    i. Pasting of copies of the advisories in key centres
    ii. Announcing in the mike-set
    iii. Board displayed at the CLIC center
    iv. It is important that there is discussion among the farmers on the forecasts. Forecast messages need to be linked to sowing rules, risk in input application etc.

Session- 6: Basic CLIC Operation: Protocols, Operations and Management

- ✓ **Duration:** 1 hour 30 min.

- ✓ **Objectives:** The CLIC facilitators will be able to list the normal routine operations at CLIC, records to maintain, finances and procedures, equipment maintenance and other functions. They would learn on basic protocols during their interaction with farmers.

- ✓ **Resource Material required:** Sample records to be maintained, list of inventory

- ✓ **Handouts:** nil

- ✓ **Method:** Role Play and group discussions

- ✓ **Methodology & Content:**

1. In a plenary discussion – interactively list the basic infrastructure that a CLIC must have. These will be :

    a. A computer with a large monitor (TV)
    b. UPS and power stabilizer
    c. Rainfall visualizer chart – displayed and marker pen of different colors.
    d. Posters displayed (ACCA poster set).
    e. Chairs / bench for farmers to sit and interact.
    f. Drinking water
    g. A Black board displayed outside even when the CLIC is closed – for sharing weather forecasts.
    h. A shelf to keep records/ files.
    i. Agro-advisory prints – file.

2. Brain-storm on seating arrangement: The following key points may be stressed:

    a. It is useful for the computer to face the wall so that all can see the navigation in the computer. This also frees up some space in the room.
    b. The TV must be wall mounted with at least space for 5 chairs laid before it at a convenient distance to watch. Top height of the TV must be fixed in a way convenient for 3 to 5 persons viewing.
    c. Rainfall visualizer must be pasted on the wall at a place convenient for a group of farmers to sit before it an brainstorm.

3. CLIC routine:

    a. Use Role-Play method. Divide the participants into groups and ask them to play a skit on the daily routine of a CLIC operator. While reflecting on the enactment focus on the following points:

        i. Time of opening and closing; these times must be displayed outside and must be strictly adhered to.
        ii. First the facilitator visits rain gauge every day in the morning and checks if it is ok and if there is some rainfall takes measurement & records that into a rain-gauge register.
        iii. Receives the advisory hard copy or by mail, enter that into the CLIC module in the computer, and updates the Rainfall Visualiser.
        iv. Updates the rainfall visualizer with the current data.
        v. At a fixed designated time, announces the climate forecast in the mike.
        vi. Updates the display board.
        vii. Skits also include how the CLIC operator receives a farmer, makes her/him comfortable to sit, listens to her carefully to identify the purpose and background of the visit and what the person wants; update the visit detail in the visit register etc..

Key points for Re-cap &Summarizing the session:

Session- 7: Providing Services to Farmers

- ✓ **Duration:** 45 Minutes
- ✓ **Objectives:** The CLIC facilitator will be able to receive a farmer, fills the details in a register, understand the question/ purpose of the visit and navigates to an appropriate location in the CLIC module for information.

- ✓ **Resource Material required:** CLIC software& computers; the CLIC facilitator is familiar with CLIC modules and navigation. Flash cards with frequently asked questions (by farmers) –written on flash cards

- ✓ **Handouts:** nil

- ✓ **Method:** Role Play

- ✓ **Methodology & Content:**

1. Make participants into groups. Each group has to do a role play.
2. Give the questions on flash cards to each group and they have to do a skit on each of them. Based on the interaction from the skits derive the navigation steps
3. Observe whether they followed the protocols, curtsies and navigation steps.

Key points for Re-cap &Summarizing the session:

1. The facilitator must understand the question from the farmer and pay adequate attention to it.
2. Based on the question decide on the crop and the nature of the crop – choose the navigation to the page where information is available.
3. Observe how they provide the information to the farmer:
   a. Must avoid his/her own solutions.
   b. Must read the material and explain
   c. Show the photographs and play the video.
   d. If there is any question or if the information is not adequate – must contact the Toll Free Number of the Kisan Call Center and ask.
4. Emphasise on the facilitator not providing any solution by her/ his own.

Session- 8: Understanding the CLIC modules and navigation

- ✓ **Time Duration:** 1 hr

- ✓ This session is taken up in a computer lab or with adequate numbers of computers available i.e. at least one for 3 members. It assumes prior training in basics of computers. The following steps may be followed :

Session 1 :

1. Introduce the opening up of the software CLIC
2. Trouble shooting on opening / closing of the XAMPP server

3. Explain organization of the software and different forms of navigation.
4. How to navigate the text, show pictures and videos.
   At this point, leave the participants to navigate and browse/ explore the software.

Session 2 :

1. Take the flash cards with questions.
2. Introduce the question and show how to navigate to the relevant page .
3. After 4 such questions are dealt with..give an exercise 3 questions for each of the participant group (3 member group) and ask them to go to the relevant page and do a role play of explaining to a farmer.

There must be an intensive advanced course for the CLIC facilitators on introducing various aspects of agriculture and agriculture technology.

Session- 9: Evaluation and Post Training Test

- ✓ **Time duration:** 45 Minutes
- ✓ **Objectives:** By the end of the session the participants would be able to

1) Reflect upon the learning process during this training programme
2) Give feedback for improvements, share their opinions
3) Assess/Evaluate their knowledge by writing the test

- ✓ **Tools required**:

1) Evaluation/feedback formats
2) Post training test questionnaire

- ✓ **Resource Materials for display/Use by Facilitator/Resource Person:** Nil
- ✓ **Resource Material to distribute:** Nil
- ✓ **Methodology:** Reflections on two days training by participants, filling evaluation/ feedback format and writing post training test
- ✓ **Learning outcome:** Training organizers will be able to understand the impact of training sessions they have organized, so that they plan further trainings considering outcome of the results.

Annexure - 2: Training Program on CLIC to CLIC Operators

Date: **Venue:**

Time	Session	Facilitators
DAY - 1		
9.30 – 11.00	1. Introducing the learning program : *Registration, Introduction, Pretest and objectives of the training, introducing the schedule*	
	Break	
11.00 to 13.30	2. Basics of weather, rainfall measurement and rainfall visualizer	
	Lunch	
14.30 to 17.30	3. Familiarising with agro-met advisories	
	Summary of the day	
DAY - 2		
09.30 to 11.30	4. How to use Agro-met Advisories (with break in between)	
11.30 to 1.30	5. Communicating the Agro-Advisories	
1.30 – 2.30	Lunch Break	
2.30 to 4.00	6. Basics of CLIC Operation: Protocols, operation and management	
4.00 – 4.15	Tea Break	
4.15 – 5.00	7. Providing Services to Farmers	
DAY - 3		
9.30 – 10.30	Recap	
10.30 – 11.30	8. Understanding the CLIC modules and navigation	
11.30 – 11.45	Tea Break	
11.45 – 12.30	9. Evaluation and Post training Test	
12.30 – 1.00	Concluding and valedictory session	
1.00 – 2.00	Lunch Break	

Annexure - 3: Pre - Training Assessment of Trainees

Write the answer briefly with one or two sentences in English or Telugu.

I) Skill levels with computers:

1. Type a paragraph in today's news paper in MS-Word and Notepad and save the files
2. Prepare a small table with names of 5 persons in MS-Excel, their age, education and village and save the file in My Documents
3. What are the computer parts that you know?
4. List MS-Office applications that you have learned

II) Familiarity with agriculture:

1. Write about your family agriculture background
2. What are major dry land crops of your village?
3. List important pests and diseases of paddy
4. What are essential inputs for agriculture?
5. Write are the agriculture machines and tools that are used in your village?

III) Understanding of weather and CLIC:

1. What is weather forecasting? Where do you see these?
2. How does weather affect agriculture?
3. What is CLIC? How is it useful to the farmers?
4. What do you think is the role of CLIC facilitator?

Annexure - 4: Post - Training Assessment of Trainees

Write the answer briefly within one paragraph in English or Telugu

1. How rainfall is measured write the name of instrument and units?
2. What are upper most and lower most lines in the rainfall visualizers. How visualize is useful for rainfed farmer?
3. Write the agriculture categories listed in agro-advisory
4. Write about sowing rules, what is safest rainfall to sow?
5. How you receive agro-advisory from University , what are ways and means of passing advisory bulletin?
6. What are essential electronics, peripherals and furniture to run CLIC centre in your village?
7. Describe the installation procedure for CLIC-Information System?
8. What are modules available on CLIC site? Write any 5 important pests and disease seen on CLIC site
9. Describe facilities available on each slide of module, what are advantages of slide system?
10. How CLIC centre is relevant to your village? Justify your services.

Appendix 7 – Brown 2015: A review of ICT – Part 1

A review of ICT Agriculture Initiatives in Cambodia

Stuart Brown, CamAg Consulting

Unpublished report.

Part 1: A review of ICT Agriculture Initiatives in Cambodia

For CSIRO

CamAg Consulting April 30, 2015

PREFACE

This report was prepared by CamAg Consulting. Author of the report is Mr Stuart Brown (stuart.brown@camagconsulting.com). The views expressed are those of the consultant in accordance with the objectives of the research as per the scope of work defined by CSIRO.

CamAg Consulting cannot be held liable for the recommendations arising from this report.

April 2015

CAM AG CONSULTING

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ABBREVIATIONS AND ACRONYMS

ACCA	Adaption to Climate Change in Asia (ACIAR Project LWR/2008/019)
ACIAR	Australian Centre for International Agriculture Research
ADB	Asia Development Bank
ASPIRE	Agriculture Services Programme for Innovation, Resilience and Extension
ATSA	Agriculture Technology Services Association
CAMIP	Cambodian Agriculture Market Information Project
CAMIS	Cambodian Agriculture Market Information System
CAVAC	Cambodia Agriculture Value Chain Program
CBIT	Centre for Biological Information Technology
CEW	Commune Extension Workers
CIDA	Canadian International Development Agency
DFID	Department for International Development
FAO	Food and Agriculture Organisation (of the United Nations)
FBA	Farm Business Advisor
GDA	General Directorate of Agriculture
GISB	Grameen-Intel Social Business
GIZ	Gesellschaft für Internationale Zusammenarbeit GmbH
GTZ	Gesellschaft für Technische Zusammenarbeit
ICT	Information Communications Technology
IFAD	International Fund for Agricultural Development
iREACH	Informatics for Rural Empowerment and Community Health
IRRI	International Rice Research Institute
IVT	Interactive Voice Technology
MAFF	Ministry of Agriculture, Forestry and Fisheries
M&E	Monitoring and Evaluation
MST	Mobile Support Team
NGO	Non-Government Organizations
NiDA	National Information and Communication Technology Development Authority
PADEE	Project for Agricultural Development and Economic Empowerment
PSU	Project Support Unit
QDPI	Queensland Department of Primary Industries
RAPID	Rice Pest and Disease Identification Tool
RGC	Royal Government of Cambodia
SoFT	Selection of Forages for the Tropics (ACIAR Project AS2/2001/029)
SMS	Short Message Services
SNV	Netherlands Development Organisation
TC	Telecenters or Information Centers
TSSDP	Tonle Sap Smallholder Development Project
TSTD	Tonle Sap Technology Demonstrations for Productivity Enhancement Project
UQ	University of Queensland

1. INTRODUCTION

1. A series of interviews and reviews of documents were undertaken to assess the past and present ICT agriculture related projects and initiatives in Cambodia. These initiatives have ranged from products, packages and initiatives focussed on specific agricultural topics such as rice pest and diseases, tropical forages through to broader initiatives which are aimed at facilitating greater access to agricultural information by the rural sector in Cambodia.
2. Somewhat surprisingly there have been only a limited number of active initiatives that are operational and have been considered a "success". Some initiatives are still in development and any indicators of success are still to be determined. There are some important lessons to be learned from the implementation of ICT agriculture initiatives in Cambodia. These will be illustrated through the examination of 7 initiatives which have ICT agriculture as a focus or as a sub-component to a wider program of extension delivery.
3. This report has a threefold objective (1) to gain an understanding of the array of ICT agriculture projects past and present; (2) to learn and reflect on the lessons of successes and failures of some of these initiatives; and (3) to identify possible collaboration opportunities with current initiatives.
4. In the formulation of this report, discussions were held early with Dr Robert Fitzgerald[6], formerly involved in two ACIAR projects in Cambodia with an ICT agriculture research focus. Dr Fitzgerald is internationally recognised for his research and development work in computer-based learning, social media, ICT for rural development and mobile learning. Dr Fitzgerald provided insights into the constraints associated with ICT agriculture initiatives in a developing country such as literacy levels, language and cultural barriers to the adoption of technology and methods for providing culturally appropriate ICT based extension support for rural beneficiaries.
5. A major research issue yet to be fully tapped and understood is the effectiveness of ICT based tools as a means to provide effective extension of information to those that need it most. The rural poor often involved in agricultural production at a basic level with limited access to specific and relevant information. Dr Fitzgerald claims there is still a vast divide between ICT tools and/or Apps and relevant data sources.

[6] *Professor & Director, INSPIRE, University of Canberra, robert.Fitzgerald@canberra.edu.au*

1.1 UNDERLYING CONSTRAINTS AND OPPORTUNITIES FOR ICT AGRICULTURE IN CAMBODIA

6. In the recent past ICT agriculture was constrained by the limited availability and knowledge of computer based solutions in the Khmer language. Cambodian users unfamiliar with the Khmer keyboard on PCs have often found the navigation somewhat cumbersome to use effectively without extensive practice and long term usage. The use of the Khmer script on mobile devices is in its infancy and anecdotally the author has been advised that it requires a certain degree of knowledge and practice to comfortably use the Khmer script effectively.
7. While this is not a major constraint in the long term, which can be overcome through greater use of the Khmer keyboard, it is still a significant constraint in the short to medium term in rural communities where levels of literacy are still quite low. This however is changing and is more contained to the older generations with the younger generations displaying a higher level of both reading and writing in Khmer and computer and mobile device literacy.
8. The use of mobile phones and other mobile devices has increased rapidly in Cambodia in the last few years. Research by the Asia Foundation[7] suggests nearly 94% of Cambodian adults claim to own their own phone with more than 99% reachable through some device. Results of the survey indicate that over 50% of Cambodians are capable of communicating in Khmer script with the urban educated more commonly able to use Khmer script than rural people.
9. In terms of phone capabilities, over 28% of phones in Cambodia are smartphones with richer display and content capabilities and often with access to the Internet. The suggestion by the study is that there is now a critical mass of devices with Khmer script capabilities to facilitate communication in Khmer. This is now potentially an important opportunity for the use of mobile devices for the communication of agricultural extension information to rural people as the level of literacy, use of the Khmer script and smartphones increases further.

[7] *Kimchhoy Phong and Javier Solá, 'Mobile Phones in Cambodia 2014', Asia Foundation, October 2014, available online http://asiafoundation.org/publications/pdf/1435*

2. ICT AGRICULTURE PROJECTS IN CAMBODIA – A REVIEW

2.1 RAPID – RICE PEST AND DISEASE IDENTIFICATION TOOL FUNDED BY CAVAC

10. The Rice Appraisal Pest Identification Tool known as RAPID arose out of a call for proposals from CAVAC in 2013 to develop a sophisticated rice pest and disease identification tool for private sector partnership.
11. In a collaboration between the University of Queensland, Agriculture Technology Services Association (ATSA) and CamAg Consulting, a tool was developed as a standalone application for the PC, as a server side tool accessed over the Internet and as a downloadable application for Android based smartphones and tablets. CAVACs main purpose for the tool was to build the capacity of private sector input supply companies in order to provide a correct identification of common pest and diseases in the rice sector.
12. A private sector approach was taken by CAVAC in order to ensure the product has a degree of sustainability over the long term. Often the problem with large sophisticated ICT products with a public good associated with it is that once the funding ends there is little ownership of the tool to ensure it gets the appropriate updates and renewal.
13. The approach by CAVAC has been to work closely with up to eight companies involved in the supply and delivery of inputs for the rice sector. Predominantly the profile of these companies are suppliers of plant protection products, largely in the rice production sector. The companies activities include the provision of extension advice regarding the protection of rice crops for small to medium sized farmers in the major rice production provinces in south east Cambodia such as, but not exclusively, Kandal, Takeo, Prey Veang, Svay Rieng and Kampot.
14. RAPID was developed using software created by CBIT at UQ, which has subsequently evolved into a private company called IDENTIC. This software includes Lucid™, which is a platform for the development of identification products ranging from insects to plants, and even medical conditions. If a particular set of species, or objects can be described by an identifiable set of characteristics, known as features, then it can be arranged within the Lucid™ platform as a standalone IT product available on multiple platforms.
15. Currently there are well over 300 individual Lucid™ based applications that have been developed around the world in multiple languages. Lucid™ products can be delivered as a server based tool available as an embedded component in a website, a stand-alone product as an application on a PC through the JAVA runtime environment, and as a mobile application for both phones and tablets in both the Apple iStore format and through the Google Android format on the Google Play Store. The wide variety of player platforms across multiple operating systems allows for a large audience of users without having to subscribe to one particular device platform.

16. Each company with access to RAPID has been given a licence to modify and develop further the product. Each company can modify fact sheets for each pest and disease and provide information specific to their company and suite of chemical or biological products. The actual pest and disease identification tool can also be modified if required.
17. The identification tool was initially based on the existing IRRI rice pest/disease identification tool and modified for Cambodia by adding relevant pests not otherwise accounted for in the larger IRRI tool. Many nutrient deficiencies were removed that were of little relevance in Cambodia's predominantly acid soil growing conditions. Local images were sourced as much as possible to ensure there was a high relevance and recognition rate for users and farmers.
18. The App version of the tool places priority on the display of images to describe the characteristics of the pest and/or disease. While all operators within the companies have a high literacy rate, the tool is often best used in conjunction with a farmer who will have their own verbal description of the crop affliction. It is incumbent on the trained user of RAPID to often interpret what the farmer is describing in order to correctly operate the tool.
19. RAPID is designed in such a way that the user is guided through the identification by commencing the process according to the stages of the crop development. For example the first question asks the user at which stage of development is the rice crop: vegetative, reproductive or grain ripening. Upon selection, the user will be guided to other questions directly related to issues within this stage of the crop, rather than having to assess all the options across the three stages.
20. Internal reviews by CAVAC and private comments by Mr Pieter Ypma, Agribusiness and Information Systems Manager at CAVAC responsible for managing the project, indicate the level of use within the first company to take on the identification tool is high. Reviews done with local call centre companies has also shown a high correct identification rate with trained call centre operators, with the average rate of correct identification over 65%. In the absence of farmers being able to observe the pictures of symptoms and pest and disease reference images to compare to their own field problem, the identification rate by call centre operators is good.
21. Key informants:
    a. Mr Stuart Brown, CamAg Consulting – stuart.brown@camagconsulting.com
    b. Mr Pieter Ypma, Agribusiness and Information Systems Manager, CAVAC pieterypma@cavackh.org
    c. Mr Matthew Taylor, Chief Executive Officer, Identic Pty Ltd, matt@identic.com.au
22. Key takeaway messages:
    a. CAVAC has strong links to the private sector, which encourages ownership of RAPID within each organisation. This is a strong signal for the future maintenance and continued usage of the tool. This might be a sustainable

way to ensure updates to the science continues and the tool maintains its relevance.

b. RAPID addresses a real problem in the rice production sector, that being the management and control of pest and diseases through the use of a sophisticated yet easy to use identification tool incorporating clear images and the Khmer language. It has direct relevance to a significant problem. The climate adaptation research at the focus of this scoping study also has direct and immediate relevance. However, it must answer the question of long term maintenance and "upgrades" to the science if it is to remain relevant.

2.2 EPADEE – THE ICT COMPONENT TO THE PADEE PROJECT

23. The Ministry of Agriculture Forestry and Fisheries (MAFF) of the Kingdom of Cambodia, with its Project Support Unit (PSU), commenced the implementation of the IFAD-funded Project for Agricultural Development and Economic Empowerment (PADEE) with FAO, SNV Netherlands Development Organisation and iDE as implementation partners / co-financiers. The aim of PADEE is to improve the livelihoods of poor rural households through the establishment of Improved Group Revolving Funds combined with improved knowledge, technology and marketing services.
24. To accelerate access to agricultural technical information and advice, especially for rice productivity management, the ePADEE concept was conceived to establish an Agriculture Expert System to be integrated within Sub-component 2.1 - Support to innovation in capacity building of the PADEE project. ePADEE has been established to pilot technology in selected PADEE provinces, those being Kandal, Kampot, Takeo, Svay Rieng and Prey Veang.
25. As at April 2015 the project has completed the information gathering and development of the core modules of seed selection (Ankur), fertiliser optimisation (Mrittika) and pest and disease management (Protikar). Training has been provided to over 150 Mobile Support Teams (MSTs) and Farmer Business Advisors (FBAs) from the PADEE target provinces and Android based tablets have been distributed to each trainee to eventually provide advice to farmers.
26. The underlying premise of the tools was that Cambodia only has a limited number of technical specialists available to provide detailed advice regarding the management of a rice cropping system, by making this information available through an electronic platform, more farmers will be able to get better cropping system information. By encapsulating the information in this platform, the physical necessity of communication with specialists is lessened, hence facilitating wide-spread access to relevant information about rice production.
27. The individual modules of Ankur, Mrittika and Protikar are all developed by Grameen Intel Social Business (GISB). Each of these modules operates independently

of each other, but generally Ankur and Mrittika are utilised at the same time in order to provide the farmer with options related to seed selection and fertiliser management prior to the development of the rice crop. Underlying the information contained within the modules is the collective knowledge of experts in the rice sector from MAFF/GDA, NGOs and National/International Research Institutions.

