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International Agricultural Research

Success stories in agricultural water management research for development

92

ACIAR TECHNICAL REPORT

Success stories in agricultural water management research for development

Dr Evan W Christen (Editor)

ACIAR

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The Australian Centre for International Agricultural Research (ACIAR) was established in June 1982 by an Act of the Australian Parliament. ACIAR operates as part of Australia's international development assistance program, with a mission to achieve more productive and sustainable agricultural systems, for the benefit of developing countries and Australia. It commissions collaborative research between Australian and developing-country researchers in areas where Australia has special research competence. It also administers Australia's contribution to the International Agricultural Research Centres.

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Cover: A seepage pit installed near wheat crops in the medium-uplands of Jharkand, India. The pit is used to teach farmers how to access ('harvest') shallow groundwater when irrigating dry-season crops following rice. Photo: Peter Cornish

Foreword

Agricultural water management has been an integral focus of the Australian Centre for International Agricultural Research (ACIAR) since the centre's inception in 1982. As the global demand for natural resources increases and the challenges of a changing climate intensify, so too does the critical importance of research to inform sustainable agricultural water management.

Water scarcity—both surface water and groundwater—and water quality degradation (salinisation, and pollution from nutrients, biocides and heavy metals) affect most developing countries. Water scarcity and water quality degradation occur at local, regional, national and international levels. As much as 60% of the global population is predicted to face water scarcity in some form by 2025.

The basic factor driving water scarcity and degradation is increased competition for resources due to increasing populations and expanding economies. Competition for limited resources leads to unsustainable management practices, and greater demand for more refined foods and meat products places further pressure on water resources. Climate change amplifies these challenges.

Water scarcity and degradation often affect the most vulnerable people in the world—including the rural poor who depend on water resources for their sustenance and livelihoods. Those with poor or no access to water resources are denied the benefits of economic development in rural areas.

ACIAR recognises that to increase water productivity, profitability and sustainability, management must be improved through innovative technical, social and policy approaches. Inclusive agricultural development also requires equitable access to land and water resources for those marginalised by poverty, gender, age, disability, tribe, cast or religion.

ACIAR funds research in irrigated areas to increase water productivity through improved on-farm management of irrigation water, improved management at the irrigation scheme level, and more appropriate conjunctive use of surface water and groundwater. In rainfed areas, ACIAR funds research to increase crop production per unit of rainfall, rather than per unit of land, and to investigate the development of sustainable small-scale irrigation using surface water and groundwater.

The vision of ACIAR is to reduce poverty and improve the livelihoods of many in the Indo-Pacific region. As well as improving productivity and identifying new, more sustainable technologies, our research also seeks to understand how societal and economic factors can be better managed for more equitable and inclusive access to land and water resources for poor and marginalised people.

This report presents a snapshot of six ACIAR-supported projects investigating agricultural water management in the past decade. The outcomes demonstrate the effectiveness of the ACIAR model of brokering and funding research partnerships to build knowledge, while creating impact pathways that improve the livelihoods of smallholder farmers.

Andrew Campbell
Chief Executive Officer, ACIAR

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Acronyms

Shortened term	Definition
ACIAR	Australian Centre for International Agricultural Research
AIP	agricultural innovation platform
CLIC	Climate Information Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
NGO	non-government organisation
WSD	watershed development

Units

Unit	Definition
cm	centimetre
ha	hectare
kg	kilogram
km^2	square kilometre
kPa	kilopascal
m^3	cubic metre
mm	millimetre
t	tonne

Summary

ACIAR has funded a great deal of research relating to agricultural water management over its lifetime. This research has been undertaken under a number of ACIAR programs but was a specific focus of the Land and Water Resources program, which evolved into the Water and Climate program in 2018.

This report presents six short papers in the field of agricultural water management. The papers outline the findings from ACIAR-supported research during the past 10 years.

The papers cover a broad range of topics, from on-farm agronomy for improved water use efficiency to participatory management of groundwater resources. The research findings, which have been published in peer-reviewed journals, show wide-scale impact and positive outcomes on the ground. The projects reported provide a good example of rigorous research that creates impact pathways that improve the livelihoods of smallholder farmers.

A brief summary of each project is provided as follows.

1 Improving rainfall use efficiency on the East India Plateau

Frequent failure of rainfed rice and low-rainfall productivity underly poverty among indigenous people and other smallholders on the East India Plateau, and were the issues addressed in this project. A renowned in-country non-government organisation (NGO) was involved in the project, building on trust to engage local communities and facilitate project implementation.