28. These experts designed the content for the electronic platform and should be available to update it annually with new available information (i.e. new crop varieties, new fertiliser recommendations, insect pest and disease prevention and treatment, etc.). It is expected that the rollout of the tools and use within the target provinces will provide feedback to be used to improve training materials and capacity building programme under Component 2 of PADEE.
29. The key assumption behind this electronic expert system is that farmers who use it will have more management control of their rice production by using improved and higher yielding varieties, more targeted application of fertiliser, thus saving money, and more understanding and control over pests and diseases. It should allow them to reduce production losses and cultivate a healthier crop, thus resulting in increased productivity. That is the general aim of the project and the follow up monitoring and evaluation will seek to identify if this is the case.
30. At the time of writing an M&E activity is occurring to assess whether the selected PADEE beneficiaries demonstrate accelerated uptake of technical information and increased productivity (i.e. less production losses as a result of improved pest and disease management) compared to other farmers performing similar rice production but not receiving advice. The information will be used to determine the success of the pilot project and the technical and financial opportunity to up-scale to all project beneficiaries.
31. At this stage a critical omission in the tool is the link to the market. For example the Ankur module determines the seed variety selection based on bio-physical characteristics in the absence of market related data. Often in Cambodia, particularly in the provinces bordering Vietnam, farmers will be encouraged by Vietnamese traders to produce varieties suitable for the Vietnam market. The current Ankur seed selection module excludes external varieties and also does not maintain a list of "local varieties" which often do not have names.
32. Many small holder farmers continue to grow traditional varieties for household consumption and sell only surplus amounts into the market. This characteristic has not been accounted for in the ePADEE approach.
33. Key Informants:

Mr Stuart Brown, CamAg Consulting – stuart.brown@camagconsulting.com

Mr Srinivas Garudacher (Grameen-Intel Social Business)
srinivasbgarudachar@gmail.com

Mr Pavel Hoq (Grameen-intel Social Business) Chief Operating Officer - pavel.hoq@grameen-intel.com

34. Key takeaway messages
    a. The ePADEE concept began with no or limited assessment of the true requirements of the farmer in terms of management practices or information gaps in the sector. Generally before an ICT system is implemented a user needs analysis is performed to gain a clear understanding of how and if this technology can assist the end users and recipients. Additionally there was no use case analysis of the users, the FBAs and MSTs, prior to the implementation of the project. These two aspects are critical to the long term success of the pilot and the possible roll out to wider audiences.
    b. The ePADEE approach has been crafted from existing software called the eAgro suite developed for the vegetable and rice sectors in India and Bangladesh. Certain modifications to the delivery of information through the software were suggested but were constrained by the underlying design of the tool. It became apparent during phase one of the ePADEE development in 2014 that the tool was not sufficiently flexible in its design to account for major wish lists of changes to the way information was displayed. This is a critical issue in terms of using generic preconceived software for new initiatives in Cambodia. It is important that the science should not be forced to adapt to the software, rather the other way around.

2.3 ASPIRE INITIATIVE

35. ASPIRE has been designed on the assumption that the public sector, represented by MAFF and its sub-national agencies, will continue to have an important role in the extension sub-sector, but with the understanding that their role must adapt to the changing context of agriculture in Cambodia and to the increasing importance of private sector extension providers.
36. The provinces of Kampong Cham, Kampong Thom, Kratie, Preah Vihear Battambang, Banteay Meanchey and Pursat were identified as candidates from which five pilot provinces will be selected. According to the project design, subject to satisfactory progress, ASPIRE will expand into Kampot, Kandal, Prey Veng, Svay Rieng and Takeo with the phasing out of the PADEE project in those Provinces in 2018. This also has a direct relationship to the ePADEE activities currently being implemented in these five provinces.
37. A sub-component of the ASPIRE initiative is related to improving extension and knowledge management in the form of an “extension hub” within MAFF. Within this sub-component a series of functions are expected which will include (a) the integration of existing extension materials and web content; (b) a system of extension demand assessment and extension service planning; (c) development of new extension materials and training content; (d) and importantly related to ACCA,

the establishment of the extension portal for ICT support to extension[8]. A critical relationship to ACCA may also be the additional sub-component within ASPIRE related to support and development of climate resilient agriculture through extension to support smallholders in areas of high climate risk. While this may be more specifically related to the improvement of critical irrigation resources it may also be significant in terms of the ACCA research through ways and means to adapt to climate variability with and without irrigation resources.

38. According to ASPIRE documentation and communication with Mr Julian Abrams, ASPIRE will provide support to the Extension Research and Advisory Board, general workshop events and web-based dissemination and feedback. Some of this support will come in the form of selected media activities and through supporting international and national experts in knowledge management and in ICT and will also support a journalist / media consultant who will be responsible for facilitating field visits and other forms of communication with the national media. This initiative will need to be investigated further in so far as the ACCA research is concerned as a possible entry point for the application of ACCA research into programs of extension under the auspices of ASPIRE.
39. According to the underlying principles of ASPIRE, the lack of access to up-to-date, relevant information on farming technologies, markets and climate risks, together with the lack of the skills needed to use information effectively, are key constraints to the improvement of smallholder farm businesses. While many of these constraints are true, there is a need for a clearer understanding of exactly what are the farmer's information needs and tailoring a solution to address that rather than extension activities that are broadly based.
40. Small holder farmers can tend to fall out the bottom when new or enhanced agricultural research or techniques are developed due to their lower economic status and limited access to information that makes sense to them. Agriculture production in this sector is generally subsistence in nature, with limited surplus then only going to market. One of the stated aims of ASPIRE is to enhance the capabilities of existing public sector activities to try to strengthen the rural economy, generate employment and reduce competition for existing off-farm jobs.
41. With particular reference to the ACCA research, the ASPIRE initiative identifies that climate vulnerability is a major concern with implications for existing smallholder incomes. Extension advice and support to smallholders should be tailored to these small holder farmers to ensure sustainability and resilience as well as to improve short-term profitability. For many smallholder farmers in the most climate-vulnerable areas, adaptive production techniques are needed to manage the perceived climate variability now and in the future. This is where the ACCA research

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[8] *IFAD, March 2014, 'Agriculture Services Programme for Innovation, Resilience and Extension: Detailed Design Report'*

has a direct relevance to the goals of ASPIRE and a closer association and promotion of this research as a management tool could be an important part of their climate resilient focus.

42. Information developed in a publicly funded manner is considered a public good and should be provided to sectors of the economy which are not necessarily the focus of private sector activities. Smallholder farmers fit into that category in Cambodia due to undeveloped nature of the sector, which is still focussed more on food security and less so on the market. In this context the public sector is likely to retain a key role in the agriculture extension sub-sector. ASPIRE suggests that this role should complement and reinforce, but not crowd out, investments in extension by the private sector. This will be a challenging exercise to get the balance right and the ACCA research may provide that balance to bring in new thinking to a stagnant yet important sector in terms of assisting human development and reducing poverty.
43. This sector, while stagnant in terms of productivity is also in a critical period of flux as pressures emerge in terms of greater urbanisation, and less labour becomes increasingly apparent in the sector. Another stated aim of ASPIRE is to assist the extension services to become more client driven requiring a "service provider" approach. This is important if any extension message is to be useful to the farmer, indicating behavioural change on the part of extension provider and farmers. The use of ICT technologies may form a component of this process and potentially find creative ways to bring a new extension philosophy to Cambodia.
44. Key Informants:
    a. Mr Julian Abrams, Consultant, Aspire - julianabrams@gmail.com
    b. Mr Meng Sakphouseth, Country Programme Officer for Cambodia IFAD, m.sakphouseth@ifad.org
45. Key takeaway messages
    a. A large amount of money, over USD$50 million, through loans and grants provided by IFAD along with the Royal Government of Cambodia has been earmarked for this initiative. It appears to be a serious push to strengthen the public extension services in ways that may or may not "crowd out" the emerging private sector. The alignment of ACIAR's policies with the public sector is strong and ASPIRE is likely to be seen as a logical avenue in which the public good research of ACCA can be rolled out. The uncertainty is in how this is manifested.
    b. Through communication with the key informants of this initiative it is unclear whether ASPIRE project funds could be used for the development of "tools" related to the ACCA research or whether the funding is to be directed more to wider extension processes that would benefit from the messages arising from the research, that being increased flexibility and researched enhancements to production techniques.

c. If point b is a correct assessment, and if the ACCA research is to be implemented as an extension guide for a more flexible approach to rice production within the context of climate uncertainty, then the development of a package or tool might need to be publicly funded through other means with the view that it would form a component of the ASPIRE program. Further clarification is needed from ASPIRE to assess the availability of funding and what form of collaboration could arise.

2.4 TONLE SAP SMALLHOLDERS DEVELOPMENT PROJECT (TSSDP) – RURAL ICT CENTRES

46. The TSTD was designed as a precursor to a larger investment by RGC, ADB, IFAD, and the Government of Finland – the Tonle Sap Poverty Reduction Smallholder Development Project (TSSDP). Output 2 of TSTD was tasked with piloting and establishing 20 financially sustainable telecenters (TC) to contribute to the distribution of agricultural information in rural communities and to lessen the information divide[9].
47. The rural sector in Cambodia has seen a number of telecenters implemented within the last past 5 to 10 years. Three highly visible previous projects included the Informatics for Rural Empowerment and Community Health (iREACH); the Asia Foundation Community Information Center (AF-CIC); and the predecessor to the TSSDP project, the ADB TSTD project outlined above. Many of these TCs have struggled to reach the aspirations held out for them at their beginnings. This section will concentrate only on the TSTD due to its focus on agriculture and identify its successes and failures which in turn may help us understand the processes in play in relation to implementing some form of ICT platform for ACCA.
48. The TSTD was ostensibly established to improve the ICT capacity and resources in four provinces. Access to agriculture-focused ICT-resources, like extension services to the commune, access to financial services, research outreach, and other useful local content and capabilities both within NiDA and MAFF was to be the focus of activities. However, the reality was quite different in practice due to a mixture and a combination of the following:
    a. The focus on physical central locations using stationary technologies such as a desktop PC with Internet connection, a printer and other accessories, represented a singular view of how to distribute information to rural populations. It failed to adequately identify and consider other forms of distribution mechanisms. Mr Ludovic Pommier suggested it was a hardware first approach which precluded a thorough understanding of information and knowledge.

9 ADB (June 2009). Project Number: 42037 - Capacity Development Technical Assistance (CDTA) - Kingdom of Cambodia: Tonle Sap Technology Demonstrations for Productivity Enhancement.

b. According to Mr Pommier an ontological approach, that is, a framework for organizing information as a set of concepts in domains, is necessary to first organize information in a way that fits rural recipients. He goes on to suggest it ought to be associated to a deeper understanding of information seeking behaviours and worldviews of the target population[10].

49. For any ICT agriculture initiative it is important that once the above has been defined and understood, only then, tools to distribute information should be defined/selected. Computer technology and networks are just part of a range of possible media, including radio, mobile phones, oral transmission. Together with the definition of tools, comes the identification of the logical purveyors of the information, which may include public and private extension agents.

50. According to anecdotal information through Mr David Moles, Project Leader TSSDP, many of the rural ICT telecenters had a limited impact and the reasons for their establishment was not adequately communicated to the operators and the local communities involved. On a few occasions the facilities evolved to be used as locations whereby the operators began running businesses unrelated to the original concept of a conduit for agricultural information to that of a printing and photocopying centre in a few instances.

51. The readiness of the rural market for ICT was not adequately studied, particularly the information behaviours of the targeted beneficiaries. The consequences for the pilot project were that TSTD did not adequately provided the market awareness campaign needed to create the demand for TC services; ICT services such as access to digital agricultural information did not meet the needs of the farmer; and lastly, the readiness of the rural sector particularly the farmer was embryonic. According to an evaluation of the pilot the preference of farmers was still to be provided information thru observation and listening rather than through reading.

52. Key informants:
    a. Mr Ludovic Pommier – Rural ICT consultant ludovic_pommier@yahoo.com
    b. Mr David Moles, Team Leader ADB Project - TSSDP, tsprsdp.tl@gmail.com

53. Key takeaway messages
    a. The TSTD pilot represented a model that while successfully implemented in other regions such as India, it failed to get a clear understanding of the cultural and physical constraints in Cambodia. Those being the limited exposure to computer technologies by the proposed beneficiaries and the cultural issues associated with the telecenters often being based in private households or politically aligned commune council centres.
    b. A great deal of work understanding the information needs and how that information is most comfortably accessed is critical to success. A research

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[10] Ludovic Pommier, August 2013, 'TSTD Telecenters and Rural ICT: Determinants of Success and Recommendations' NIRAS

concept can undoubtedly make sense when devised in the presence of like-minded research associates. However the end beneficiary needs to be closely studied in order to understand how the research message can best be implemented on the ground. The use of technology as a convenient dissemination package without adequate understanding of the audience will discount the quality of the information and if lessons are to be learned from the failings of the TSTD then a measured approach taking into account the audience will provide a sounder basis for success.

2.5 CAMBODIAN AGRICULTURE MARKET INFORMATION PROJECT (CAMIP)

54. CAMIP was an initiative launched in 2006 and supported by the Canadian International Development Agency (CIDA) as a peer-to-peer architected information system to support specific market development objectives. These included the establishment of a farmer marketing school and market information objectives such as providing accurate and timely market information and improved coordination between agricultural marketing and production.
55. Market information services were provided through radio broadcasting and SMS exchanges of market prices between traders for a small fee. According to Mr Pieter Ypma the incentive for traders to provide pricing information was to broadcast their prices to potential buyers in an effort to sell surplus commodities particularly in the fresh fruit and vegetable sector which has a highly perishable nature if not sold immediately. Radio broadcast of agriculture related information had also been transmitted through 7 provincial radio stations with a wide coverage of listeners.
56. Today the CAMIP project has limited activity, although there are traders that continue to use the SMS functionality to share market information. The objectives, concepts and the technologies provisioned through the project appear relatively sound. However, according to a previous review[11], the primary reasons for its lack of sustainability are as follows:
    a. There was no critical mass of farmers that either have the technical literacy, access or general interest to actively participate in the exchange of market information.
    b. Traders, not farmers, benefitted the most by obtaining market prices and establishing themselves in a stronger negotiating position than farmers.
    c. There was lack of consistency in the collection and information dissemination after funding for CAMIP ended in 2009.
    d. An exit strategy was not clear nor was the operation sustainable. After funding, operations of CAMIP moved back into MAFF. As the funding ran

[11] Lauro Vives and Anouvath Sreng, 2013, 'Rural Information Communications Technology Assessment', Grant 0191 CAM: Tonle Sap Smallholder Development Project (TSSD), ADB

out, so was the capacity to support the project. In hindsight, a workable exit strategy may have been to incorporate CAMIP into the business of telecommunications operators and call centres given the profit potential through SMS exchanges and value-added services.

57. In correspondence with Mr Pieter Ypma, CAMIP was meant to stand alone as an SMS and broadcast arrangement, however through the insistence of MAFF an online presence was established through MAFF in the form of CAMIS. Of late the online presence has not managed to maintain consistency in terms of reporting prices in real time and often the online presence is not available due to technical and database problems. In view of the funding constraints and the lack of a "champion" with a funded strategy for maintenance, CAMIS is likely to have a decreasing relevant presence in the future.

58. Key informants:
    a. Mr Pieter Ypma, Agribusiness and Information Systems Manager, CAVAC pieterypma@cavackh.org

59. Key takeaway messages
    a. CAMIP is technically sound and uses technologies that are simple and currently widely accepted in Cambodia. Much of the population in rural areas have access to a mobile phone and radio for daily broadcasts. The point made earlier regarding sustainability is a direct reference to the inclusion of private sector partners which would likely maintain a system of SMS and radio broadcasts if there was a profit margin associated with the service.
    b. For example a private sector operated call centre would benefit from the margins around the price of an SMS if a user were to send a request for information based on a specific code for commodity type. This would not need to be overly complex and would at least provide relevant pricing information relative to location for many users. In terms of radio broadcasting, advertising revenue could be generated by placing relevant advertising around specific broadcasting of prices for produce in specific areas.
    c. CAMIP and CAMIS are yet another example of a sound concept that has not made the appropriate plans for long term maintenance and management of valuable real time information. Future efforts in the ICT agriculture domain need to address the long term sustainability of processes when the funding ceases. It appears that unless the government see this as a high priority and is aligned with policy then the initiative is likely to fail unless the private sector can be involved and sees value propositions for their business.

2.6 OXFAM CAMBODIA - DEVATAR INITIATIVE

60. Oxfam Cambodia has launched an initiative which aims to provide development stakeholders with a collaborative platform, provisionally named Devatar. The purpose of which is to share documents and knowledge in specific locations; to access relevant data in the development field; and to utilise a “crowd-sourcing” approach to build a vast amount of development publications, reports and data. As of writing the Devatar initiative is in a pilot phase to test the concepts proposed by the initiative.
61. The potential for Devatar is to increase the efficiency of development aid by removing duplication of work, improving project quality and providing a chance to analyse data in more detail and identify trends. Currently some of the essential features identified for the future development of Devatar include the ability to manage vast quantities of knowledge in a user friendly way with an easy to manage information retrieval system.
62. A long term vision for the system is to achieve a critical mass of data from which to derive inferences from the disparate data sources in order to make better quality decisions regarding development initiatives by NGOs, government and other public bodies in the field of international development. This concept is aligned with the notion of “big data”, whereby large dataset are interrogated in order to form inferences or observed patterns that otherwise may have been obscured through individual analysis.
63. In cooperation with Nokia Corporation, DEVATAR is being developed as an IT application for the development sector that can eventually be downloaded in smartphone and desktop formats. It will attempt to provide access to large data sets and other information in real-time to potentially bring more effective and efficient development designs and practices to the recipients of development programs.
64. The smartphone/tablet version of DEVATAR is to be built around a GPS-linked data set on development activities so that the user can identify data at a village level, with the following features:
    - Identification of the village including profile, population, demographics, lists and photos of key people, contact details and infrastructure resources
    - Contact lists of development agencies active in the village
    - List of development activities in the village linked to relevant data sets an public domain reports
    - Eventually list the chorological development activities in the village with links to research and learning initiatives
65. Phase two of the Devatar initiative is expected to provide for remote data upload through an App which would collect information from the field as data is collected. A desktop version would provide for a more sophisticated view of the dataset with search and analysis features.

66. The major audience for the development of this initiative are international development actors developing programs for the advancement of livelihoods in Cambodia and organisations wanting to disseminate information generated through research or development activities. Thereby making that information available to other actors in a relevant way to improve practices of development practitioners and beneficiaries. At the time of writing the first stage of Devatar is due to be released for public comment and beta testing on May 19 2015.

67. Key informants:

Mr Ludovic Pommier – Rural ICT consultant - ludovic_pommier@yahoo.com

Mr Brian Lund - Regional Director, Oxfam America Regional Office in East Asia - blund@oxfamamerica.org

68. Key takeaway messages
    a. Devatar is an ambitious initiative that has a number of challenges in its approach. It is reliant on organisations or individuals to provide relevant development publications, reports and data for the system. While much data is in the public domain, often relevant up to date data is proprietary and maintained within agencies for internal use. There can often be a degree of territoriality with international development and research agencies in terms of the information which is made available in the public domain which may make the availability of relevant data limited. This is not always the case but is a consideration that must be managed in order to build a long term library of dataset.
    b. The suggestion implied by Devatar is that over time vast amounts of information will be built up and that this data can be used to further analyse trends and provide insights previously not apparent. This further implies that the "big data", that is, vast amounts of somewhat related and complex data will be able to be analysed and disgorged into a sensible interpretation. The consultant's view of this is that this is a complex scenario and would be a challenge in terms of management, IT and computational capabilities to be performed adequately.
    c. Devetar may be a suitable partner in terms of making the research that has arisen from the Cambodian component of the project "Developing Multi-Scale Climate Change Adaptation Strategies for Farming Communities in Cambodia, Lao PDR, Bangladesh and India". The development community would perceivably benefit from the research surrounding adaptation to climate change. However this will be dependent on the flexibility of the format in which information and data would be expressed under the Devatar initiative.

2.7 SELECTION OF FORAGES FOR THE TROPICS (SOFT) – ACIAR PROJECT AS2/2001/029

69. The Selection of Forages for the Tropics (SoFT) website (www.tropicalforages.info) and CD database was developed through ACIAR project AS2/2001/029, with supplementary funding through DFID and GTZ (now GIZ), and released at the XX International Grasslands Congress in Dublin in 2005.
70. It contains 180 species that are either currently being used or have potential for animal production, landscape rehabilitation and soil conservation/amelioration in the tropical regions of the world. The database represents a comprehensive source of tropical forages information for researchers, students, extension workers, NGO's and farmers around the world.
71. In 2009, entries for 40 key species suitable for South East Asia from the original database were translated into Khmer, Vietnamese and Indonesian. User interest has been strong, with SoFT being used for teaching in various countries including Central and South America, even though Spanish or Portuguese versions are not currently available.
72. Since 2009 it had become obvious that certain aspects of the original database needed attention, and the site had become dated, based on the advancement of technology, forage species information and user interest in the web site. However, while there have been proposals put forward by the author of this report and others involved in the original development for an upgrade, ACIAR and other funding bodies have been non-committal.
73. This was a publically funded initiative which in effect had many stakeholders but no "champion" to drive and improve the tool as new technologies and research and development occurred in tropical forages. This has resulted in a tool that has become dated and at times offline due to limited direct ownership of the tool through the various organisations involved in the original development of the tool. At the time of writing, the SoFT tool at www.tropicalforages.info is offline and has limited prospects for further management.
74. Key informants:
    a. Mr Stuart Brown, CamAg Consulting – stuart.brown@camagconsulting.com
    b. Mr Bruce Cook, formerly QDPI – brucecook@aapt.com.au
75. Key takeaway messages
    c. This tool is an invaluable resource particularly at a time when the demand for protein through livestock is increasing in many of the emerging economies in the tropical regions. However it was developed through an ACIAR project and had no mechanisms in place to continue to fund further development. CIAT was given responsibility to host the identification tool on its server, yet this has been unfunded by CIAT and no further maintenance or management has resulted. If an organisation does not have the continued funding for the tool then its continued management will be uncertain.

d. The message regarding the climate adaptation research might be that if there is no ongoing management and maintenance of a "tool" then it is likely to suffer the same fate as SoFT. SoFT was funded by ACIAR, DFID and GIZ at a value of over $AUD1 million and while it is difficult to calculate returns on investment since the products release over 10 years ago, only a small further investment would maintain the tool in a way that will allow this public good to continue.

3. CONCLUSIONS

76. This report constitutes the first part of a two part review and analysis of implementation and collaboration opportunities. Part 2 will determine the options and the principles that need to be addressed to implement the ACCA research into a program which may include an ICT component.
77. The overarching message consistently recurring in this report alludes to the real need to understand the information needs and learning capacities of rural beneficiaries in any proposed ICT agriculture program. With the increasing awareness and use of Khmer script enabled mobile devices, the limited access to information of the past will dramatically lessen. The key is to find the right mix of approaches to embrace the emerging technologies and their distribution capabilities with information in a format relevant to the cultural and learning capacities of the users.
78. At this stage of the analysis, four groups are in a position to assist with furthering the research through part 2 into how the ACCA research may be extended to communities at risk of climate change. These include MAFF through the ASPIRE initiative, GISB in ePADEE, Devatar through OXFAM America and Identic Pty Ltd, the developers of Lucid™. The author has communicated in detail with these groups and will put forward a strategy and recommendations in Part 2 to determine the most suitable approach to extending the ACCA research into programs which may or may not include an ICT component.

Appendix 8 – Brown 2015: Implementation and collaboration – Part 2

Implementation and collaboration guidelines for ACCA research

Stuart Brown, CamAg Consulting

Unpublished report.

Part 2: Implementation and collaboration guidelines for ACCA research

For CSIRO

CamAg Consulting

June 15, 2015

PREFACE

This report was prepared by CamAg Consulting. Author of the report is Mr Stuart Brown (stuart.brown@camagconsulting.com). The views expressed are those of the consultant in accordance with the objectives of the research as per the scope of work defined by CSIRO.

CamAg Consulting cannot be held liable for the recommendations arising from this report.

July 2015

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ABBREVIATIONS AND ACRONYMS

ACCA	Adaption to Climate Change in Asia (ACIAR Project LWR/2008/019)
ACIAR	Australian Centre for International Agriculture Research
ASPIRE	Agriculture Services Programme for Innovation, Resilience and Extension
DAE	Department of Agriculture Extension
EPADEE	Electronic Component to the Project for Agricultural Development and Economic Empowerment
FBA	Farm Business Advisor
GDA	General Directorate of Agriculture
GISB	Grameen-Intel Social Business
ICT	Information Communications Technology
iDE	International Development Enterprises
IFAD	International Fund for Agricultural Development
MAFF	Ministry of Agriculture, Forestry and Fisheries
MST	Mobile Support Team
NGO	Non-Government Organizations
PADEE	Project for Agricultural Development and Economic Empowerment
PDA	Provincial Department of Agriculture
RGC	Royal Government of Cambodia
USAID	United States Agency for International Development

1. INTRODUCTION

1. As a continuation from "Part 1: A review of ICT Agriculture Initiative in Cambodia", this report identifies opportunities for the ACCA research to be included now and into the future as a key component to relevant Cambodian extension and communication initiatives.
2. Research has identified that a mobile app is not necessarily a priority for the ACCA research due to the limited audience to which the mobile app tool would be relevant. The more likely path to implementation is through partnerships with organisations and groups dedicated to the delivery of information and innovations related to climate adaption.
3. This report has a twofold objective (1) to identify the major parties in which to collaborate with to deliver the message from the ACCA research to the audiences that will benefit the most; and (2) to identify how the collaboration with these organisations can be structured in a practical way.
4. In the previous report, multiple parties were identified as possible partners in a collaborative project to bring the ACCA research into mainstream extension activities. These organisations included Grameen-Intel Social Business (GISB) based in Dhaka, Bangladesh; Identic Pty Ltd based in Brisbane, Australia and responsible for the development of the Lucid™ identification and selection tool among others; Devatar initiative funded through Oxfam and the ASPIRE extension strengthening program funded through IFAD.
5. Subsequent to the previous report it was assessed that GISB would not be the most appropriate organisation to move ahead with in terms of collaboration to bring the ACCA climate adaptation response farming research into PADEE. GISB have a defined set of business goals which focus on bringing basic information to farmers regarding seed selection, optimum fertiliser application and simple identification of pest and disease management. Whilst the separate modules are simple they do attend to a basic need of improvements in knowledge about the three main constraints to production in rice farming systems in Cambodia.
6. The business model at this stage according to GISB is limited to rolling out these concepts primarily before other more sophisticated cropping systems are required. In terms of the ACCA research, the level of understanding and the usability of the management options are likely above that of the current user base which as of July 2015 is small but growing. The target audience for GISB within EPADEE are extension staff associated with GDA called MSTs and FBAs aligned to iDE.
7. Adding a climate adaptation module to this would be an added degree of sophistication which I believe the users are not capable at this stage of interpreting correctly. Their main focus is on providing better seed, fertiliser and pest management choices.
8. Previously Identic Pty Ltd based in Brisbane, Australia were identified as important providers of identification and selection software in the area of agricultural

problems such as pest and disease identification in rice amongst others. They have a solid track record of achievement in this field and expressed interest in collaboration.

9. However as was identified in the previous report, they can provide PC and mobile applications if a concept can be adapted to their platform. What this is referring to is when a concept has a distinct need (from users) and entities can be defined and selected to reach a specific identification then a tool can be rapidly developed to provide a solution to users. This works well when one is considering aspects such as pest/disease identification based on known characteristics which then can be interrogated to supply a known solution in the form of a factsheet of information about a particular rice affliction.
10. There are a number of aspects to the Cambodian ACCA research which is likely to preclude the development of a specific PC or mobile application tool with Identic Pty Ltd. These include:
    a. A specific audience and user base is still ill defined. It is not appropriate at this stage to apply the ACCA research as a module which might be used by EPADEE considering the level of capacity of the user base for EPADEE.
    b. While the logic underlying the management procedures in the multiple cropping scenarios in ACCA are based on an "if/then" selection, the ultimate aim is for better management practices rather than a solution per se. The logic of ACCA is more of a decision support tool rather than an identification of a problem.
11. The ultimate aim of the ACCA research is to feed into better practices for rice crop management based on the presumption of multiple cropping options in the context of climate adaptation. This has a distinct extension enhancement flavour to it than necessarily a one off tool to aid decision making in the field by field technicians or support staff.
12. In this context the following analysis with accompanying recommendations focusses on how the ACCA research can contribute to current initiatives in Cambodia which seek to disseminate information and frame new innovations in extension.

2. REVIEW OF POTENTIAL PARTNERS

2.1 ASPIRE: EXTENSION AND TRAINING STRENGTHENING

13. ASPIRE has been designed on the assumption that the public sector, represented by MAFF and its sub-national agencies, will continue to have an important role in the extension sub-sector, but with the understanding that their role must adapt to the changing context of agriculture in Cambodia and to the increasing importance of private sector extension providers.

14. A recent agricultural extension initiative announced through the Phnom Penh Post (29th May 2015[12]) highlighted a policy to increase the number of extension officers throughout Cambodia. The initiative developed with the assistance of USAID cooperation and funding will, according to the Director of DAE, Mr Mak Soeun, strengthen the agricultural extension regulatory framework; increase the capacity of officers and agents; incorporate affordable and practical farming techniques; improve information and messaging; and incorporate better delivery systems for this information.
15. In discussions with Mr Julian Abrams, this extension initiative was developed separately to the IFAD funded ASPIRE initiative and due to its recent announcement it is still uncertain what implications it has for the functioning of the initiatives expected to flow from ASPIRE.
16. The fundamental driver for the new agricultural extension policy is to shift the mindset of extension services from a supply driven service to a demand driven service with distinctly more connections to market systems and private sector suppliers of information, such as input supply companies.
17. One major constraint on the horizon that may continue to stifle agriculture extension in Cambodia even under this new extension framework is that the RGC will continue to be the major funder for agriculture extension now and into the future. In the past funding has been less than adequate for major innovations and the system still requires substantial funding input by donors, NGOs and international development organisations. It is the consultant's view that a significant ramping up of private sector partnerships will be necessary to achieve many of the goals of strong and efficient agricultural extension in Cambodia.
18. The agriculture extension policy does allude to more engagement with private sector groups in the agriculture sector and this is also a theme encapsulated with the ASPIRE program. Time will tell what type of engagement with the private sector will result and if it will be a truly sustainable arrangement which allows private sector providers to make a profit from the supply of information and innovations to farmers.
19. In terms of ACCA's collaborative opportunities in this new environment of shifting mindsets in the extension sector, a clear opportunity is through ASPIRE's initiative within Sub Component 3.2: Innovations for Climate Resilient Agriculture. This sub component supports the development of on-farm trials demonstrating improved on-farm water management, adjustments to the cropping calendar particularly including introduction of early wet season rice or other crops and the introduction of climate resilient varieties.
20. It is pertinent that the ASPIRE documentation explicitly states that they are seeking improved on-farm water management which can be interpreted a few ways. One

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[12] *http://www.phnompenhpost.com/business/new-policy-boost-farming*

interpretation may refer to improved infrastructure to bring greater water security to farmers particularly in the critical early wet season but may also refer to better use of stored soil moisture. Currently this concept is little acknowledged in Cambodian rice farming systems.

21. The ACCA research clearly identifies that not enough understanding of soil moisture and storage occurs in the decision making surrounding the establishment of rice cropping sequences. The data presented in the technical documents prepared by ACCA identify financial opportunities for farmers that have a clearer understanding of key “trigger points” at specific times in the early and main wet season. However the data presented in the technical document is for trials achieved over two years with supplementary data coming from simulation modelling.
22. The innovations proscribed by the ACCA research will require trials in other medium to high rice cropping lands, and with differing soil types to determine location specific management practices. The current results from ACCA are from two provinces on a limited soils data set. In order to scale the research across the major rice zones in Cambodia, medium to high lands which excludes the recession rice production zones, further trials would be necessary to understand the specific management practices needed.
23. ASPIRE’s expected focus provinces are initially Kampong Chhnang, Pursat, Battambang, Preah Vihear, Kratie, Kampong Speu and Peah Sihanouk. Upon the conclusion of the current PADEE project, ASPIRE is likely to continue and benefit from the enhancements to extension and rural capacity building already underway in Prey Veng, Svay Rieng, Kampot, Kandal and Takeo, and likely to conclude in 2018.
24. The ACCA research work is a natural fit with the aims of Sub Component 3.2 and should be closely explored with ASPIRE to determine the best path to implementation under funding for technical innovations which will be directed by the ASPIRE Extension and Research Advisory Board.
25. Another relevant component within ASPIRE is Sub Component 4: Infrastructure Supporting Climate Resilient Agriculture. This focusses on key investments in water management infrastructure such as canals and multi-purpose reservoirs in communities. These decisions will be determined through a Performance Based Climate Resilience Grant (PBCRG) that will require input in terms of climate resilience benchmarks. The mechanisms of the benchmarking is yet to be determined and is a likely collaborative opportunity for the research of ACCA.
26. Better water use efficiency in cropping systems through extension of ACCA research is likely to have a circular feedback effect with regards to the grant provisions to develop new or improve existing infrastructure. That is, if trials of the ACCA research are implemented through ASPIRE in targeted districts it may be useful in terms of benchmarking climate resiliency and the associated irrigation infrastructure required.

27. The overarching theme of the ASPIRE project is the improvement of extension services and knowledge management. Component 2: Capacity Development for Extension Services will be seeking to improve the quality of existing extension and through the research advisory board identify gaps in the knowledge management and new initiatives through which to development new extension service information. This may take many forms such as traditional media dissemination through to the creation of an "extension hub" and the development of stronger linkages and partnerships with private sector groups with the capacity to provide extension messages to farmers.
28. According to Mr Julien Abrams, ASPIRE has the funding to implement training and the rollout of trials under the research advisory board. This is an indication that if ACCA was to collaborate closely with ASPIRE there would be likely, given research advisory board approval, more trials of the ACCA research across the ASPIRE focus provinces to determine if there was specific climate adaptation management measures that would serve as a benchmark for the ramping up of production particularly in the early wet season.
29. The funding for the extension innovations will be under control of MAFF and they will have the final approval through the advisory board to allocate funds projects and innovations they deem appropriate and consistent with the aims of ASPIRE. A recent understanding of the funding arrangements highlighted that there will be limited opportunities for direct funding for external technical assistance. If outside agencies have an innovative technology or enhancement to existing farming systems the likely scenario will be a co-investment outcome which appoints funds to the technical advisory input of the external agency with the local rollout funding of the ASPIRE programme.
30. Key Informants:
    a. Mr Julian Abrams, Consultant, Aspire - julianabrams@gmail.com
    b. Mr Meng Sakphouseth, IFAD - m.sakphouseth@ifad.org
31. Implementation path:
    a. There appears to be a clear and direct affiliation between the research outcomes of ACCA and the direction ASPIRE wishes to take in terms of climate adaptation innovations under subcomponent 3.2. The path that may be considered by the ACCA team may include a partnership in the further on-farm research requirements that are proscribed under the subcomponent to further the climate resilience of small holder Cambodian rice farmers.
    b. As identified previously the ACCA research was focussed on two provinces, Svay Rieng and Prey Veng, and further localised on-farm research and trials are likely needed to ensure crop management is appropriate to these differing conditions. ACCA's guidance is likely necessary to ensure the trials are conducted according to the true meaning of the research. This will

obviously need to be negotiated through ASPIRE's Extension and Research Advisory Board through the processes the programme puts in place to assess the innovations to be funded.

c. Recent discussions with Mr Julian Abrams and Mr Meng Sakphouseth indicates that the best path to cooperation is through a joint funding arrangement which sees personnel involved in the original ACCA research finding funding to cover their input of technical assistance with ASPIRE contributing to the technical rollout costs associated with trials and extension materials.
d. Further exploration of external funding opportunities will be necessary for the ACCA research to be fully implemented under ASPIRE. The alternative scenario proffered by Mr Julian Abram and Mr Meng Sakphouseth is one that would require the ACCA innovations to go through a public tendering system which is yet to be determined under the ASPIRE programme.
e. The ASPIRE programme has just commenced and any approval of new innovations becoming a part of an extended rollout and trialling under ASPIRE is likely to be reviewed and approved in the early half of 2016 prior to the end of the dry season for rice related innovations. In light of this there is up to six months to engage with funding bodies to seek cofounding agreements with ASPIRE to incorporate the ACCA research.

2.2 DEVATAR INITIATIVE

32. Devatar is aiming to become the hub for development related information in Asia. The concept is seeking to encourage the development community to share high quality information and to better coordinate its actions through the use of a financially sustainable social platform. As at the 15th of June 2015 Devatar is still to be released to the general public for the searching and downloading of relevant documents.
33. The Devatar initiative is a platform to share geo-localized and key word specific development related information, giving the subscriber the ability to give and collect feedback from their peers, and interact with the community. The subscription fees are yet to be determined as the system is still in a beta testing period. It is the understanding of the consultant that the service will be open to both individuals and organisations at differing subscription rates on a yearly basis. The concept for future maintenance is based on that of a social business whereby the business is seeking to be a self-sustaining "break even" entity with funding going towards staff, infrastructure and document acquisition.
34. The distribution policy for ACIAR publications suggests an open release of project reports and other material with most of ACIAR's publications freely available as downloadable PDFs from the ACIAR website. ACIAR currently has a significant library of information on the organisation's website that is freely available for download. However it is not widely known by international development professionals and at

times does not necessarily show on search engines when one is searching on quite specific geographies. This is not always the case, however under Devatar, searching by geo-reference and topic may bring up relevant multiple documents and project initiatives of associated work in specific areas.

35. Many organisations have gone down the path of incorporating knowledge management into their organisational structure and business processes. With respect to ACIAR, their knowledge management is generally broad due to the wide scope of research and wide region within which they are focussed. As a publically funded organisation, ACIAR is committed to the availability and dissemination of this public data.
36. While ACIAR's current knowledge management is excellent regarding the availability of completed project reports and other material produced during projects, it may also benefit from the "information hub" approach of Devatar. The hub would obviously bring together data from disparate sources and make the data research processes easier and more focussed.
37. It is the view of the author that the Devatar platform is a worthwhile service in which to support through the release of and inclusion of information arising from ACIAR research past, present and future initially in Cambodia and eventually in the South East Asian region.
38. In terms of relevance and the potential to interlink Devatar with other programs in Cambodia, the new extension policy developed under USAid funding emphasises the need to use ICT more as a means of extension communication and more effectively delivering messages regarding agricultural innovations. Rather than developing their own extension hub, Devatar might act as one of the portals to deliver innovative technologies to the development community including international and local NGOs.
39. As identified in "Part 1 – A review of ICT agriculture initiatives in Cambodia", the Devatar service will rely on a critical mass of data to be useful in the long term. This will take a significant amount of work to find, assess the information, collate and organise into a useable and searchable format.
40. The current beta version of this tool utilises geo-locator tags combined with key word tags to enable a complex search of relevant data so that location and topic specific information is returned to the user. The use of detailed maps allows users to

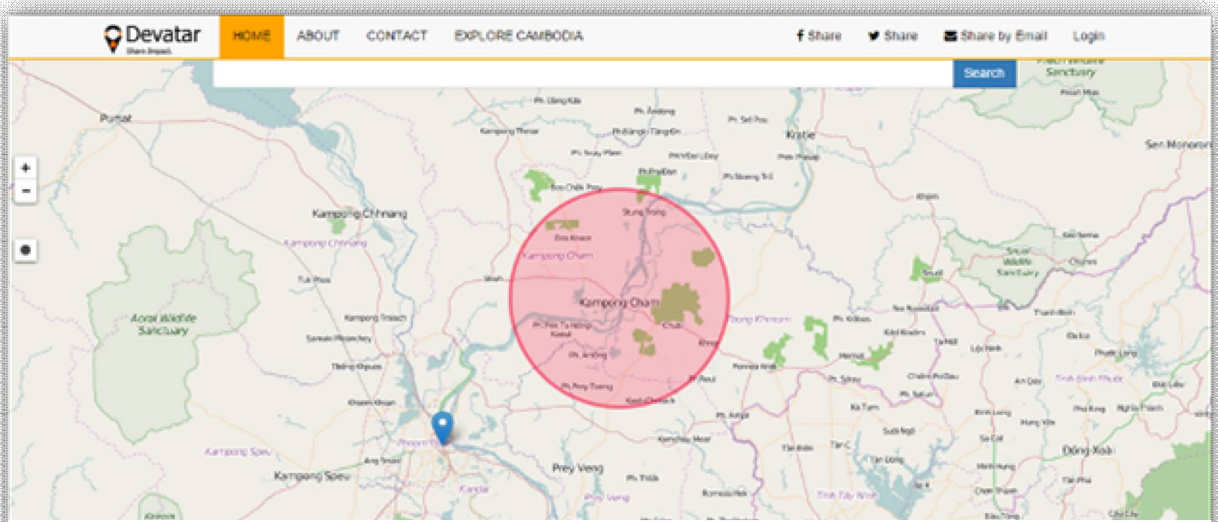


Figure 1: Devatar Geo location tool

identify an area of interest by drawing a circle to filter the data specific to an area of interest. For example if a user was interested in documents and projects in Kampong Cham for instance, the mapping "circle tool" can be used to define a specific location from which to source data. Figure 1 shows the geographic location tool as a data filtering facility in Devatar. Focussed on Kampong Cham as an example, the search algorithm finds all relevant documents with a geo-locator tag focussed on an area in "Kampong Cham".

41. Figure 2 displays the resulting search result based on the geo-location selection with no additional keyword tags used in the search algorithm. This search results in the return of four documents related to Kampong Cham. If the addition of a keywords search term such as "rice" is added to the initial geo location search result, an additional filtering to provide documents related to "rice" and "Kampong Cham" is the result. Testing is ongoing in relation to these search capabilities and a number of errors are still being observed during the beta testing period.