Using water balance measurement and modelling, the research found that the distribution and variability of rainfall were such that transplanted ponded rice crops were likely to fail in 50% of years on the main rice-growing land (terraced hillslopes), although rainfall would be adequate every year if ponding were not required. Using a participatory action-learning approach that focused on women farmers, the project developed the technique of direct seeding rice without ponding. This proved very successful, and modelling anticipates a harvestable crop in 90% of years, addressing food security.

The project also developed vegetable crops for uplands in the monsoon, as well as techniques for growing crops directly after rice using the remaining soil moisture alone or with supplementary irrigation from small, easily constructed 'water harvesting' structures. This led to increased cropping intensity and diversity, and enabled farmers to earn cash incomes, which changed their lives remarkably. The principles are being out-scaled across various states by the NGO and state governments.

2 Managing climate risk through participatory weather data collection and on-farm research

This project aimed to help smallholder farmers manage climate risk by helping them to understand climate variability, collect local data and have access to external data, and undertake research to understand how to use the data.

The researchers collected historical rainfall records and worked with farmers to develop outputs that they could understand, resulting in a ‘rainfall visualiser’. Farmers were assisted to collect weather data for their own villages, providing them with confidence in the relevance of data to their farms. Participatory on-farm trials were undertaken to determine when best to plant crops based on cumulative rainfall for the season, rather than sticking to traditional calendar days, which are ineffective in variable climates.

Farmers were linked to external information ‘agro-climatic advisories’ and other useful data—initially paper based, but now online—that help them to make agronomic decisions on issues such as fertiliser application and pest management.

The project approach resulted in climate information centres, which are now being outscaled and taken up in major development projects funded by the International Fund for Agricultural Development.

3 Transforming small-scale irrigation in southern Africa

Smallholder irrigation schemes in southern Africa have not delivered the development outcomes hoped for. They have very low productivity (basically subsistence farming), producing little or no surplus to increase national food security or provide cash incomes to lift farmers out of poverty.

The project took a two-pronged approach: increase agricultural production and link the farmers to markets. It introduced easy-to-use tools to the farmers to measure soil moisture and soil nitrate, together with agricultural innovation platforms (AIPs) to link farmers to input suppliers and markets for their crops.

By using the tools, the farmers quickly learned that they were overwatering and washing the nitrate out of their crop root zones. Most farmers adapted by skipping irrigations, and some reduced irrigation times. By the end of the project, many farmers were irrigating only half as often as before. They also found that their yields had doubled. They were able to market their crops better as a result of the links created by the AIPs.

4 Participatory groundwater management: making the invisible resource visible and giving ownership of its sustainability to villagers

Falling groundwater levels are the norm around the world as a result of overuse of groundwater, especially for irrigation, and reduced recharge of aquifers due to climate and land-use change. This project sought to tackle this problem by empowering local communities to understand their groundwater system and take steps to manage it sustainably.

The project was able to demystify groundwater for the village communities by training local people from each village to collect data on the depth to groundwater and rainfall for their village, and having them discuss the data with the other villagers. This led to the villagers understanding the link between rainfall and groundwater levels, and that groundwater is a finite resource and they are pumping from one common pool of groundwater.

The research team developed simple models that showed villagers the amount of groundwater available and area of land that could be sustainably irrigated, depending on the wet-season rainfall. The villagers then determined how that limited groundwater could be shared among themselves through forming village groundwater cooperatives.

The approach has been successful in monitoring and managing groundwater, and in increasing agricultural output by better management of irrigation water and agronomy. The findings have been taken up by the Indian Government and included in the national groundwater management programs funded by the World Bank.

5 Making the best of watershed development in India

Watershed development, mainly the building of small dams and weirs to supply water and recharge groundwater, is widespread in India. It is generously funded by the government because it is seen as a way of improving food security and alleviating poverty. However, the approaches used tend to lack appreciation of the effects of upstream works on downstream water supply, and also often lack understanding of the hydrogeology. This has led to suboptimal or ineffective works that do not provide the development outcomes that were hoped for.

The research project investigated approaches to tackling upstream and downstream issues to improve equity in watershed development among those living in a catchment. It also developed simple hydrological models to better inform the design of the watershed interventions. This led to strategies that improve community resilience to drought and sustainability of watershed development following the project. The approaches have been taken up by state and national governments.