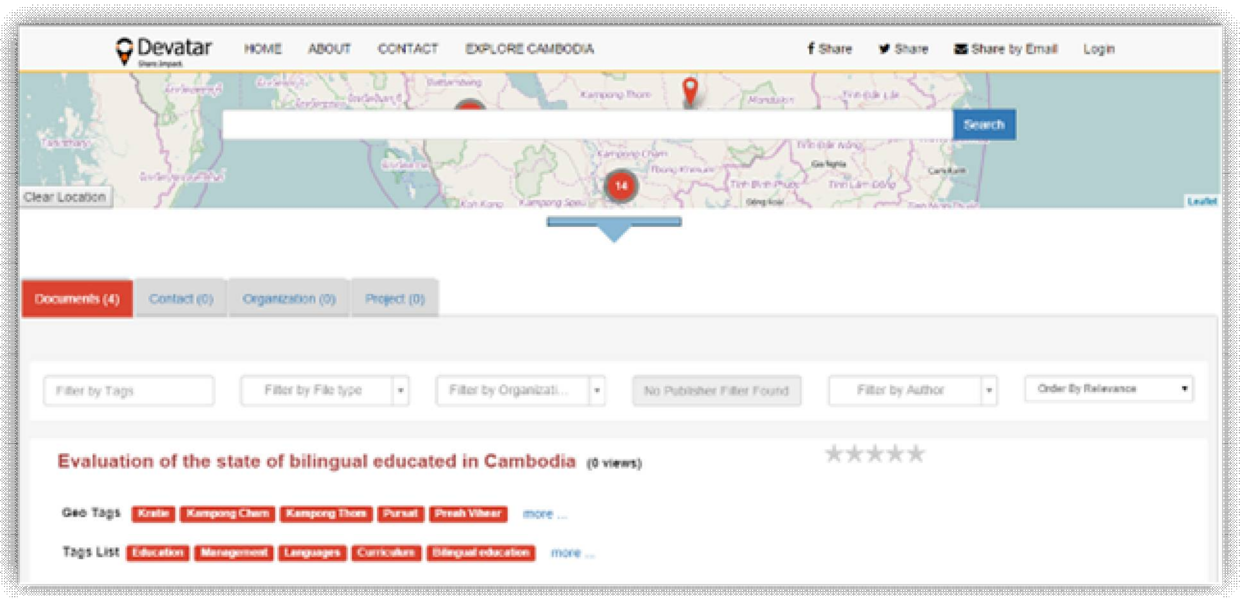


Figure 2: Geo location search result

42. A major feature of Devatar is the mobile application available on Android smartphones. This application replicates the web based version but has additional geo-location features that deliver location specific data to users based on their location in the field. For example, if a researcher of project member was visiting a site for a preliminary review of the location for inclusion in research activities, Devatar will have the ability to deliver localised data. Such data may include contact details of the local PDA representatives, contact details for the relevant commune office, relevant reports from previous projects in the region and other resources such as census data (current 2013 Cambodian population census is already

included). Significantly for the international development sector, efforts are being made to include data such as IDPoor and agricultural census data.

43. The provision of data is contingent on the critical mass of information that is to be built over time. The "buy in" for people or organisations providing that relevant data to Devatar is dissemination of location specific data, possible collaboration opportunities and a wider audience exposed to the benefits of the included research documents.
44. The research message arising from ACCA would be a considerable asset to developing the critical mass of data required in Devatar. There is no requirement for ACIAR to provide publically available data directly to Devatar as links to documents can be made by Devatar directly to publications hosted on the ACIAR publications website. However, reports and other documents held by a project and deemed suitable for release by the project leader and relevant program manager in ACIAR could find a suitable home with Devatar and have the opportunity to reach a wider audience. This is in direct reference to the research paper titled "Increasing flexibility in Cambodian monsoonal rice cropping systems".
45. Once a critical mass of data and documents is approached in Devatar, the resulting search trends including geo-locational searches can be analysed by Devatar to assess the high priority areas of research over time including locations. This may act as a mechanism to identify important current foci of research for development agencies operating in Cambodia. As identified in the previous report, the analysis of trends may also lead to inferences to be made regarding priorities in research and development by commodity and by region.
46. Key informants:

    Mr Ludovic Pommier – Rural ICT consultant - ludovic_pommier@yahoo.com
    Mr Hong Sokheang – Rural ICT consultant - sokheang.hong@gmail.com

47. Implementation path:
    d. As an initial step it is recommended that the research that has arisen from the Cambodian component of the project "Developing Multi-Scale Climate Change Adaptation Strategies for Farming Communities in Cambodia, Lao PDR, Bangladesh and India" be included as material to be accessed through the Devatar platform. The development community would benefit from the research surrounding rice cropping system adaptation to climate change and it would add considerably to the body of knowledge being accumulated through this platform.
    e. The provision of research materials will require no or limited devotion of resources from ACCA and can be simply delivered to ACCA for inclusion on their web portal. Alternatively for information available through ACIAR's website a direct link to the web is immediately possible without permissions from ACIAR as this is publically available data.

f. The subscription basis of the tool is a necessary component to the long term maintenance of the information hub. For many organisations contributing data to the system or authorising access to their online data resources, this may be questionable. However, the only way a development information portal can manage the data collection and continue to provide these services is if it is financial. This aspect will require careful negotiations with each organisation and in the case of the ACCA research, with ACIAR to come to a mutually beneficial outcome.

3. CONCLUSIONS

48. The Devatar initiative is a lower priority than a close association with the ASPIRE programme. Devatar is a start-up that warrants some consideration as a possible outlet for ACCA and ACIAR research outputs however for the time being will have a somewhat limited audience reach.
49. As mentioned Devatar is still in the start-up phase and likely to take a while to establish itself as a major conduit for international development information and portal. While ACCA might be in a position to provide access to relevant agricultural information it is likely best to be limited at this stage to publically available information accessed through the ACIAR publications website.
50. Collaboration between ACCA and ASPIRE is likely to have two possible pathways:
    a. ACCA would bring the research into ASPIRE through the tendering process whereby they would be in competition with other groups seeking to provide innovations to the ASPIRE programme. This would likely have to come in the form of the previous researchers developing a proposal and submitting a bid for consideration.
    b. Alternatively if ACCA research can secure additional funding through another funding body or through additional funding from CSIRO to provide funds to provide technical leadership from the residual ACCA team, then partnering with ASPIRE in terms of providing research guidance might be possible. Mr Julian Abrams consulting for the starting phase of ASPIRE has stated this is the best route through which ACCA can provide input to the rollout of extension related innovation in the programme.

Appendix 9 – Dalgliesh et al 2013: Summary of Key informant Interviews

Developing multi-scale climate change adaptation strategies for farming communities in Cambodia. Outcomes of Key Informant Interviews, Svay Rieng Province

Neal Dalgliesh, Perry Poulton, Mao Minea, Phally

Unpublished report. October 2013

Developing multi-scale climate change adaptation strategies for farming communities in Cambodia

Outcomes of
Key Informant Interviews

Svay Rieng Province

October 2013

[1]Neal Dalgliesh, [1]Perry Poulton, [2]Mao Minea and [3]Phally

[1]CSIRO Australia, [2]Cambodian Department of Agricultural Extension and the [3]Svay Rieng Provincial Depart of Agriculture

1. Introduction

Farmer group discussions (FGD), undertaken in August 2013 by consultant Emmanuel Santoyo Rio and the Cambodian Department of Agricultural Extension (DAE) were conducted with selected groups of farmers in five villages in the three communes of Svay Yea, Svay Ang and Kampong Chamlong in Svay Chrum district, Svay Rieng province. Nine FGDs were conducted in villages where climate change adaptation strategies were implemented in the last three years, namely three FGDs each in Kbal Damrei, Koul and Chea Reassey. Four FGDs took place in control villages: two in Sampore and two in Kien Tasive. The target villages were previously selected by CSIRO and DAE as suitable locations to conduct on-farm research on climate change adaptation strategies. Control villages were selected with the help of district heads of the Provincial Department of Agriculture (PDA). The requirement was that they be similar in nature to two of the project villages. This allowed for comparison of farmers' perceptions on changes in climate and adaptation strategies. Each FGD consisted of 8-10 participants, who were selected to represent six differing household typologies (Table 1). The results of this study are reported in '*Developing multi-scale climate change adaptation strategies for farming communities in Cambodia-Report on qualitative research*' (Rio 2013) which is currently in draft form.

Table 1: *Household types as used in the classification of FGD participants and identification of key informant interviews.*

Household typology	Attributes
A	Small, rainfed farms with no irrigation and high levels of migration
B	Large, rainfed farms with limited irrigation
C	Small, mainly rainfed farms with limited irrigation and high levels of migration
D	Large, mainly rainfed farms with access to canal irrigation
E	Small recession rice farms with no irrigation
F	Large, recession rice farms with no irrigation

Building on the work of Rio *et. al*, key informants were selected from the farmer discussion groups to represent local household typologies and the gender diversity found in the farming community. The objectives of the KIIs were to:

- Validate the household types and identify whether cropping systems differed between them
- Understand the benefits and constraints of particular cropping systems and develop crop management calendars and 'decision trees' to enable systems simulation and analysis.

2. Methodology

Interview process

Twelve farmers (6 male and 6 female) were identified for interview (Table 2) through discussion with the FGD consultant, DAE and iDE. Those selected represented 5 of the 6 household types identified in Table 1. Individuals were contacted by a local PDA representative and invited to participate. Individual interviews were conducted over 4 days with each taking around 1.5 hours (undertaken at the home of each farmer). A team of 4 participated in the interviews-Neal Dalgliesh (interviewer), Perry Poulton (scribe), Phally (PDA) (white board depiction of cropping calendars) and Mao Minea (DAE) (translator). The team was generally accompanied by 1-2 senior representatives of the local village and commune. An audio recording was undertaken with the prior approval of each participant. Initial questioning aimed to provide information on the livelihood mix of the farmer and their cropping system/s. Outcomes of this discussion were used to focus the remainder of the interview around the particular cropping systems of relevance to the individual, including the agronomy and management of traditional rice production, the growing of 2 short duration crops using the technologies suggested by the project and the situation where farmers were 'cherry picking' available technologies to suit their own requirements. The full interview protocol is attached as Appendix 1 and the results of individual farmer interviews as Appendix 3.

Table 2: *Characteristics of the 12 farmers selected and interviewed as key informants.*

Participant (gender)	**KII Typology (previous FGD typology)**	**Comments**	**Village**
1 (f)	A (C)	3700m^2, rain fed, grows vegetable	Kbal Damrey
2 (f)	D (C)	4000m^2, rain fed rice, grows some vegetables to sell, off-farm income	Kbal Damrey
3 (m)	D (D)	3.5 ha, irrigation	Kbal Damrey
4 (m)	D (D)	2.5 ha, access to canal, depends on agriculture	Koul
5 (m)	B (A)	1.5 ha, limited access to canal, depends on agriculture	Koul
6 (m)	B (B)	2.5 ha, some access to irrigation	Koul
7 (m)	B (-)	Depends on rice, animals and vegetables, access to ground water	Kbal Damrey
8 (f)	C (A)	9000m^2, some irrigation access, remittance (control)	Sampor
9 (f)	A (B)	2 ha, access to irrigation canal (control)	Sampor
10 (f)	C (D)	1.3 ha, some irrigation, remittance (control)	Kien Tasiv
11 (m)	F (F)	1.3 ha, access to canal, some off farm income, recession rice	Cheas Ressey
12 (f)	F (E)	1 ha, recession rice, off-farm income	Cheas Ressey

Post-interview data processing

Household types and cropping system differences: The FGD process identified the household types relevant to the 12 individuals selected for interview. It was understood that some discrepancies existed between the FGD typology groups identified during the initial selection by commune officials and those found to be the case during the actual FGD interviews. The KII process was used to confirm previously identified typologies and to ascertain links between typology and cropping system. Data relating to these topics was identified in the discussion on farmer livelihood and general cropping system.

Cropping calendars: Notes recorded during the interviews were collated into individual interview summaries confirming the household type, cropping systems used and particular attributes relating to the individual farm (Appendix 3). Further refining of these notes led to the development of more general seasonal calendars for cropping system types including:

- Rainfed or irrigated double cropped, short duration, wet season rice
- Rainfed or irrigated medium/long maturity wet season rice (both traditional and modern varieties)
- Wet season short duration rice and dry season recession rice cropping.

The crop calendar data was then used as the basis of a generalised APSIM manager template for use with the suite of cropping options available to farmers in Svay Rieng. This tool allows the input of crop calendar decision/trigger points sued by the individual farmer and the analysis of the system under both current climatic conditions and future climate change scenarios.

3. Findings of key informant interviews

Impacts of project intervention

General views on the adoption of new farming technologies and their impact on crop production were expressed by participants during interview. The following comments provide some insight into the challenges and opportunities provided by the new cropping technologies being tested including the use of double cropping and mechanisation.

a) *Drum seeding*-while only 25% of interviewees routinely used drum seeding, another 50% have adopted hand broadcasting to establish the majority of their rice crop. Some traditional varieties continue to be transplanted but there seems to be a general trend (if these farmers are representative of the district) towards direct seeding. In my view, the use of hand broadcast is a transitionary phase between transplant and more effective direct seeding techniques and would expect to see increasing levels of adoption of drum seeding over time. The main reasons expressed for moving to direct seeding (drum and hand) were the reduction in labour costs (exacerbated by the reality that more family members are migrating to the city) and the speed of planting. One farmer indicated that planting time had moved from 40 person days/ha with transplant to 2.2 hours with drum seeding. In many cases, the constraint to adoption of drum seeding related to the high cost of seeder purchase (~US$50/unit) and not to any agronomic deficiencies. There were some comments regarding the difficulty of dragging a drum seeder through mud, and its use in high water conditions, however none of those currently using the seeder indicated that they would stop.

   While it might have been thought that weeds would be considered a negative in hand broadcast crops due to the random nature of rice seed distribution (compared to the rows which result from drum seeding) and the less efficient weeding of the crop, this did not appear to be the case with the majority of farmers either hand spraying or applying herbicides in granular form in conjunction with the application of fertiliser. Almost all of those interviewed (10 of 12) used herbicides and used personal safety equipment during application. Granular application seems to be becoming more popular due to the difficulties associated with moving through a wet paddy whilst carrying a heavy knapsack sprayer.

b) *Use of Cambodian short duration rice varieties and double cropping*-The majority of those wet season producers located in Kbal Damrey, Koul and the control villages who were growing short duration varieties as part of their cropping strategy used the CARDI recommended varieties, IR66 and Chul'sa. Yields for individual crops ranged between 1.8 and 4 t/ha. One farmer indicated that he also used Vn504. The 2 recession farmers at Chas Ressey grew Vn504 for both recession and wet season cropping with yields of between 3.5 and 5 t/ha.

   The observation made in the FGD report (Rio 2013) that farmers were only likely to grow short duration crops on secure land adjacent to their dwelling is supported in this survey. Farmers cited management of animals as a major issue for 'out of season' crops. Given this constraint, it is likely in the short and medium term that the use (and area) of short duration crops will continue to increase but will form only part of the overall farmer cropping strategy which will continue to include medium and long duration varieties. This strategy will help to spread the risk of drought or other catastrophic events, as well as spread seasonal labour demand. At some point in the future, when the proportion of short to medium and long duration crops reaches a certain stage, there may be sufficient area of the short duration varieties in the landscape to mitigate the current security issues. This has occurred in the recession rice areas where dry season irrigated crops, and cattle appear to co-exist without major mishap.

c) *Crop transition periods*-An area of concern to researchers has been the time spent in transitioning between crops in a double cropping system. While the transition time had to be kept to a minimum, it was thought that the logistics of harvesting and ploughing and the time required to break down stubble were a major limitation to the adoption of the system. On-farm research often showed totally unacceptable transition periods of between 20 and 30 days which resulted in later than optimal second crop establishment and regular crop failure due to a lack of water at the end of the wet season. However, when asked to comment on their own experiences, not one farmer saw transition time as an issue, having already developed techniques to keep transition below 7 days without jeopardising second crop yield. Farmers described harvesting the first crop, including the straw (in some cases sold for animal feed), irrigating if required (and available), ploughing and levelling using a 2 wheeled tractor, applying fertiliser and then direct seeding the second crop by either hand broadcast or drum seeding.

d) *Differences in adoption between villages*-two seasons of on-farm research in the villages of Koul and Kbal Damrey indicated differing levels of interest in the testing of cropping options amongst the farmer groups. In Kbal Damrey there was keen interest in double cropping, whereas in Koul interest was lack lustre. A key informant interviewee estimated that in the village of Kbal Damrey, which started with 1 group of 18 growers in 2011, there was now around 80% of village farmers' double cropping part of their farm (170 farmers in the village). Of the original 18, 14 are still double cropping although many have moved to hand broadcasting due to the cost of the drum seeding equipment. In terms of double cropping, the farmers of Koul appear to have caught up with their neighbours with all of the 3 interviewees double cropping part of their land and all hand broadcasting to establish their short, medium and long duration crops. Drum seeding adoption is also slow in this village with about 10 farmers using the technology in 2013. Of interest, was the common use of direct seeding and short duration varieties in the control villages where there has been no farmer exposure to project activity. It is surmised that adoption has occurred through the activities of agencies such as PDA, iDE and social engagement between the villages which are all within close proximity.

e) *Differences in adoption between typologies*
All of the farmers who represent the typologies that describe the rainfed, wet season rice production systems (Table 1: a, b, c, d) appear to have adopted the use of double cropping and modern varieties. The majority are using fertiliser (albeit often in sub-optimal quantities) and direct seeding with mechanised land preparation and harvesting rapidly becoming the norm. None of these technologies appear to be the domain of any particular typology. Prior to this survey, it was considered that the larger, resource rich farmers were likely to be the early adopters of direct seeding and short duration varieties, but contrary to this, small, subsistence farmers who are only interested in food security are also adopting the technologies because they save labour and allow the family to focus on other interests such as off-farm income or migration without jeopardising family food security. There also appears to have been some movement of individuals between typologies. Surveys undertaken in Kbal Damrey in 2011 indicated a low level of access to irrigation resources, this seems to have changed in the last 3 years with the majority of the original farmer group of 18 now having access to canal, pond or tube well water. It is surmised that this is a result of a number of things including project activity which provided loans to some of the group members for irrigation infrastructure (tube wells) and the expansion of the government canal network.

f) *Irrigation use*-it became apparent that around half of the wet season farmers interviewed had access to irrigation at the commencement of the current season, either from tube wells or ponds, with many indicating that they had the flexibility to 'plant to date' and were not constrained by a lack of rainfall. These farmers indicated that they would commence irrigation in late April, early May and plant within 2 weeks of commencement of land preparation. The majority of the remaining growers indicated that they would await sufficient rainfall before they would be confident of planting but all indicated that they expected to plant the first short duration crop in May.

When asked about their strategy where the wet season rains were late, those with irrigation were confident that they could 'plant to date' and still grow 2 crops within the season. Those who were relying on rainfed production indicated that they would continue to plan for 2 crops but if the first crop did not mature until the end of September they would forgo the second crop. These insights showed that farmers were not working to a set cropping 'recipe' but were actually considering the options open to them both prior to and during the season and making logical decisions on the risk associated with various cropping strategies.

What became very evident during the interviews was that the farmers most likely to adopt double cropping in the longer term will be those with irrigation because it takes the risk out of the timing of crop establishment and provides a buffer against water shortages during the wet season, particularly in the July/August period which is commonly known locally as a 'drought' period.

g) *Estimating season start*-One of the challenges for researchers has been to understand the process whereby farmers make the decision to plant, when the early wet season is such an unreliable and risky environment in which to establish crops. Like western farmers who use a rain gauge to measure rainfall and to determine an appropriate planting time, it was assumed that Cambodian farmers had some inherent system of estimating the riskiness associated with crop establishment at this time of year. It turns out that the Cambodian farmers had their own rain gauge all along, their paddy. While the rule of thumb varied between individuals, all of those interviewed indicated that they commenced land preparation and planting when their paddy reached a particular depth of water, generally between 10 and 20 cm. In fact, many decision points, such as the time to plough, plant and fertilise were often based on the depth of water in the paddy. Having rules for land preparation and crop establishment based on water depth rather than just rainfall makes it much easier for researchers attempting to understand and model the rice cropping systems.

h) *Fertiliser use*-11 of the 12 farmers used either an NPK fertiliser or urea, or a combination of both. Some applied trace elements as part of a mixed fertiliser sold in the market. All 9 farmers who grew wet season short duration rice used inorganic fertiliser, although only 3 applied nitrogen at, or above the CARDI recommended rate of 50-60kg/ha (Figure 1). Manure was also used at or around the time of sowing by 8 wet season growers, although a number indicated that application was limited to every second or third year due to supply shortages. The recent installation of 6 biogas demonstration units in the district by PDA (Japanese funding) may result in more manure becoming available in the future. The 2 recession rice growers used only inorganic fertilisers sourced from Vietnam.

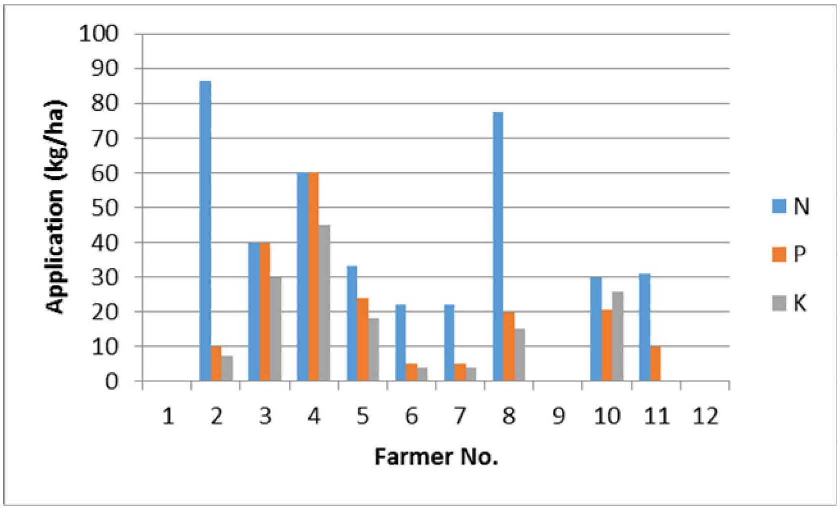


Figure 3: Fertiliser application rate for the first short duration rice crop grown in 2013. Note that application rate is quoted as kg/ha n, P and K.

i) *Mechanisation*-the use of combine harvesters and binding and threshing equipment to harvest rice is increasing rapidly. Five of the 12 farmers indicated that they hired contractors in 2012 or for the first crop in 2013 (~US$75/ha for a combine harvester) citing a lack of labour and the speed of harvest as the main reasons. Mechanisation of tillage is now almost universal with all but 1 of the farmers using 2 wheeled tractors for ploughing.

j) Cash and vegetable crop production
The original premise of the engagement with farmers in Svay Rieng was to investigate the opportunities to broader farmer livelihoods through the production of irrigated/residual soil moisture, dry season cash and vegetable crops, as follow-on crops to the wet season production of 2 short, or 1 medium duration rice crop. This was tested with a small number of collaborating farmers in 2011, 2012 with some success under irrigated conditions. During interview a number of farmers indicated that they did grow vegetables around the dwelling, mostly for home consumption but with surplus sold locally. Only 2 farmers indicated that they were growing crops in the way envisaged by the project i.e. after the rice crop, in the paddy. Both were located in Kbal Damrey with 1 having successfully grown both maize (for green cob) and vegetables (cucumbers and long bean) from January to March/April. He indicated that both crops had been financially successful but cited security as an issue. The other farmer has a very successful operation in the rice fields adjacent to his dwelling. Compost, based on animal manure is used to fertilise a range of vegetable crops after harvest of the rice. Both of these examples show that there is potential to grow dry season vegetable and cash crops although a number of criteria need to be met including the availability of irrigation, good security, a market for the produce and sufficient labour, given that many farmers migrate for work during the dry season.

k) *Provision of information to farmers*-Three sources of crop production information were referenced by the farmers. In the recession rice areas along the Vietnam border farmers indicated that the majority of their information came from the Vietnamese merchants who provide their inputs, seed, credit and markets. In the other villages, not as influenced by this cross border activity, both PDA and iDE were regularly mentioned as the main sources of information. One very poor farmer who had a small production area of deep water rice indicated that she had never received any information on the growing of rice. This was reflected in her use of an old variety, her lack of fertiliser use and the use of seed that her family had been retaining for a period of 20 years. Her crop yield averaged around 600kg/ha.

Typology confirmation

There was some difference in the initial allocation of 'typology to individual' determined during the FGD process and those later attributed as part of this study. This was generally a result of the mis-interpretation of FGD requirements by commune authorities when selecting farmers, resulting in some mixing of typology type within particular FGD discussion groups (from which individuals were identified for key informant interviews). However, it was also considered difficult by the key informant team to adequately allocate the farmers to the range of typologies available. While this was a general issue across typologies, the most obvious example related to the recession rice farmers where both available typologies indicate no access to irrigation, whereas the reality is that they all have irrigation access. Table 2 shows both the typologies allocated by the KII team and those originally allocated during the FGD process.

4. *Crop calendars and development of simulation capability*

Crop calendars for each of the identified farmer cropping systems (Figure 2) were an important output from the interview process. It should be noted however, that the calendars were developed from the notes of the English speaking researchers and may be further refined when translations of the Khmer white board versions become available (Appendix 2).

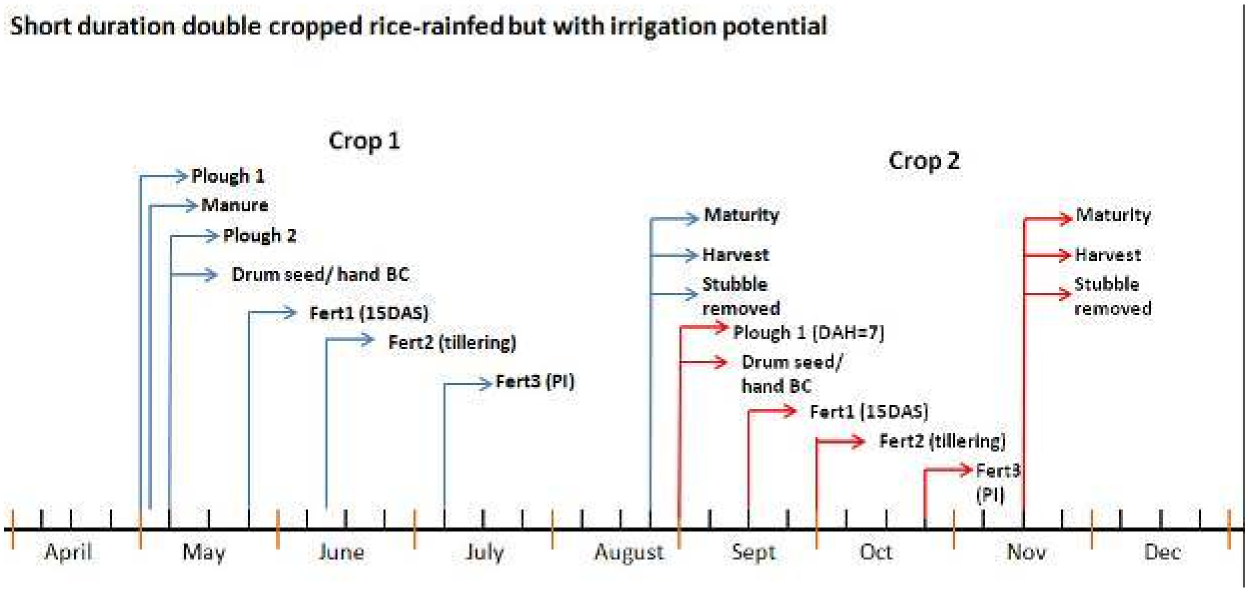


Figure 4: An example of crop calendar elicited from key informant interviews showing the time line of farmer operations for the production of 2 short duration rice crops grown during the wet season in Svay Rieng province.

While a paper-based calendar is a useful visual tool for presentation and discussion of a particular system it becomes particularly important when used as the basis of cropping systems simulation modelling. The intermediate step required before this can be attempted is to develop code around the timing of farmer actions that allows information input to the model. While this could be done by developing rigid code that reflects the timing of actions of each individual farmer, in each season and for all of their cropping systems (Figure 3), this is not an appropriate approach given that farmer decisions change seasonally based on climatic and production variables and the whole aim of simulation is to explore the riskiness of the cropping systems through time. Consequently, a more flexible APSIM manager module has been developed which will enable the simulation of the Svay Rieng rice systems (Figure 4; 5) over a prolonged period based on long-term climate data. This approach provides the user with potential to select ‘action triggers’ for each of the possible management options that have been provided by the farmers during interview and to subscribe values to those actions before an event is triggered. For example, the option for growing 2 short, or a single medium duration variety during the wet season may be based on the receipt of a particular amount of rainfall prior to a particular date, or crop sowing may be triggered by the occurrence of rainfall that results in a designated depth of water in the paddy, or the timing of fertiliser application (and the type of fertiliser and rate of application) may be based on seasonal or crop physiological triggers.

While there is still some fine tuning of the manager module to be undertaken, it is thought that the modelling of the cropping scenarios used by the 12 Svay Rieng farmers is now possible.

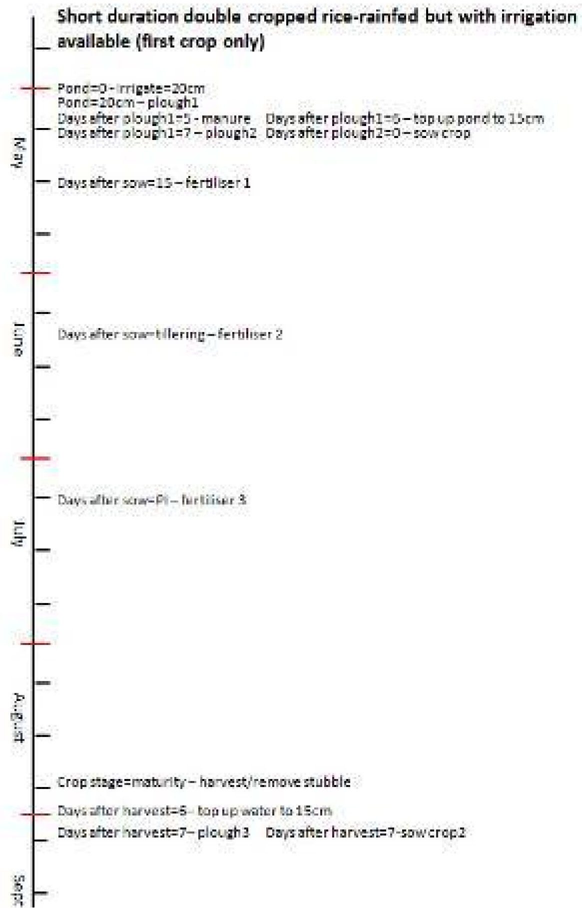


Figure 5: *An example of the development of inflexible coding of a cropping system for use in APSIM*

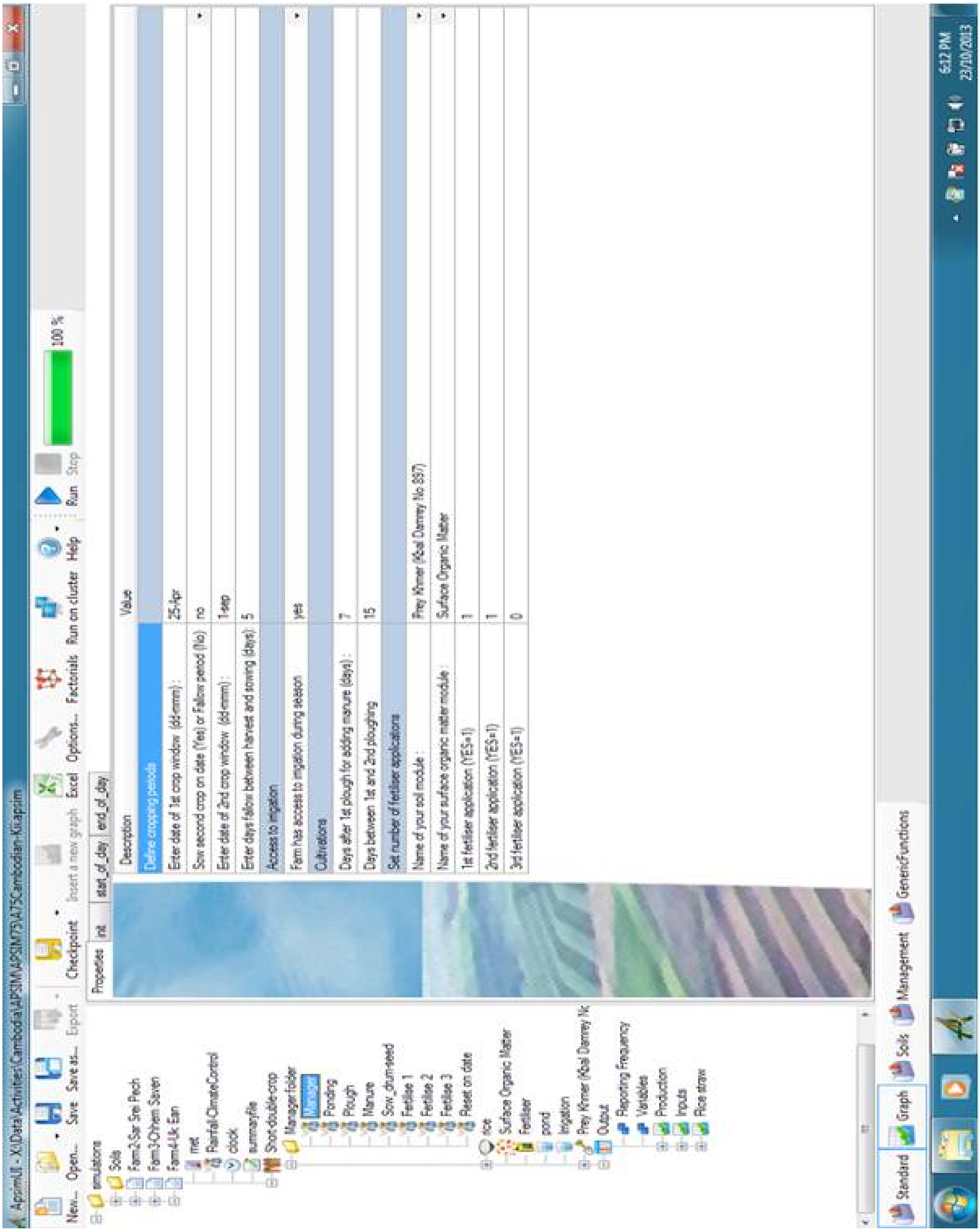
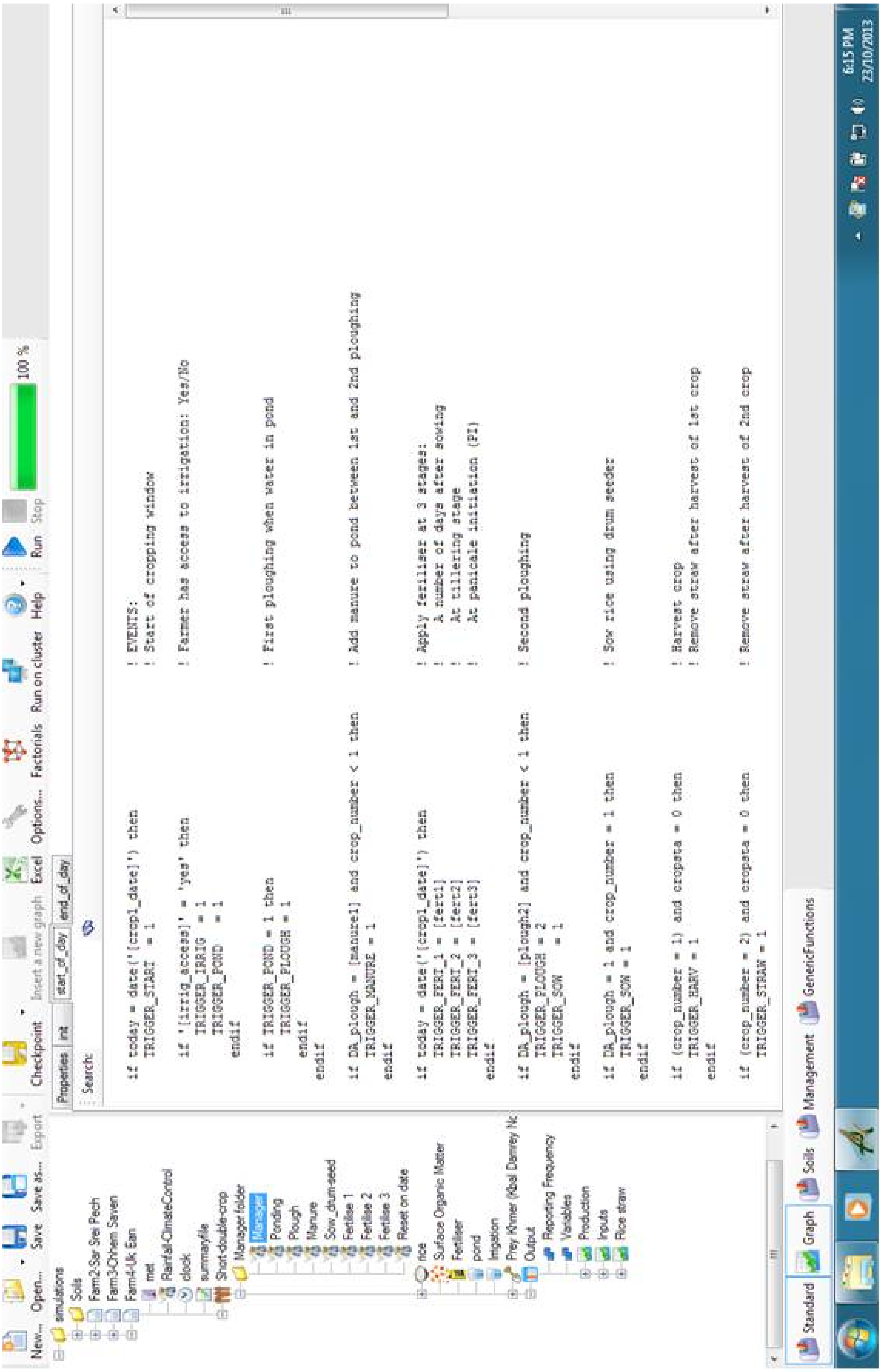


Figure 6: *APSIM screen shot showing the Cambodian rice manager module developed to handle the cropping options identified during the key informant interviews at Svay Rieng.*



Apı ***Figure 5:*** *APSIM screen shot showing farmer decision and trigger points embedded in the APSIM rice manager module.*

Objectives and Interview Questioning

Interview time: 1.5 hours; plan to undertake 3 interviews per day subject to farmer availability (likely that the first couple of interviews will take longer than planned)

Item	Description	Time
Introduction	• Introduction to the interviewer and team • Introduction to the study and to the interview process	5 minutes
Interview	• Clarify farmer typology • Discuss individual farmer practices and commence the development of a decision support tree for cropping systems	80 minutes
Conclusion	Wrap-up	5 minutes
Total Time		90minutes

Objectives of the interviews:

- Identify if and how cropping systems differ between household types i.e. is there a clear difference in both the cropping systems that particular typologies utilise and the use of particular technologies within those systems e.g. drum seeding, fertiliser, varieties etc.
- Understand the benefits and constraints of particular systems of crop production
- Validate the household types-match against practices
- Elicit 'decision trees' used by farmers in making crop management decisions for rice based systems in Svay Rieng, with the aim of coding the decisions into APSIM to enable systems simulation and analysis.

Selection of interviewees:

3-4 farmers from each collaborating village will be selected to participate in the KII. They should represent the range of household typologies defined by the project and found within particular villages. Individuals are to be identified through the Focus Group Discussion process. Gender diversity is important.

In some villages there may only be 1 typology present. I would suggest that in this case we identify variations in the way that crop production is approached e.g. in Village 1, all of those interviewed in the FGD may be Type C, but some may continue to produce medium duration, traditional varieties while others may have embraced the use of 2 short varieties, or drum seeding or the whole package tested by the project. In this case differences should be identified through the FGD for use in the KII process.

Villages:

Koul, Kbal Damrey, Chas Ressey, Control x 2

The control village interviewees should represent the local traditional system i.e. the growing of a single, medium duration rice variety in the wet season or some version of a traditional recession system if such a system still exists.

Typologies:

Household Typology A: Small, rainfed farms with no irrigation and high levels of migration.

Household Typology B: Large, rainfed farms with limited irrigation.

Household Typology C: Small, mainly rainfed farms with limited irrigation and high levels of migration

Household Typology D: Large, mainly rainfed farms with access to canal irrigation.

Household Typology E: Small recession rice farms with no irrigation.

Household Typology F: Large, recession rice farms with no irrigation.

Instructions for facilitators:

Introduction

Find a quiet area without distractions in which to undertake the interview. Introduce yourself, thank the interviewee for their participation and give the relevant background information and an overview of the topic. Emphasize that this is an opportunity for the participant to give voice to their opinions and that the researchers are there to learn from the participants. Explain what the results of the focus group will be used for and what form the data will take.

Outline the ground rules

- Emphasize that one person speaks at a time
- Indicate that notes will be taken to ensure that all comments are recorded
- Seek permission for the audio or video capture of the discussion
- Assure participants that no specific names will be used in the final report
- Emphasize that all points of view are important to the discussion

Example of introduction

Thank you for agreeing to be part of this focus group discussion. I would like to explain briefly the purpose of this discussion, so you can get a better understanding of its aims.

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Department of Agricultural Extension (DAE) of MAFF and other partners are working together to understand strategies that farmers use to adapt to changes in the weather and to vulnerability. This information will be used as a basis for improving their projects and to help them develop better ways to assist farmers with climate change.

The information that you provide to us during this discussion cannot be traced back to you as an individual. We will only use information in a generic form. The discussion will take around 1-1.5 hours to complete. We will record this discussion to be able to analyse our conversations later and to ensure that we capture all the information correctly. You are free to refuse to participate or to leave at any time. Please be totally truthful in your responses. Your participation is very important. We fully appreciate your time, and we thank you in advance for your valuable contribution to our study.

Interview prompts:

My preference is to develop discussion around identified areas of research focus instead of attempting to pre-empt detailed questions prior to the interview. In essence, a conversation between 2 people about a topic that, over the course of the discussion, drills down into the areas considered important.

A visual aid will be developed that allows the farmer to compare cropping system interventions with their traditional cropping system. It is anticipated that providing a visual description of the timing of operations and how the system has been modified will be a useful, both as a backdrop to discussion and in facilitating development of the modelling 'decision tree'.

Note: In the following pages the comments in italics and brackets suggest the thinking behind particular questions, or provide suggestions for interviewer prompts, or an indication of where it is considered that discussion will likely lead.