6 The realities of water ‘saving’ in rice–wheat systems in north-west India

The rice–wheat agricultural system of north-west India produces large volumes of rice and wheat, but has led to an unsustainable system with extensive groundwater overuse and falling groundwater levels. Much research has been undertaken, with results showing that water ‘saving’ would help reduce groundwater use. However, most of this research only looked at part of the water balance and did not consider the whole system. ACIAR funded a series of research projects that shed more light on the true water savings that would reduce groundwater use, and which of these could be undertaken without reducing crop yields significantly.

The research assessed the effects on water use of conservation agriculture techniques such as zero tillage and stubble retention, use of beds, alternate wetting and drying, and changes in the time and duration of crop planting. It found that the only water savings that could actually reduce groundwater use were those that reduced crop evapotranspiration. This has helped to clarify previous misconceptions and target government interventions.

The only effective means for reducing crop evapotranspiration was found to be reducing crop duration and changing planting dates. However, with current varieties, this led to reduced yields, indicating the urgent need to develop high-yielding short-season varieties.

The research on zero tillage and stubble retention resulted in the development of the ‘Happy Seeder’, which is now being used on 0.5 million hectares. It is expected to be used on 60% of the cropped area in 2019–20 as a result of large government subsidies for the equipment and government enforcement of a law that prohibits burning of rice stubble.

Conclusion

The research projects were selected for this report because they cut across a broad cross-section of the issues associated with agricultural water management. The findings add to understanding of how agricultural water management can be improved to increase water use efficiency of crops and increase yields (the first three projects). Commonly, increased water use efficiency is also promoted as ‘water saving’, especially in irrigation. However, the ‘rebound effect’ (Jevons paradox) means that, when a resource can be used more efficiently or effectively, it leads to increased, rather than decreased, use of that resource. Therefore, when promoting increased water use efficiency and productivity on-farm in research for development, water managers need to be aware about the effects on the overall water resource. This is where the approaches and findings from the last three projects should be considered, along with the watershed development aspects of the first project.

In terms of research execution, these projects were all based on excellent partnerships between Australian and partner-country research agencies. This was coupled with inclusion of appropriate government departments and NGOs from the outset of the projects, to ensure that pathways to impact were established that would endure after the projects.

The research approach taken was participatory with the local farmers—that is, the research was done on farmers’ fields, and in some situations the farmers ended up leading the research. This led to highly relevant, locally adapted research and effective on-the-ground impacts. Governments and NGOs have taken the approaches to scale, or are in the process of doing so.

A short policy brief on each project was produced and is available from ACIAR.[1]

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[1] www.aciar.gov.au/publications

1 Improving rainfall use efficiency on the East India Plateau

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Summary

Participatory research on the East India Plateau evaluated climate risk in the rice–fallow system, developed options for managing risk, and evaluated ways to intensify and diversify cropping. Women played a key role in implementing the research.

Most rice is currently grown on medium-upland, where the research found that transplanted rice often fails because ponding requirements are not met. This risk can be managed by growing short-duration direct-seeded rice, which also opens up possibilities for multiple cropping. Results confirm the potential for watershed development (WSD) but, more importantly, show that gains in rainfall productivity can be made without full WSD, resulting in large impacts on livelihoods.

Introduction

Eastern India is the least developed and poorest region of the subcontinent, home to 220 million people who are mostly subsistence farmers practising a rainfed rice–fallow system. The region includes half the rice area in India, but yield increases lag behind those in irrigated areas. Monocropping and low yields result in low rainfall productivity. Despite perceived drought susceptibility, the region is thought to have great potential because the high monsoon rainfall (>1,200 mm) provides excess water that may be 'harvested' for irrigation through watershed development (WSD). An ambitious WSD program in India aims to improve livelihoods where there is little irrigation infrastructure, but implementation has been limited by funding and expertise. So there remains a need for less risky and more productive rainfed cropping systems based on existing water resources, including residual soil water left by rice and existing or easily constructed 'water harvesting' structures (e.g. seepage pits, ponds).

This study relates to the elevated East India Plateau, comprising the states of Jharkhand and Chhattisgarh, and parts of West Bengal, Bihar and Odisha. Transplanted rice is by far the most important crop, with average yields of <2 t/ha. Rice was once grown only on lowlands favoured by run-off and seepage, but population pressure has forced expansion onto terraced slopes (medium-uplands), where most of the rice is now grown (Figure 1.1). The vast majority of families in this area have not benefited from WSD, and few have significant irrigation capacity, although small water harvesting structures are common.