Questions:

1. **The livelihood**
   a) 'Big picture' family system information *(Ice breaker; confirmation of typology)*
      - Livelihood mix *(Crops, animals, off-farm income, migration; etc)*
      - Farm size *(owned, leased, shared?)*
      - Relative importance of livelihood components *(Farm: crops, animals etc-food security, commercial sale; off-farm income and migration importance)*
      - Family size and engagement *(number involved in farm; off-farm; migration; school)*

2. **Cropping system overview**
   a) Crops grown *(Listed; relative importance of each to farming system)*

   b) Rice
      - Area grown to rice
      - When grown *(rainfed wet season; irrigated dry season; both)*
      - Rainfed or irrigated *(proportion of farm irrigated; irrigation source; season in which irrigation used; what used for-full vs. supplementary)*
      - Rice varieties *(traditional; improved; duration; why particular ones grown)*
      - Reason for growing *(food security; commercial sale; proportion)*
      - Productivity *(Yields; gross margin)*
      - Marketing *(food security; sold locally; provincial; international)*
      - How is rice grown *(traditional vs. research modified vs. cherry pick of options; why are particular systems being used; tease out what systems and particular technologies are being used to grow rice, this will then direct later questioning to specific systems and technologies)*
      - Proportion of farm under different rice systems *(is research modified still only on small trial area?)*
      - Location of rice production systems on the farm *(reasons)*
      - Has the mix changed over time *(time frame, why; drivers of change-direct research intervention; changing climate; through peers; PDA; NGO; irrigation expansion)*
      - Have you experienced change in the seasonal climate that influences your cropping decisions

   c) Other crops (vegetables; cash crops)
      - What crops did you grow this year/last year?
      - What crops did you grow 5- 10 years ago? *(what has changed and why)*
      - How long have these crops been important to livelihood *(time frame)*
      - Drivers of change *(family economics; climate variability; ???)*
      - Dryland or Irrigated *(availability; source)*
      - When and where are other crops grown on the farm *(season; house or paddy; in conjunction with rice; timing)*
      - Knowledge of new crops *(source of information; project; peers; PDA; NGO)*

3. Agronomy and management of rice grown traditionally

This is the status quo for the particular typology. In rainfed monsoonal systems it is likely to be a single, medium duration, traditional rice variety grown with small amounts of organic fertiliser. Where irrigation is present, a second crop may be grown in the dry season or the water used to supplement the rainfed crop. No other major crops are likely to be grown. In recession rice areas, it is likely that the norm will be the production of 2-3 crops per year under rainfed/irrigated conditions using higher inputs of fertiliser and Vietnamese short duration varieties (note that recession rice production is not currently mentioned in detail in the protocol but could be easily developed from the following)..

a) Growing 1 medium duration variety

- Summarising the cropping system as used by the farmer *(farmer view of what they are doing; observations on its applicability)*
- Area under system
- Rice variety *(is production totally around traditional, local varieties, or are improved lines used as well; if so, what proportion)*
- Neighbourly interest *(is their traditional system common to their neighbours and peers)*
- Opportunities and constraints to continuing use of the traditional system *(will they continue to use the system into the future-why would they not change to using new technologies; advantages; disadvantages to the system; what would make them change the current system)*
- Why continue to grow 1 medium duration variety when other options are available *(food security met; insufficient labour; costs)*

b) Agronomic practice for 1 medium variety (use visual aid to discuss options in this section)

- Deciding when to plant *(how is the decision made on when to plant-rainfall, date, tradition, inherent knowledge; supplementary irrigation; other)*
- Seedling nursery establishment *(when; how is the decision made)*
- What constitutes an early, normal or late season start *(on what criteria are these judged)*
- Initial land preparation *(when do they start; what are the triggers-rainfall, if so how much, time of season; how long does it take and how is it done; what are the constraints-labour and equipment availability)*
- Secondary land preparation *(when do they start; what are the triggers-rainfall, if so how much, time of season; how long does it take and how is it done; what are the constraints-labour and equipment availability; how long between ploughing and first drum seeding)*
- If rains have started but the trigger point for transplanting has not been reached, what do they do *(i.e. is it rainfall that triggers the decision or some other indicator)*
- If the rains are late how do they respond *(will they plant at all costs to meet food security i.e. are they responding to the conditions or still thinking in terms of a recipe approach; get some dates around these decisions)* (visual aid)
- Transplanting crop *(timing; labour; advantages/disadvantages; work rate; is drum seeding an alternative)*

- Fertiliser application *(is fertiliser used, if so what type-organic/inorganic; cost; availability, knowledge source; application rate and timing; does timing of application or rate vary with time of planting-early, late)*
- Pesticide use *(are they used; thoughts on the use of herbicides and insecticides; opportunities and constraints to use; safety issues; have they used in current season, if not, why not)*
- Harvesting crop *(labour issues; harvest work rate; issues around timing and ability to harvest and dry grain; how much stubble is left standing i.e. is the crop cut near the soil surface or below the head; is mechanised harvesting an option)*

c) Economics of a single, medium duration rice crop and fertiliser use

- Identify whether individuals see rice production as a business or as food security only *(sell rice in the market or for family use)*
- Profitability of 1 crop *(is it all about food security; comparison with other livelihood options)*
- Response to observing higher rice yields from higher rates of inorganic N in trials *(have they increased N use in traditional crops; if not why not; what would it take to change current practice; what rates have they used; when has it been applied; do they use organic fertilisers, if so, what sort, how much and how often)*
- Is increased N use linked to the livelihood goals of the individual *(already food secure and don't need to sell rice because of other components of the livelihood are contributing to the overall family income)*

d) Irrigation

- Irrigation availability *(canal, pond, tube well; supplementary or full)*
- *Has access changed over the past 5 years (new communal schemes; investment in tube wells; access to trickle through iDE)*
- Constraints to investment in irrigation *(credit; labour; is irrigation infrastructure increasing, if so, how might that effect future investment)*
- Area of land able to be irrigated seasonally *(wet and dry seasons)*
- Annual availability of irrigation *(at planting, mid season or end of season; is there sufficient irrigation to finish second crop)*
- Supplementary irrigation *(How often has it been used in the last 3 years; what time of year)*

4. Agronomy and management of 2 short duration rice crops, vegetables and cash crops

This is where the farmer has indicated that they are following the proposed researcher modification of 2 wet season, rainfed, short duration crops using an improved variety with the first planted earlier than traditional practice. Supplementary irrigation supply is likely. The crop is drum seeded and reasonable levels of inorganic fertiliser applied. All of the above strategies need to be present to be considered in this section.

a) Growing 2 short varieties

- Summarising the 2 crop system as used by the farmer *(farmer view of what they are doing; observations on its applicability)*
- Use of technique outside of the OF trials *(research only or commercial practice)*
- Area under system *(compare with rest of rice area)*

- Neighbourly interest *(is there expansion out from research collaborators/on-farm sites; which has been the catalyst)*
- 2013 activity *(what area planted to 2 crop system; any modifications to the system; outcomes; if not done, why not)*
- Opportunities and constraints to continuing use *(will they continue to use the 2 crop system into the future; advantages; disadvantages to the system; constraints-seed and fertiliser supply, money; have they modified or considered modifying the current system)*

b)* Agronomic practice for 2 short duration crops of rice *(use visual aid to discuss options in this section)

- Deciding when to plant *(how is the decision made on when to plant-rainfall, date, tradition, inherent knowledge; supplementary irrigation; other)*
- What constitutes an early, normal or late season start *(on what criteria are these judged)*
- Initial land preparation *(when do they start; what are the triggers-rainfall, if so how much, time of season; how long does it take and how is it done; what are the constraints-labour and equipment availability)*
- Secondary land preparation *(when do they start; what are the triggers-rainfall, if so how much, time of season; how long does it take and how is it done; what are the constraints-labour and equipment availability; how long between ploughing and first drum seeding)*
- If rains have started but the trigger point for planting has not been reached, what do they do *(i.e. is it rainfall that triggers the decision or some other indicator)*
- If the rains are late when do they respond and move from a 2 crop scenario to another cropping choice *(do they plan to plant later than optimal and still plant 2 crops or revert to 1 SD crop or 1 MD crop i.e. are they responding to the conditions or still thinking in terms of a recipe approach; get some dates around these decisions)* (visual aid)
- If rains start early what triggers the planting of 2 SD crops *(plant first crop ASAP or wait until confident in weather-if so, what are the criteria on which the decision is made)*
- Planting crop 1 *(how do they plant i.e. drum seeder, broadcast, dry sowing etc)*
- Issues around planting *(availability of drum seeder; do they own a drum seeder-of not, why not; hire of DS-cost and availability; advantages/disadvantages over transplant; work rate; general view of usefulness; will they use for other rice crops e.g. traditional; thoughts and experience of other direct seeding technologies; cost of seed and comparison with other establishment options)*
- Fertiliser application *(use of fertiliser-cost, availability, knowledge source; application rate and timing-how are these decisions made; does application timing or rate vary depending on the time of planting-early, late; have similar rates been used in 2013 now that there are no project subsidies or credit)*
- Pesticide use *(direct seeded rice will require better weed control, insect control will likely result in improved yields; thoughts on the use of herbicides and insecticides; opportunities and constraints to use; safety issues; have they used in current season, if not, why not)*
- Harvesting crop 1 *(labour issues; harvest work rate; issues around timing and ability to harvest and dry grain; has the process had to be modified compared to traditional methods; how much stubble is left standing i.e. is the crop cut near the soil surface or below the head; is mechanised harvesting an option)*

- Transitioning between crop 1 and 2 *(what is current transition time-do you want to reduce the time, if so, how might it be achieved; comments on the challenges of land preparation; ploughing work rate; stubble management; fertiliser application; availability of labour and equipment i.e.2 wheeled tractors; observations on productivity of second crop-is it suffering from N tie up for example)*
- Decisions surrounding the growing of a second crop *(influence on decision to plant-time of harvest of crop 1 and transition time, previous experience, availability of irrigation, food security requirements; how late is too late to grow crop 2; is an overt evaluation of the risks associated with second crop planting made i.e. I will not plant because it is too late to catch late wet season rainfall and I have no irrigation water, so therefore I will look for other options, or will they blindly try to grow the crop)*
- Planting crop 2 *(Method-drum, broadcast, transplant; comments on planting rate and labour requirements; issues of establishment in the middle of the wet season-challenges of high water levels-how is that managed; what level of water is required; when would you consider that it was too late to plant a second crop)*
- Harvesting crop 2 *(issues around timing and ability to harvest and dry grain; has the harvesting process had to be modified compared to traditional methods; how much stubble is left standing i.e. is the crop cut near the soil surface or below the head; is mechanised harvesting an option; use of land afterwards-does it impact on how the land is managed at harvest i.e. removal of stubble; traditional use of stubble)*
- Impacts of growing 2 crops on labour *(overall labour requirements; changes in distribution of labour; impact on overall livelihood-changes to resource allocation within agriculture and overall)*

c) Agronomic practice for late wet season, early dry season vegetable/cash crop production

- Experience of growing secondary crops *(clarify that they are not just around the house; when are they growing; will they start/continue to grow cash and vegetable crops; challenges; opportunities)*
- Drivers for growing vegetables and cash crops *(time of season; irrigation availability; credit; markets; availability of advice)*

d) Economics of 2 crop strategies

- Profitability of 2 crop scenario *(comparison with traditional, or other cropping options; comparison with other livelihood options)*
- Drivers of the use of 2 crop system *(profitability; food security; ?)*

e) Using short duration improved varieties

- Given the yields of the CARDI lines, will they continue to use them *(if not, why not; seed availability; retaining seed)*
- Are they using Vn504 *(when and why; how is it established-generally broadcast; availability of seed; retaining seed; is there a preference for 504-if so, why)*

f) Drum seeding (DS)

- Experiences of using DS *(opportunities; challenges-drought, high water levels, heavy rain, weeds, uneven fields, crop establishment)*

- Will they continue to use DS and why *(labour saving; weed control)*
- Are they using DS for their own cropping program or just in on-farm experiment *(reasoning)*
- Access to DS *(owned/rented/contractor)*
- DS saves time, how will the time be re-allocated *(more area/migration/other activities outside of agriculture in local area?)*
- Land levelling *(DS works best in a level field with no clods-would they be prepared to invest time in land levelling using the labour saved through the use of drum seeding)*
- Consideration of other direct seeding technologies *(dry seeding opportunities; interest in testing)*

g) Using higher rates of fertiliser

- Identify whether individuals see rice production as a business or as food security only *(sell rice in the market or store for family use)*
- Response to observing higher rice yields from higher rates of inorganic N *(have they increased N use in traditional crops or in 2013 2 crop strategy; if not why not; what would it take to change current practice; what rates have they used; when has it been applied; do they use organic fertilisers, if so, what sort, how much and how often)*
- Is increased N use linked to the aims of rice production *(already food secure and don't need to sell rice because of other components of the livelihood are contributing to the overall family income)*

h) Irrigation

- Irrigation availability *(canal, pond, tube well; supplementary or full)*
- Constraints to investment in irrigation *(credit; labour; is irrigation infrastructure increasing, if so, how might that effect future investment)*
- Area of land able to be irrigated seasonally *(wet and dry seasons)*
- Annual availability of irrigation *(at planting, mid season or end of season; is there sufficient irrigation to finish second crop)*
- Supplementary irrigation *(How often has it been used in the last 3 years; what time of year)*
- Access to iDE loan for irrigation infrastructure *(did you access loan; if not, why not; did access to credit facilitate the decision to invest-would they have done it anyway, where would they have got the loan from; have others invested more recently-source of funds)*

5. Agronomy and management of rice grown with 'cherry picked' technologies

This is where the farmer has been selective in using particular technologies from the researcher modified package above. These could be drum seeding, short duration varieties, higher nutrition etc. I would assume that we will realise when commencing to discuss the 2 crop scenario, whether we should really be moving to questions about a more 'as hoc' approach to the technologies on offer. It may be that we start with the 2 crop scenario and then quickly move to this set of questions if required.

a) Using demonstrated technologies but in a way that differs from above.

- Summarising the cropping system/s used by the farmer and the technologies borrowed from the 2 crop system *(farmer view of what they are doing; observations on its applicability; how have they changed the traditional, or 2 crop system to better suit their needs; how are they using particular technologies)*

- Number of rice and other crops being grown per year
- Area of production using modified technologies
- Neighbourly interest *(is there expansion out from research collaborators/on-farm sites; which has been the catalyst)*
- 2013 activity *(technologies used; outcomes)*
- Opportunities and constraints to continuing use *(will they continue to use particular technologies; advantages; disadvantages to the system; constraints e.g. seed and fertiliser supply, money)*

b)* Agronomic practice for rice production *(use visual aid to discuss options in this section)

There is a lot of duplication in this section and cherry picking of appropriate questions will be required depending on how the 2 crop system has been modified by the farmer. This decision will be made at the time of interview.

- Deciding when to plant *(how is the decision made on when to plant-rainfall, date, tradition, inherent knowledge; supplementary irrigation; other)*
- What constitutes an early, normal or late season start *(on what criteria are these judged)*
- Initial land preparation *(when do they start; what are the triggers-rainfall, if so how much, time of season; how long does it take and how is it done; what are the constraints-labour and equipment availability)*
- Secondary land preparation *(when do they start; what are the triggers-rainfall, if so how much, time of season; how long does it take and how is it done; what are the constraints-labour and equipment availability; how long between ploughing and first drum seeding)*
- If rains have started but the trigger point for planting has not been reached, what do they do *(i.e. is it rainfall that triggers the decision or some other indicator)*
- If the rains are late when do they respond and change cropping choice *(they may already be using a medium duration so this may not be relevant; do they plan to use 1 SD crop or 2 SD crops but with different technologies; get some dates around these decisions)* (visual aid)
- If rains start early what triggers the planting of 2 SD crops *(plant first crop ASAP or wait until confident in weather-if so, what are the criteria on which the decision is made, or are they doing something quite different with a MD variety but some new technologies)*
- Planting crop 1 *(how do they plant i.e. drum seeder, broadcast, dry sowing etc)*
- Issues around planting *(availability of drum seeder; do they own a drum seeder-of not, why not; hire of DS-cost and availability; advantages/disadvantages over transplant; work rate; general view of usefulness; will they use for other rice crops e.g. traditional; thoughts and experience of other direct seeding technologies; cost of seed and comparison with other establishment options)*
- Fertiliser application *(use of fertiliser-cost, availability, knowledge source; application rate and timing-how are these decisions made; does application timing or rate vary depending on the time of planting-early, late; have similar rates been used in 2013 now that there are no project subsidies or credit)*
- Pesticide use *(direct seeded rice will require better weed control, insect control will likely result in improved yields; thoughts on the use of herbicides and insecticides; opportunities and constraints to use; safety issues; have they used in current season, if not, why not)*

- Harvesting crop 1 *(labour issues; harvest work rate; issues around timing and ability to harvest and dry grain; has the process had to be modified compared to traditional methods; how much stubble is left standing i.e. is the crop cut near the soil surface or below the head; is mechanised harvesting an option)*
- Transitioning between crop 1 and 2 *(what is current transition time-do you want to reduce the time, if so, how might it be achieved; comments on the challenges of land preparation; ploughing work rate; stubble management; fertiliser application; availability of labour and equipment i.e.2 wheeled tractors; observations on productivity of second crop-is it suffering from N tie up for example)*
- Decisions surrounding the growing of a second crop *(influence on decision to plant-time of harvest of crop 1 and transition time, previous experience, availability of irrigation, food security requirements; how late is too late to grow crop 2; is an overt evaluation of the risks associated with second crop planting made i.e. I will not plant because it is too late to catch late wet season rainfall and I have no irrigation water, so therefore I will look for other options, or will they blindly try to grow the crop)*
- Planting crop 2 *(Method-drum, broadcast, transplant; comments on planting rate and labour requirements; issues of establishment in the middle of the wet season-challenges of high water levels-how is that managed; what level of water is required; when would you consider that it was too late to plant a second crop)*
- Harvesting crop 2 *(issues around timing and ability to harvest and dry grain; has the harvesting process had to be modified compared to traditional methods; how much stubble is left standing i.e. is the crop cut near the soil surface or below the head; is mechanised harvesting an option; use of land afterwards-does it impact on how the land is managed at harvest i.e. removal of stubble; traditional use of stubble)*
- Impacts of growing 2 crops on labour *(overall labour requirements; changes in distribution of labour; impact on overall livelihood-changes to resource allocation within agriculture and overall)*

c) Agronomic practice for late wet season, early dry season vegetable/cash crop production

- Drivers for growing vegetables and cash crops *(time of season; irrigation availability; credit; markets; availability of advice)*
- Experience of growing such crops *(challenges; opportunities; will they continue to grow)*
- Plans for future *(are they planning to continue or start for first time)*

d) Economics of modified cropping strategy

- Profitability of cropping scenario *(comparison with traditional, or other cropping options; comparison with other livelihood options)*
- Drivers of the use of the system *(profitability; food security; ?)*

e) Using short duration improved varieties

- Given the yields of the CARDI lines, will they continue to use them *(if not, why not; seed availability; retaining seed)*
- Are they using Vn504 *(when and why; how is it established-generally broadcast; availability of seed; retaining seed)*

f) Drum seeding

- Experiences of using DS *(opportunities; challenges-drought, high water levels, heavy rain, weeds)*
- Will they continue to use DS and why *(labour saving; weed control)*
- Are they using DS in their own cropping or just in experiment *(reasoning)*
- Access to DS *(owned/rented/contractor)*
- DS saves time, how will the time be re-allocated *(more area/migration/other activities outside of agriculture in local area?)*
- Land levelling *(DS works best in a level field with no clods-would they be prepared to invest time in land levelling using the labour saved through the use of drum seeding)*
- Consideration of other direct seeding technologies *(dry seeding opportunities; interest in testing)*

g) Using higher rates of fertiliser

- Identify whether individuals see rice production as a business or as food security only
- Response to observing higher yields from higher rates of N *(have they increased N use in traditional crops or in 2013 2 crop strategy; if not why not; what would it take to change current practice; what rates have they use; when has it been applied)*
- Is N use linked to the reason for rice production *(already meeting food security and don't need the extra rice to sell because of other components of the livelihood contributing to overall family income)*

h) Irrigation

- Irrigation availability *(canal, pond, tube well; supplementary or full)*
- Constraints to investment in irrigation *(credit; labour; is irrigation infrastructure increasing, if so, how might that effect future investment)*
- Area of land able to be irrigated seasonally *(wet and dry seasons)*
- Annual availability of irrigation *(at planting, mid season or end of season; is there sufficient irrigation to finish second crop)*
- Supplementary irrigation *(How often has it been used in the last 3 years; what time of year)*
- Access to iDE loan for irrigation infrastructure *(did you access loan; if not, why not; did access to credit facilitate the decision to invest-would they have done it anyway, where would they have got the loan from; have others invested more recently-source of funds)*

6. Thinking about other opportunities that haven't been formally tested by researchers (but may have been considered/tested by the farmers)

There are other possible cropping options that have not been explored though on-farm research, but make sense in terms of systems intensification. Some of these should be modelled as part of late-2013 simulation activity. As part of the interview process we will ascertain whether these strategies are being used or if farmers consider them practical. If they have not been used, we will discuss the opportunities with participants to gauge their interest and their thoughts about the various interventions. These data will then be used to establish 'decision trees' for these options.

a) Higher input single crop, short duration rice production

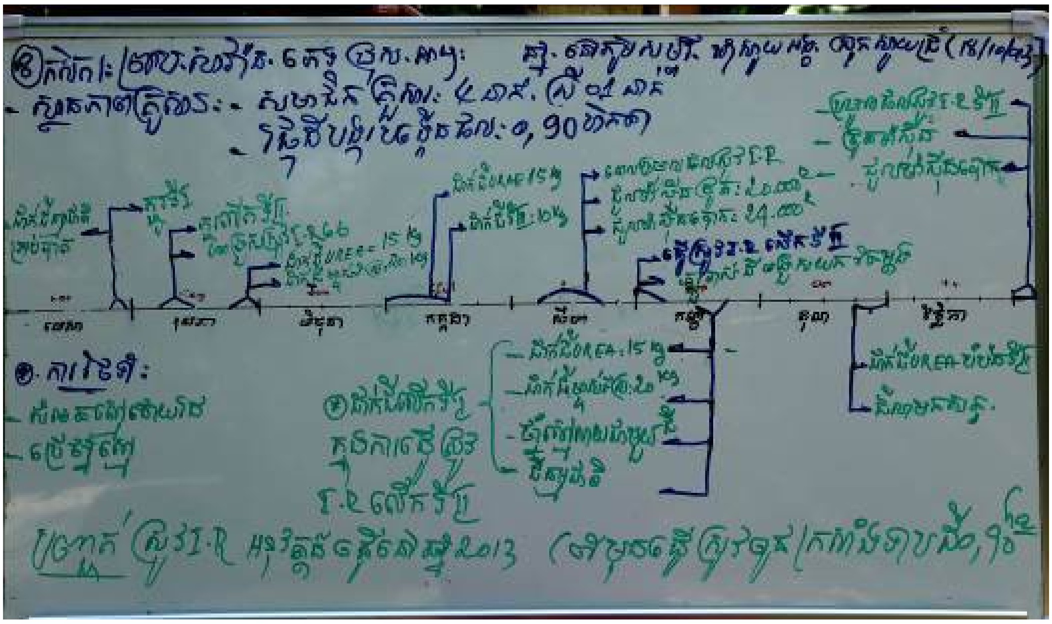
- Explain that it would be possible to grow 1 improved, short duration crop, drum planting a little later when rainfall reliability is higher but still harvesting in the dryer part of the wet season

- As there is only 1 crop being grown, it would be possible to invest the inputs from the alternative 2 short duration crop scenario into the 1 crop, probably reducing climate risk and increasing the chances of higher yields, but with less labour required for sowing and harvesting and lower costs for inputs such as seed, pesticides etc
- Growing a single crop means that the chance of terminal drought at harvest time is reduced, thus increasing the probability of higher yield. The downside may be rainfall or flooding at harvest and issues with grain drying.
- Labour is reduced in terms of planting and harvest and land preparation between a first and second crop
- Increased flexibility provides opportunities to either grow a late wet season cash crop e.g. maize, or to plant vegetables as the dry season declines and the risk of flooding abates.

b) An early wet season cash crop, followed by a high input, short duration rice crop, followed by an early dry season cash or vegetable crop .