The project team included expertise in rural development and WSD from the non-government organisation (NGO) Professional Assistance for Development Action (PRADAN), and expertise in soils, agronomy and hydrology from two Australian universities and the Indian Council for Agricultural Research. The aim was to explore opportunities to improve livelihoods through better use of rainfall. Specific aims were to characterise rainfall-related risks in the current rice–fallow system (Figure 1.2), suggest options for managing these risks, identify and evaluate opportunities to intensify and diversify cropping systems, and develop a platform for out-scaling findings.

Methods

The inclusion of an NGO helped the project team to interact with villagers and provided a basis for out-scaling of the research results. PRADAN was chosen for this role. Interaction between the project leaders and PRADAN ensured alignment between the research objectives and the mission and vision of PRADAN. The team consequently adopted a participatory action-learning methodology. This approach to identifying and solving real-life problems involves taking action and reflecting upon the results to improve the problem-solving process while arriving at practical solutions. The intention was to improve scientific insight, while facilitating changes in how farmers understand and manage their resources to improve livelihoods. PRADAN developed women's self-help groups and managed project implementation through representatives of these groups, who

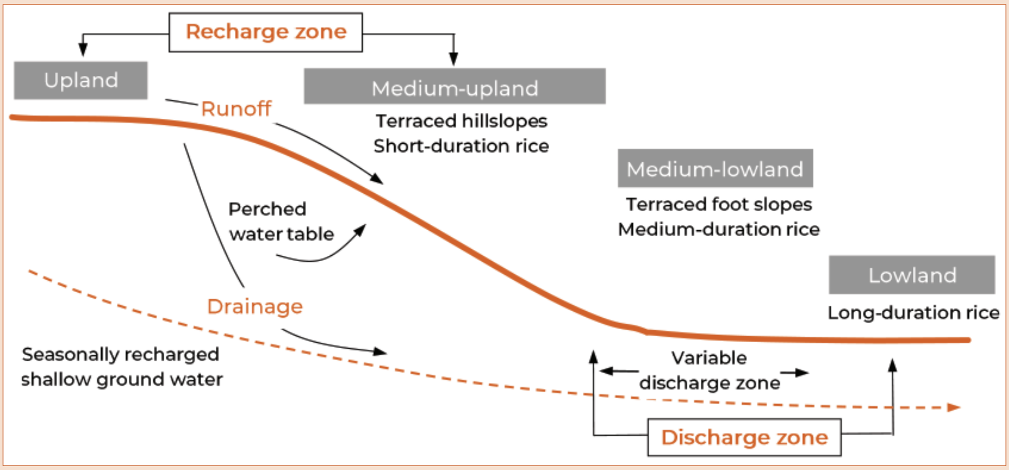


Figure 1.1 Landscape schematic. Medium-uplands comprised ~80% of the rice area and 65% of the watershed. The discharge zone varies in extent with rainfall. Ponds may be constructed on hillslopes to capture run-off and in lowlands to capture seepage water, providing small, privately owned, distributed irrigation infrastructure.

Figure 1.2 Severely drought-affected transplanted rice in medium-uplands, November 2005. A great deal of effort went into understanding why rice fails so often despite high rainfall, and into developing alternative rice production technology.

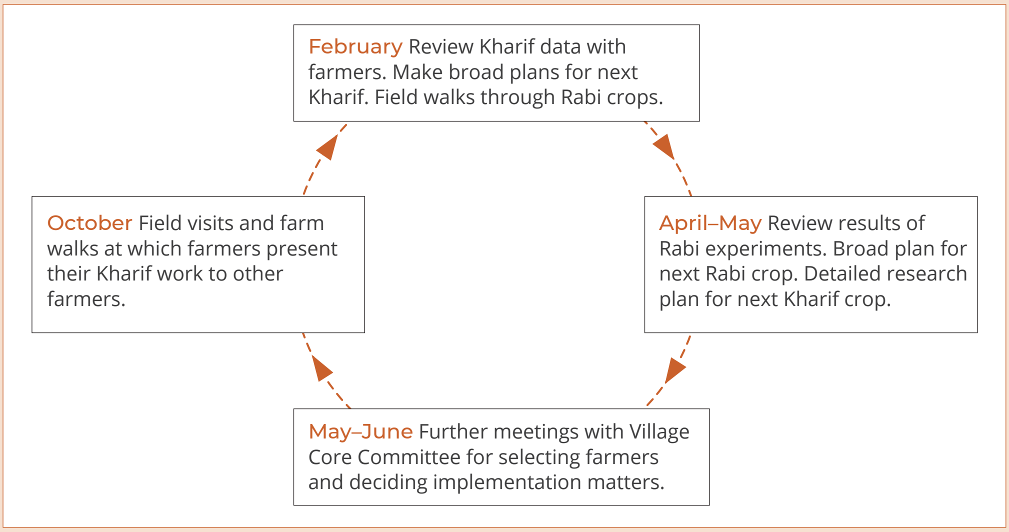
formed a Village Core Committee that played a key role in ensuring that research plans were implemented. The team met regularly to plan both the engagement process and the interventions designed to address the research questions, as well as to reflect and draw out learning.