- This is a derivative of a) where the early wet season is utilised for the production of vegetables or a short duration cash crop. With supplementary irrigation, it should be possible to plant a crop in mid-April, harvest in early-mid June and to then drum seed a short duration rice followed by a cash crop or vegetables as suggested above. This scenario will also be discussed.

Appendix 2: Khmer crop calendar example



Khmer version of crop calendar which will be translated to confirm accuracy of English based version.

Appendix 3: Summaries of outputs from key informant interviews

Key informant interviews Svay Rieng Province
October 16- 19 2013

Farmer 1(f)

Typology: 'a' (formerly listed as 'c' but has no access to irrigation and a small land area)

Family: 7 members

- Husband: farmer
- Wife: farmer
- Daughter: garment factory
- Grand-children: 4

Farming: 6000m^2

- 3000m^2-traditional varieties (around house)
- 3000m^2-traditional deep water rice (500-800m from house)
- Vegetables around house

Livelihood (in order of importance):

- Rice production
- Vegetables
- Animals (some pigs previously nothing 2013)

Irrigation:

- No irrigation, too far away (500m from canal)

Farm labour:

- Husband and wife (older couple) + off farm labour during peak rice production periods

Calendar: using traditional rice variety

- Sow on rainfall for land preparation, 2 months from Buddhist New Year (Apr)
- Ploughing first rains in June with 20cm water in paddy
- Fertiliser basal 2 carts Manure + 1 cart ash (Cart= 500-600 kg)
- Ploughing 2 weeks later with 20cm in paddy, repair bunds to 30cm height and 30cm wide
- Drum seed 120 kg/ha
- Fertiliser 1-@sowing NPK 10kg/ha + urea 7 kg/ha mixed with seed + possible fungicide
- Fertiliser 1-15 days post sowing urea @166 kg/ha
- Fertiliser 2-30-40 days post sowing NPK @166 kg/ha
- Fertiliser 3-@PI urea 66 kg/ha
- Yields: 2 t/ha (lower fertiliser rate), 2.4 t/ha (current fertiliser rate)

Marketing of rice:

- Credit for crop then pay at harvest

Drought mitigation strategies

- Deep water rice

General systems comments

- Tried IR66 during drought (was this Aug?) but no yield (applied 10 kg urea)
  no pesticides used
- Drum seeder has been used for last 3 years (4 hours to sow 3000 m^2)
  advantages: less labour, higher yields
- Vegetables grown around house (Nov-Mar) by husband (long-bean, cucumber, green mustard) using ground water access at house, by bucket
- Information comes from IDE
- Past experience last 20 years and have adopted some new technologies in last 3 years
- All village use machine harvest
- 2010 Machine harvest (straw used for animal feed- collected from field), 2011 Hand harvest, 2012 no crop
- Traditionally rainfed long varieties – plant mid July and mature late Nov
- Harvesting occurs directly after maturity
- Harvest using contract mechanised combine harvester @ $12:50 (30min) compared to traditional hand harvest of 1person X 4 days (3 harvest, 1 threshing)

Farmer 2 (f)

Typology: 'd' (formerly listed as 'c'-this farmer is small i.e. 'c' but has good access to pond and tube well i.e. more than limited access to water)

Family: 4 members

- Husband: famer, moto driver in Phnom Penh
- Wife: farmer
- Children: 2 (young)

Rice farming: 5800m^2

- 3000m^2-IR66 double cropped (2 wet seasons) drum seed and broadcast
- 2000m^2-traditional varieties drum seed
- 800 m^2- sticky rice broadcast
- Vegetables around house

Livelihood (in order of importance):

- Rice production
- Vegetable
- Cattle 2-3 cows
- Off farm income (taxi driver 6 months/year)

Irrigation: Pond and tube well; if no rain in May will use irrigation to wet up (2012 20cm standing water in field in May- no irrigation required)

Farm labour: Hires drum seeder $1/ha

Calendar: Medium duration traditional

- Ploughing 1st week May when 20cm water in field
- Bunds: 30cm high and 50cm wide – repaired 2 days before second cultivation
- Manure applied every second year (from 2-3 cows)
- Ploughing 2nd Week May when 20cm water in field and level with board (puddle) and broadcast medium variety (KD)
- Fertiliser 1-15 days post sowing NPK 50 kg/ha
- Fertiliser 2-@PI urea 166 kg/ha
- Harvest by hand
- Yields: 2.8 t/ha
- Straw cut at 30cm to feed cattle

Calendar: Short duration double cropped rice

Crop 1

- Ploughing 1st week May when 20cm water in field
- Bunds: 30cm high and 50cm wide – repaired 2 days before second cultivation
- Manure applied every second year (from 2-3 cows)

- Ploughing 2nd Week May when 20cm water in field and level with board (puddle) and drum seed IR66
- Fertiliser 1-15 days post sowing NPK 50 kg/ha
- Fertiliser 2-@PI urea 166 kg/ha
- Harvest by hand
- Yield 2.8 t/ha
- Straw cut at 30cm to feed cattle
- Fallow for 1 week
- Ploughing when 20cm water in field and level with board (puddle) and drum seed IR66
- Fertiliser 1-15 days post sowing NPK 50 kg/ha
- Fertiliser 2-@PI urea 166 kg/ha
- Harvest by hand
- Yield ?? t/ha

Marketing of rice:

- Buyer collects rice from farm, $0.30/kg in Aug, $0.23-0.25/kg in Nov

Drought mitigation strategies

- Irrigation from pond/ground water (sufficient for supplementary irrigation
- If no rain in May, will use irrigation to wet up prior to plant (2012 20cm standing water in field in May- no irrigation required)
- Late rains, would consider change to shorter maturing varieties (IR) and if rain early would plant early

General systems comments

- Wife managed farm (while husband working off-farm) but decisions jointly made by both husband and wife
- Double cropping only behind house with traditional crop 200m from house
- Traditional practice of transplanting local varieties now influenced by IDE on use of short duration varieties and drum seeding
- Sowing two crops: better returns (double crop) but increased problems from insects and animals late in season
- Takes 20 minutes to sow 1500m^2 using drum compared to 2 people X 3 days transplanting (40 days/ha)

Farmer 3 (m)

Typology: 'd'

Family: 6 family members

- Husband: farmer, village vet technician
- Wife: farmer, sells clothing
- Other: 3 work on farm

Rice farming: 3.5ha

1.0ha short duration (Chul'sa)
2.0ha medium (KD)
5000m^2 long duration

3000m^2 dry season vegetables

Livelihood (in order of importance):

- Rice production
- Animals 50 chickens, 10 pigs, 6 buffalo
- Vegetables (plants vegetables into rice field at back of house)

Irrigation:
Has tube wells and access to canal for 1.0ha

Farm labour:

- Grows a range of varieties of different duration to reduce risk associated with labour shortage at certain times of the year
- Previously required extra labour from neighbours at harvest but now machine harvest

Calendar: Medium duration improved variety

- Ploughing late May or 1st week June with 3 cultivations (weed control)
- Sow medium variety (Phka romdol) 4th week June by drum seeder
- Fertiliser 1-15 days post sowing NPK (20,20,15 ?) @ 100 kg/ha
- Fertiliser 2-@tillering NPK 100 kg/ha
- Harvest – machine (by water festival) but would harvest earlier if needed
- Yield – 4.0 t/ha

Calendar: Short duration double cropped rice

Crop 1

- Repair bunds first rains in April 30cm High & 50cm Wide
- Ploughing 1st week May when 5-10cm water in pond
- Fertiliser 1-basal slurry from biogas 7-8 carts [200-300kg/cart]

- Ploughing 2-2nd week May when 5-10cm water in pond then sow IR66 by drum seeder
- Fertiliser 2-15 days post sowing NPK (20,20,15 ?) 100 kg/ha
- Fertiliser 3-@tillering NPK 100 kg/ha
- Harvest at end of August-Yield 4.0 t/ha

Crop 2

- Fallow for 5 days
- Ploughing when 5-10cm water in pond then sow IR66 by drum seeder
- Fertiliser 2-15 days post sowing NPK (20,20,15) 100 kg/ha
- Fertiliser 3-@Tillering NPK 100 kg/ha
- Harvest in November-Yield ~4.0 t/ha

Marketing of rice:

- Chul'sa used for home consumption, other grain sold
- Store grain at house, rice merchant buys from villagers for 18-20c/kg August and 25c/kg November

Drought mitigation strategies

- If late rain will irrigate to plant in May

General systems comments

- Double cropping constrained by area of land nearest to house and then by access to labour
- Grows short varieties near house (security from animals, birds, pests) and medium duration varieties further from house
- Traditional transplant of long/medium duration local varieties only
  2011 change (after visit by IDE) – use of drum seeder (now owns a drum seeder)
- Double cropping and use of drum seeder (>borrowing from neighbours) increasing in village with 18 households (2011) and now 80% of 170 households using drum seeder and double cropping (to some extent)
- Advantages of drum seeding to hand broadcast:
  less seed, row crop, better light, easier weed control, saves time (compared to transplanting- 7p X 5days/ha vs 2hrs by drum seeder)
  Economic decision to change to short duration (IR) and drum seeding
  Husband, wife and mother all use drum seeder
- Disadvantages of drum seeding:
  Tiring to use drum seeder, problem when there is too much water in paddy (can sometimes drain?), requires 2 people when too much water, increased herbicide/pesticides required
- VN504 4.5-5 t/ha – farmers applies his own agronomy rather than Vietnamese prescription.
- 2012- used header ($25) and thresher (30$)
- 2013- hand harvest (heads) straw to neighbour
- Used urea in past but resulted in dark grain so prefer NPK?

Farmer 4 (m)

Typology: 'd' (more reliance on remittance than most 'd' farmers, could be described as a 'b' also)

Family: 8 members

Husband: farmer, health worker
Wife: farmer
Sons: 4 work off farm, remittance
Daughters: 2 work off farm, remittance

Rice farming: 2ha (had >3ha but 1.5ha provided to son and daughter in law)

- 1ha traditional medium rice
- 1ha tradition sticky rice (breakfast)
- 1000m^2 IR66 near house
- 500m vegetables around house

Livelihood (in order of importance):

- Health service (support nursing in local district)
- Animals 4 pigs, 3 buffalo
- Vegetables
- Rice production
- Sons provide cash for any additional labour (as they work off farm)

Irrigation: Has access to canal for emergency irrigation if required

Farm labour: Sons provide cash for additional labour at harvest of short duration IR66 but will contract harvester for traditional varieties (KD) @$30 per ha

Calendar: Short duration

Crop 1 (no 2nd)

- Repair bunds first rains in April 25-30cm H & 40-50cm W
- Ploughing 4th week April when 5-10cm water in pond
- Fertiliser 1- 2nd week May basal manure (fields close to house)
- Ploughing 3rd week May when 15cm water in pond then sow IR66 by broadcast
- Fertiliser 2-7 days post sowing NPK@150kg/ha
- Fertiliser 3-@Tillering NPK@150 kg/ha
- Harvest by hand (Aug)
- Yields: 3.6-4.0 t/ha

Calendar: Medium duration improved variety

- Fertiliser 1- cart manure to fields furthest from house during dry season
- Repair bunds first rains in April 25-30cm H & 40-50cm W
- Ploughing 4th week June – 1st week July with 15 cm water in pond

- Ploughing 4th week July with 15 cm water in pond then sow medium variety (Phka romdol) broadcast
- Fertiliser 2-15 days post sowing NPK 150kg/ha
- Fertiliser 3-@Tillering NPK 150 kg/ha
- Harvest by machine $30/ha + threshing costs
- Yields: 2.0-2.4 t/ha and < 2.0 t/ha sticky rice

Marketing

- Rice for home consumption to feed 11 people

Drought mitigation strategies

- Has access to irrigation from canal and would plant early if early rain occurs in April.
- Would plant traditional varieties as late as August, change to shorter variety if no rain till end of August.

General systems comments

- On board of directors of local village community which supports agricultural and animal production, low interest loans (credit) to its members. US$8 membership, 49 current members, 60+ shareholders total.
- Drum seeding seen as too expensive (no money to buy)
- Broadcast less labour intensive
- Sprays herbicide with fertiliser application (uses protection)
- Chemical and seed purchased local market
- Whole village of 205 households- 3 farmers own drum seeder with some neighbours borrowing seeder, 10 farmers used drum seeder on 5 ha of land (but not all of their entire farms)
- PDA supplied seed KD and IR (last 5 years) but has own local seed
- 2013 season has been good, 2011-2012 some seasonal variability [possible drought periods July-Aug] – 1-2 weeks normal 1 month less often
- 2012 – all transplant
- 2013 – Phka romdol /traditional – hand broadcast, sticky rice transplanted

Farmer 5 (m)

Typology: ‘b’ (formerly listed as ‘a’ but has access to limited irrigation)

Family: 7 members
Husband: farmer
Wife: farmer
Daughter: farmer
Son in law: farmer
Grand-children 3

Rice farming: 3.5ha
- 0.5ha IR66 (high land)
- 2.0 ha medium duration (high land)
- 1.0ha local long variety (deep water rice)
- 2000m^2 vegetables (home consumption - around house)

Livelihood (in order of importance):
- Rice production
- Animals 2 cows, 2 buffalo, 6 pigs
- Vegetables
- Off-farm income (work away for 2 months/year)
- Small shop at house

Irrigation: limited to 1ha along canal

Farm labour: 2012 hired additional labour but normally managed by entire family

Calendar: Short duration improved

Crop 1 (no 2nd)
- Ploughing 3th week April when 5cm water in pond
- Fertiliser 1- 2nd week May basal manure, repair bunds to 30cm High
- Ploughing 3rd week May when 5cm water in pond then sow IR66 broadcast after draining field of excess water
- Fertiliser 2-10 days post sowing NPK 80 kg/ha + urea 20 kg/ha
- Fertiliser 3-@Tillering NPK 40 kg/ha
- Yields: 1.8 t/ha though expect better in future

Calendar: Medium duration improved variety
- Ploughing 1st week June when 5cm water in pond
- Fertiliser 1- 3rd week June basal manure + farmers own fertiliser mix 50kg/ha (mix = 50kg DAP + 50kg 16-20 + 50kg NPK + 10kg urea)
- Sow 4th week June medium variety hand broadcast
- Fertiliser 2-20 to 30 days post sowing mix @100kg/ha

- Fertiliser 3-@Tillering mix @100 kg/ha
- Harvest 3-4th week November
- Yields: 1.8 t/ha Phka romdol due to failure to use herbicide 10days after broadcast

Calendar: Traditional deep water rice

- Ploughing 1st week June when 10cm water in pond
- Fertiliser 1- 1st week August
- Sow 4th week July to 4th week August during dry period traditional varieties (sticky rice) transplant
- Yields: 1.2-1.5 t/ha

Marketing of rice:

- Rice home consumption and local sale into village

Drought mitigation strategies

Late rains will plant only 1 crop and would consider additional fertiliser but for early rains will plant 2 crops. Deep water rice field always has water in July-August.

General systems comments

- No drum seeder but interested in future use due to better weed control
- 2012 most of village transplanting but in 2013 more broadcasting
- Sow end of June-early July as a group to reduce impact of pests and roaming animals
- Planned for second SD crop (2013) but water too high in August
- Considering increasing double cropping IR to 1ha on land near canal as security is less of issue with family members visiting fields every day to chase animals and check for pest or disease problems
- Neighbour has high yield from IR, IDE provided training and seed with other NGO provided information and seed for demonstration
- Mixes herbicide with fertiliser but sprays pesticides separately (brown plant hopper and leaf spot?)

Farmer 6 (m)

Typology: 'b'

Family: 4 members
- Husband: farmer
- Wife: farmer
- Sons X 4: work off farm (locally and Phnom Penh)
  Grand-children: young

Rice farming: 2.5ha (local)
- 2ha traditional
- 0.5 ha sticky rice
- 1000m^2 IR66 –double cropping
- Recession rice

Livelihood (in order of importance):
- Rice production
- Taro
- Animals recently owned 4-5 cows, 5 buffalo, 10 pigs
- Off farm remittance from sons (irregular)
- Vegetables

Irrigation: Access to ground water near house for double cropping

Farm labour: Husband and wife, contract harvesting and spraying

Calendar: Traditional medium crop
- Ploughing 1st week June when 10cm water in pond
- Fertiliser 1- 4th week June basal manure 7-8 carts/ha (300kg/cart) and repair bunds
- Ploughing 1st week July and sow traditional varieties broadcast
- Fertiliser 2-20 days post sowing mix 50 kg/ha
  mix = 17kg/ha 20-20-15 + 17kg/ha trace (Zn,P,Fe,Mg etc) + 17kg/ha DAP + ?
- Fertiliser 3-@PI mix 50 kg/ha
- Harvest by machine
- Yields: 2.0-2.5 t/ha traditional, 1.6 t/ha sticky rice

Calendar: Short duration double crop

Crop 1
- Ploughing 1st week May
- Ploughing 3rd week May then sow Chul'sa broadcast
- Fertiliser 1-20 days post sowing mix 50 kg/ha
  mix = 17kg/ha 20-20-15 + 17kg/ha trace (Zn,P,Fe,Mg etc) + 17kg/ha DAP + ?
- Fertiliser 2-@PI mix 50 kg/ha

- Harvest by machine 3.5-4.0 t/ha
- Fallow till mid November
- Sow 3rd week November short variety (Chul'sa) broadcast
- Harvest by machine late in January 3.2-3.5 t/ha @ $65/ha

Calendar: Short duration double crop

Crop 2

- Ploughing 1st week May
- Ploughing 3rd week May then sow IR66 broadcast
- Fertiliser 1-20 days post sowing mix 50 kg/ha
  mix 17kg/ha 20-20-15 + 17kg/ha trace (Zn,P,Fe,Mg etc) + 17kg/ha DAP + ?
- Fertiliser 2-@PI mix 50 kg/ha
- Harvest by machine late July to August 3.5-3.6 t/ha @$70/ha
- Fallow till mid August
- Sow 4th week August traditional medium variety transplant (30 day seedlings)
- Fertiliser 1-20 days post sowing mix 50 kg/ha
  mix = 17kg/ha 20-20-15 + 17kg/ha trace (Zn,P,Fe,Mg etc) + 17kg/ha DAP + ? urea
- Fertiliser 2-@PI mix 50 kg/ha
- Harvest by machine November 2.5 t/ha

Marketing of rice:

- Transports rice to mill and returns with white rice for local sale to village

Drought mitigation strategies

- Wait for rain or irrigate from canal in dry years. For late rain will change to short variety

General systems comments

- Exposed to short duration varieties from Vietnam in 2002
- Information from PDA
- IR66 yields higher than local varieties

Farmer 7 (m)

Typology: ‘b’

This farmer was not part of the FGD, he was an influential farmer in the Kbal Damrey iDE group and was interviewed as past of KII because of his double cropping, , vegetable and corn production experience. The level of detail of general systems information was not collected.

Family: 3 members

- Father: farmer
- Mother: farmer
- Grandchildren 2

Farming:

- Rice-double cropped short duration and medium duration
- Some dry season vegetables around house
- Dry season maize in rice field near house

Livelihood (in order of importance):

- Rice
- Vegetables
- Animals-pigs

Irrigation: Tube well for rice and vegetables grown in paddy near house

Farm labour: 2 family members involved in rice and vegetable production

Calendar: Short duration double cropped rice

Assumes rainfall at appropriate times

- Plough 1st week April
- Fertiliser 1- 1st week April basal manure
- Plough 1st week May and fertiliser 2- mix 50 kg/ha and sow IR66 both drum seeder & broadcast. Mix = Urea + DAP + NPK + trace
- Fertiliser 2-@PI mix 50 kg/ha
- Harvest by hand early August as neighbour took straw for feed animals;
- Yield 4.0 t/ha 2013, second crop currently growing

Calendar: dry season maize

Uses tube well

- Plough 1st week January
- Plough 3rd week January, plant maize 20cm between plants and 70cm row spacing
- Fertiliser 1- 3rd week January
- Hilled 25 days post sowing around seedlings to 20cm, FDP added between plants

- Harvest by hand mid March and sold as “green corn”

Calendar: using vegetable crops

Uses tube well

- Prepare land 1st week January
- Plant 4th week January vegetables- cucumbers, long-bean etc.
- Harvest by hand March to April

Marketing of rice:

- Home consumption of rice, vegetables (cucumber, long bean, etc) good return on labour

Drought mitigation strategies

- If rain plant early but will use tube well to irrigate if rains arrive late

General systems comments

- Feed required for animals mid wet season
- Drum seed seen as better than broadcast, less labour, less time, bigger panicles, more tillers, maturity same as broadcast but no good in drier conditions (at establishment)
- Of 18 farmers in the village 14 have double cropped short duration rice in 2013

Farmer 8 (m)

Typology: 'c' (formerly listed as 'a' but has limited irrigation)

Family: 4 members

- Husband: farmer + off farm income in local area-house building, party equipment hire
- Wife: garment manufacture for 8-9 months of year, assists with rice harvest
- Son 1: migrated to PP last month, remittance expected
- Son 2: 11 years old, at school in village

Rice farming: 9000m^2

- 7000m^2-traditional deep water rice on Koktrap, acid soil-medium duration variety
- 2000m^2-IR66 double cropping (higher land)

Livelihood (in order of importance):

- House construction
- Rice production
- Cattle (2)
- Remittance and garment factory
- Party hire

Irrigation: limited access to canal but will use in an emergency if water is available

Farm labour: outside labour employed for transplant of deep water rice and at harvest time. Wife involved at harvest, husband is sole labour for rest of year

Calendar: Short duration double cropped

Crop 1

Irrigation is only used in an emergency so following calendar assumes rainfall at the appropriate times. Relies on herbicides for weed control.

- Ploughing 1-Early May when there is 10cm water in paddy; applies 3000kg/ha manure. If rains come earlier e.g. April, he would plant as long as his water depth rule is in place and accept the risk of failure if canal water was unavailable for supp. irrigation
- Ploughing 2-second week of May when 20cm water in paddy, plough and level, remove water
- Establishment of IR66 rice-hand broadcast immediately after drainage of water into puddle surface
- Fertiliser 1-15 days after broadcast-Urea@75kg/ha + precautionary insect spray
- Fertiliser 2-@tillering-NPK@100kg/ha + herbicide application (sprayed)
- Fertiliser 3-@PI-Urea 50kg/ha
- Irrigation-plans to maintain water at 10cm depth but dependent on rainfall
- Harvest- early August; mechanised (reaping US$25/ha, threshing US$25/ha); Yield 2.5t/ha

Short duration double cropped rice

Crop 2

Irrigation is only used in an emergency so following calendar assumes rainfall at the appropriate times. Relies on herbicides for weed control. Ploughing 1-August week 2 using power tiller

- Ploughing 1-2nd week August when there is 10cm water in paddy; applies 3000kg/ha manure
- Rice establishment-hand broadcast after first tillage (assume levelling in this activity also). 2 week transition from first harvest to broadcast of 2nd crop
- Fertiliser 1-15 days after broadcast-Urea@75kg/ha + precautionary insect spray
- Fertiliser 2-@tillering-NPK@100kg/ha + herbicide application (sprayed)
- Fertiliser 3-@PI-Urea 50kg/ha
- Irrigation-plans to maintain water at 10cm depth but dependent on rainfall
- Harvest- late November; mechanised (reaping US$25/ha, threshing US$25/ha); Yield not stated but likely to be 2-2.5t/ha

Calendar: Traditional medium duration variety

This is the cropping sequence used on high land prior to the move to double cropped short duration varieties.

- Ploughing 1-early June when there is 10-15cm water in paddy
- Seedling nursery preparation at same time
- Ploughing 2-early July when seedlings are ~35 days old and water is at a depth of 20-30cm
- Transplanting immediately after levelling (30 person days/ha). Dips roots of seedlings in a combination of manure and NPK.
- Relies on depth of water for weed control, no insect control
- Fertiliser 1-@PI-Urea 50kg/ha
- Irrigation-plans to maintain water at 10cm depth but dependent on rainfall
- Harvest- week 2 in November; hand harvest (15 days/ha); Yield ~ 2t/ha

Marketing of rice:

- Sells SD rice @ US$0.25/kg, keeps traditional grain for home consumption

Drought mitigation strategies

- If early rains are late, he would still plant the first SD crop until the end of June, after June he would revert to 1 short duration crop when the rains came
- If the first crop is successful but planting rains for second crop are late or fail he would consider planting until the end of October, supplementing water supply from canal (if available). If no canal water available he would not consider planting a second SD crop after the end of August
- Wants to continue using SD varieties because of the higher yields and better option in a variable climate (shorter season than med maturity varieties)
- Has no cropping option on the majority of his land because it is low land and only suitable for deep water rice (no examples of modern varieties being used in this situation, all farmers quoted traditional lines)

General systems comments

- Considering the use of more fertiliser on SD crop but worried about effect on yield (may mean loss of yield if too much vegetative growth and water runs out)
- Has never seen a drum seeder but has heard that they reduce labour, place seed in rows and easy to use so keen to trial

Farmer 9 (f)

Typology: ‘a’ (formerly listed as ‘b’ but no potential for irrigation)

Family: 3 members

- Father: farmer
- Mother: farmer
- Daughter (interviewee): farmer, local off-farm income (mat making); migration to PP for 3-4 months/year as builders labourer

Farming: 3000m^2

- 3000m^2-traditional deep water rice-land located 1km from house, Koktrap, acid soil, traditional medium deep water duration variety, no higher land for other rice types
- 1 cow, had 3 pigs but none at present due to disease issues, some dry season vegetables around house

Livelihood (in order of importance):

- Labouring in PP for 3-4 months/year (daughter)
- Mat manufacture (4 days/mat, sells for US$5) (daughter)
- Off farm rice harvest labour to neighbours (daughter)
- Cattle (1 for fattening, 3-4 year turn around)
- Bartering of labour to help neighbour transplant in return for rice tillage (daughter)
- Rice production-food security only (all involved)

Irrigation: no irrigation

Farm labour: 3 involved in farm rice production; tillage done by neighbour in return for transplanting assistance

Calendar: Traditional deep water rice

Assumes rainfall at appropriate times

- Ploughing 1-2nd week of May when there is 20cm water in paddy
- Seedling nursery established at same time
- Ploughing 2 and levelling-second week of July
- Transplant of traditional medium deep water variety-planted immediately after second tillage. Seedlings are dipped in DAP/dung mix at transplant
- Fertiliser-no fertiliser is applied
- Harvest- timing; hand harvest; Yield 360-400kg/ha

Marketing of rice:

- Home consumption

Drought mitigation strategies

- Transplanting is planned for July but can vary depending on rainfall. However if delayed until August the water is generally too deep to plant and if the water does drop, the seedling are too old to transplant. In this case the fall back is to migrate to PP for work.
- If there is a very late start to the season then the land is left fallow and migration occurs

General systems comments

- Seed from the same traditional variety has been kept for ~20 years
- Indicated that they have no access to extension services or agricultural information even though the father is the village chief and should be exposed to some level of info.

Farmer 10 (f)

Typology: 'c' (formerly listed as 'd'). Could be a 'd', as farm is reasonable size but high level of migration and limited irrigation access

Family: 8 members

- Mother (interviewee)-farmer
- 1 sister (farmer)
- 1 grandchild –farmer
- 2 grandchildren -children
- 1 daughter, husband and son-migrate to PP for construction, garment manufacture and small business with remittance + assist in rice harvest

Farming: 1.3ha

- 1ha-traditional medium duration variety 1.5km from home and distant from canal
- 1000m^2-IR66 double cropping on canal-first season of use
- 2000m2-Medium duration modern Pkarum duhl on canal-first season of use
- Cattle-5draft and sale
- Some vegetables in some seasons

Livelihood (in order of importance):

- Remittance from 3 family members in PP
- 5 cattle used for ploughing but will sell
- Vegetables in some years around house
- Rice production-food security only

Irrigation: 1ha is dryland (canal 1km away); 3000m^2 has irrigation when canal has water in it

Farm labour: 3 family members most of time + family help at harvest

Calendar: Short duration

Crop 1

Irrigation is supplied from the nearby canal although availability is dependent on time of season ie can't be totally relied upon. 2013 was the first year that SD variety has been used and it was rainfed.

- Ploughing 1-End June when there is 10cm water in paddy
- Fertiliser 1-applies 4000kg/ha manure prior to first plough
- Fertiliser 2-Manure application-between plough 1 and 2-4000kg/ha
- Ploughing 2-second week of July followed by levelling
- Establishment of IR66 rice-hand broadcast immediately after drainage of water into puddled surface
- Fertiliser 3-8 days after broadcast-16/16/20 13S@50kg/ha applied with herbicide
- Fertiliser 4-@tillering-16/16/20 13S @50kg/ha
- Fertiliser 5-@PI-Urea 20kg/ha +16/16/20 13S @30kg/ha

- Irrigation-nil
- Harvest- 3rd week Sept; method; Yield 120kg white rice (not sure if this was /ha or plot)

Short duration double cropped rice: Crop 2

- Ploughing 1, level-3rd week September when there was 5cm water in paddy
- Fertiliser 1-applied 3000kg/ha manure prior to plough1
- Rice establishment-hand broadcast after levelling, 1 week transition from first harvest to broadcast of 2nd crop
- Fertiliser 2-8 days after broadcast-16/16/20 13S@50kg/ha applied with herbicide
- Fertiliser 3-@tillering-16/16/20 13S @50kg/ha
- Fertiliser 4-@PI-Urea 20kg/ha +16/16/20 13S @30kg/ha
- Irrigation-nil
- Harvest- yet to be done; method; Yield ?

Calendar: Traditional medium duration variety

This is the cropping sequence used on 1ha distant from canal

- Fertiliser 1-Manure application-2000kg/ha prior to first plough
- Ploughing 1-2nd week of June (power tiller hire=$33/ha) when there is 10-15cm water in paddy
- Ploughing 2 and levelling (US$45/ha)-2nd week in July
- Fertiliser 2-basal NPK@50kg/ha (16/16/8+13S) at time of second plough
- Hand broadcasting of seed immediately after levelling
- Fertiliser 3-20 days after broadcast 25kg/ha NPK
- Herbicide-applied with fert 2-mixed with fert and broadcast
- Fertiliser 4-@tillering (55days after broadcast) days after broadcast 50kg/ha NPK
- Fertiliser 5-@PI-Urea@25kg/ha; NPK (16/16/8+13S)@25kg/ha
- Irrigation-plans to maintain water at 10cm depth but dependent on rainfall
- Harvest- timing?; the last few years have been dry with yields between 0.7 and 1.6t/ha

Marketing of rice:

- Home consumption

Drought mitigation strategies

- Considers 2010/11 and 12 as dry years and blames climate change, she can't remember 3 poor years in a row before (the farmer is 50-60 years of age). 2013 is seen as a better year thus far. In previous years drought has affected the crops at tillering.
- Strategy if rains started late-would continue to use the traditional variety and use old seedlings for transplant if necessary (this does not fit with her use of broadcast which has already been indicated)
- When asked whether she would consider using a modern short duration variety, she indicated that she already was (first mention of it was an hour after discussions commenced)
- Will not plant IR66 until the wet season has arrived, she understands that this may result in only 1 short crop per year
- Would she plant the first SD crop to date-yes, if canal water was available for supplementary irrigation
- The majority of village farmers have now moved to the use of herbicides

General systems comments

- Broadcasting is used in preference to transplant due to the reduced labour with similar yield potential.
- She would prefer to use drum seeder but can't afford to buy and has to wait in queue to hire.
- This is the first year that herbicide has been used and spread with fertiliser. The move has been made because of difficulty of we3eding broadcast crop. Aware of safety issues.
- Agricultural information is received from PDA, iDE
- Seed for IR66 bought from neighbour
- No drum seeders in the village but hand broadcast is increasing
- Pkaram duhl is still growing so no idea of yield although she indicated that it looked good

Farmer 11 (m)

Typology: 'f' (assuming that >2.5ha farm size=large)(there does not seem to be a typology which represents recession systems where irrigation is available)

Family: 4 members

- Father (interviewee)-farmer
- Wife-farmer
- Son and daughter (study in SR)

Farming: 3.3ha

- 1ha-dry season recession
- 3000m2 wet season rainfed rice
- 2000m^2-vegetables around house (currently beans)
- No animals

Livelihood (in order of importance):

- Rice
- Vegetables
- Off-farm income-interviewee sells Vn goods in SR district

Irrigation: irrigation for recession rice is available from the border canal and the farmer indicated that tube well water was available in emergencies for the rainfed, wet season rice

Farm labour: 2 parents and no outside labour although contract mechanised harvesting

Calendar:

Wet season rainfed rice

This crop is grown on the high lands which are not submerged during the wet season.

- Bunding-maintenance done in late August before first plough (30cm high x 50cm wide)
- Ploughing 1-Early September when there is 10cm water in paddy. Will not plant earlier because of mid-wet season drought in Aug/early September.
- Fertiliser 1-applies 2000kg/ha manure (wet weight, supplied by other family members) prior to first plough as well as receiving some manure from grazing cattle. Also used duck manure from Vn in 2012 @ 1.6t/ha
- Ploughing 2-second week of July followed by levelling
- Establishment of Vn504 hand broadcast into 20cm water
- Drainage-water removed from paddy 2 days after broadcast
- Fertiliser 2-25 days after broadcast-DAP@50kg/ha +Urea@22kg/ha
- Fertiliser 3-@PI-16/16/20 13S @30kg/ha; Urea@15kg/ha
- Weed control-No herbicides are required because of the depth of water kept on the paddy

- Irrigation-10-20cm of water kept on paddy up until 15 days before harvest-at the whim of rainfall but never experienced a season where water supply has been an issue. Does have ground water available but has never been required.
- Harvest- date?? Yield-4-4.5t/ha sold to Vn

Drought mitigation strategies for rainfed wet season crop

- Farmer is aware of climate change and listens to long term regional weather forecasts on both Cambodian and Vietnam media
- Will not plant earlier than September because of the mid-wet season drought in Aug/early September.
- Will plant no later than the end of September because the crop will be maturing in the dry season (therefore he does not want to use his ground water as he indicated previously)

Calendar: Recession rice

Crop 1-dry season, irrigated recession (November plant)

This crop is grown on the low lands which are submerged during the wet season.

- Land prep 1-ploughing in September when moist
- Land prep 2-early November as water declines at end of wet. No ploughing, just levelling-weeds not an issue due to submersion for 4-6 weeks
- Establishment of Vn504-hand broadcast into 10cm water in first 2 weeks of November
- Irrigation-1 week after seed broadcast add 20cm water prior to Urea application and then keep water at between 20cm depth up until 15 days before harvest (application every 10-14 days)
- Herbicide application-2 days after broadcast apply pre-emergent herbicide
- Fertiliser 1-7 days after broadcast-Urea@25kg/ha
- Fertiliser 2-15 days after broadcast-DAP@100kg/ha +Urea@50kg/ha
- Fertiliser 3-25 days after broadcast-DAP@100kg/ha; Urea@50kg/ha
- Fertiliser 4-@PI-KCl@50kg/ha; Urea@25kg/ha; 16/16/18/13S@50kg/ha or. If crop is looking particularly good-15/15/15@100kg/ha
- Harvest- end of January/early February; combine harvest in 85-90 DAS. Harvest is generally done about 5 days after maturity due to wait for harvester. Yield 5t/ha.

Crop 2-dry season, irrigated recession (March plant)

This crop is grown in sequence with crop 1 on the low lands which are submerged during the wet season.

- Transition from first to second crop-starts in early Feb on harvest of crop 1-fallowed until first 2 weeks of March, stubble burnt to control pests; irrigate to 30cm
- Ploughing 1-3rd week of March and level
- Establishment of Vn504-hand broadcast in week 3 of March
- Irrigation-1 week after seed broadcast add 20cm water prior to Urea application and then keep water at between 20cm depth up until 15 days before harvest (application every 10-14 days)
- Herbicide application-2 days after broadcast apply pre-emergent herbicide
- Fertiliser 1-7 days after broadcast-Urea@25kg/ha
- Fertiliser 2-15 days after broadcast-DAP@100kg/ha +Urea@50kg/ha
- Fertiliser 3-25 days after broadcast-DAP@100kg/ha; Urea@50kg/ha

- Fertiliser 4-@PI-KCl@50kg/ha; Urea@25kg/ha; 16/16/18/13S@50kg/ha or. If crop is looking particularly good-15/15/15@100kg/ha
- Harvest- mid June; combine harvest in 85-90 DAS. Harvest is generally done about 5 days after maturity due to wait for harvester. Yield 5t/ha.

Marketing of rice:

- Most of Vn 504 rice is sold to Vn traders with some kept for emergency food security. Vn504 is sold and preferred traditional varieties bought for majority of home consumption

General systems comments

- Vn504 is the only crop grown in Ches Ressey (both rainfed and recession) with all advice, inputs, credit and markets coming from Vietnam.
- 504 matures in 85 days compared to the most popular Cambodian modern variety of 100-110 days. This makes the Vietnamese variety very popular in systems where water is a constraint to production.
- Inputs for rainfed crop bought from Vn for cash (seed. Fertiliser, pesticides). Fertiliser is bought on credit for recession crops and repaid after harvest.
- Initial information was gained from PDA and iDE but most now comes from Vn traders although he does cross validate information.

Farmer 12 (f)

Typology: 'f' (although land area is reasonably small; some reliance on OFI but not major income source, good level of rice production and sale) (there does not seem to be a typology which represents recession systems where irrigation is available)

Note: This farmer has given a slightly different timing for recession rice production than farmer 11. I would use farmer 11 as the basis of the decision tree.

Family: 4 members

- Mother (not involved in agriculture)
- Father-farmer
- Wife (interviewee)-farmer and off-farm income
- Son (study and farming assistance)

Farming: 1ha rice

- 1ha-dry season recession (3 land parcels)-only has lowland, no upland for wet season rainfed production
- 2000m^2-vegetables around house (currently beans)
- 2 cows and 1 pig

Livelihood (in order of importance):

- Rice
- Animals-keeps female calves, sells bull calves
- Off-farm income-making and selling snack foods
- Vegetables (beans and cucumber sold in SR from Nov to March

Irrigation: irrigation for recession rice is available from the border canal

Farm labour: 2 parents and son, no outside labour although contract mechanised harvesting undertaken

Calendar: Recession rice

Crop 1-dry season, irrigated recession (November plant)

This crop is grown on the low lands which are submerged during the wet season.

- Land prep 1-ploughing end of August when moist and then remains flooded until end of November
- Bund maintenance before levelling-20-30cm high, 30cm wide
- Land prep 2-end of November as water declines. No ploughing, just levelling-weeds not an issue due to submersion for 4-6 weeks
- Establishment of Vn504-hand broadcast into 10cm water at end of November
- Remove water 1 day after broadcast and then 6 days later fill to 20cm and apply fertiliser 1 (drainage done to control snails)

- Irrigation-1 week after seed broadcast add 20cm water prior to Urea application and then keep water at between 20cm depth up until 15 days before harvest (application every 10-14 days)
- Fertiliser 1-Urea@50kg/ha
- Fertiliser 2- 17 days after broadcast-DAP@50kg/ha; Urea@25kg/ha
- Fertiliser 3- @PI-Urea@50kg/ha; 16/16/8 13S@50kg/ha; KCl@50kg/ha
- Harvest-early February; Yield 4t/ha; mechanised harvest

Crop 2-dry season, irrigated recession (March plant)

This crop is grown in sequence with crop 1 on the low lands which are submerged during the wet season.

- Transition from first to second crop-starts in early Feb on harvest of crop 1
- Ploughing 1-plough soon after harvest 1 and then fallow and allow to dry
- Irrigation-last week March-add 20cm depth
- Tillage-harrow and level-2-3 days after irrigation
- Rice establishment-last week of March-hand broadcast Vn504 into 15-20cm water
- Remove water 1 day after broadcast and then 6 days later fill to 20cm and apply fertiliser 1 (drainage done to control snails)
- Irrigation-1 week after seed broadcast add 20cm water prior to Urea application and then keep water at between 20cm depth up until 15 days before harvest (application every 10-14 days)
- Fertiliser 1-Urea@50kg/ha
- Fertiliser 2- 17 days after broadcast-DAP@50kg/ha; Urea@25kg/ha
- Fertiliser 3- @PI-Urea@50kg/ha; 16/16/8 13S@50kg/ha; KCl@50kg/ha
- Harvest-late June; Yield 3.5t/ha; mechanised harvest. Yield for crop 2 is generally lower because of late crop weed invasion as wet season rains start

Marketing of rice:

- Sells 3 of 4t from first recession crop, saving 1 ton for food security. Rice sold to Vn traders. Second crop is all sold to Vietnam

General systems comments

- Vn504 is the only crop grown in Chas Ressey (both rainfed and recession) with all advice, inputs, credit and markets coming from Vietnam.
- 504 matures in 85 days compared to the most popular Cambodian modern variety of 100-110 days. This makes the Vietnamese variety very popular in systems where water is a constraint to production.
- This farmer uses insecticides but not herbicides. They are applied at the time of fertiliser application based on observation and I suspect, a recipe from Vietnam
- Advice is received from Vietnam traders, PDA, iDE and neighbours
- Farmers in the village co-ordinate the timing of crop production to minimise the risk of insect damage
- In discussion with Minea it was agreed that a small recession farmers has <2.5ha and a large one is >2.5ha

References

Rio (2013). Developing multi-scale climate change adaptation strategies for farming communities in Cambodia-Report on qualitative research. Internal report to CSIRO as part of the ACIAR project LWR/2008/019-*Building capacity of farming communities in Cambodia, Laos, Bangladesh and India to adapt to climate change.*