Farmers participated in framing research questions, designing treatments, choosing sites and interpreting data. Planning initiated recurrent cycles of planning–doing–observing–reflecting, a derivation of the Kolb experiential learning cycle. Formal interactions between farmers and the research team were scheduled according to the cropping cycle (Figure 1.3).

The research combined measurement and modelling of soil water (Cornish et al. 2015a), and hydrologic measurement and modelling to underpin the assessment of water resources and evaluation of WSD (Croke, Cornish & Islam 2015, Croke et al. 2018), and participatory agronomic research (Cornish et al. 2015b) with smallholders in two small (<2 km^2) watersheds in West Bengal from 2005 to 2011. Agronomic research included rice crop surveys; research into direct-seeded aerobic rice; and evaluation of fertiliser responses, alternative Rabi (winter-planted) crops and Kharif (monsoon season–planted) vegetables. Experiments also provided learning experiences for farmers and data for evaluation of water balance models. The engagement process used when working with farmers was itself the subject of research, leading to the engagement of women as farmers and joint decision-makers early in the project, and more broadly to the methods used for out-scaling.

Agronomic trials were randomised complete block designs. Blocks were farmers' fields, within which treatments were randomised. Weather data were recorded on-site. The agronomic research did not attempt to develop an optimal package of practices. Rather, the premise was that farmers who identify an opportunity through sound learning experiences will have gained the capacity to initiate any further learning needed to optimise production methods for their situation (after Pretty 1995).

Soil water was estimated using a daily water balance model. Evapotranspiration (ET) was modelled as a function of reference ET estimated using the Penman–Monteith equation. Outputs included available soil water, ET, deep percolation and run-off. Water was allowed to pond above the soil



February Review Kharif data with farmers. Make broad plans for next Kharif. Field walks through Rabi crops.

April–May Review results of Rabi experiments. Broad plan for next Rabi crop. Detailed research plan for next Kharif crop.

May–June Further meetings with Village Core Committee for selecting farmers and deciding implementation matters.

October Field visits and farm walks at which farmers present their Kharif work to other farmers.

Figure 1.3 Schedule of formal interaction according to the annual cropping cycle. Planning, doing, observing and reflecting are separate activities, but may overlap (e.g. Kharif crop reflection and Rabi crop planning). Rabi crops are sown in winter and harvested through to early summer; Kharif crops are sown in the monsoon and harvested mostly in the post-monsoon season.

surface with rice. Water was modelled for the research watershed for 2006–11 using on-site data, and for three other East India Plateau locations for 1971–2009 using long-term rainfall records.

To understand the hydrology at one watershed, measurements were made of run-off at the catchment outlet, and the depth of water in ponds, wells and piezometers (Croke, Cornish & Islam 2015; Croke et al. 2018). Hydrological responses to water harvesting structures were modelled using the IHACRES rainfall–streamflow model, with the catchment moisture deficit version of the nonlinear loss module. The model was modified to include a surface store to account for the impact on infiltration and run-off of ponds, bunds, pits and so on.

Findings were incorporated into a cropping systems planning tool to help farmers assess their water resources (including residual water) and develop a climate-responsive annual crop plan. Development professionals were trained to use the tool. A program for out-scaling was developed by PRADAN (Purulia), with the aim of reaching 3,000 families over 2 years.

Results

The ponding requirement for rice was not met on medium-uplands at the research site in 5 of the 7 years from 2005 to 2011, leading to delayed or failed transplanting and/or periodic or premature draining of fields. Ponding duration was more variable than rainfall (coefficient of variation [CV] 0.55 and 0.29, respectively), highlighting the riskiness of transplanted rice. Most farmers try to manage the risk by growing medium-duration varieties on this land (Figure 1.1); however, the long-term ponding duration of 65 days at three locations fell short of the ~90 days required for medium-duration rice. It was <50 days in ~25% of years, and transplanting was not possible in 10% of years.

Modelling soil water without ponding simulated direct-seeded rice. In this scenario, the mean duration of readily available water for 2006–11 was 155 days (CV 0.11), sufficient for aerobic rice or other crops every year. The duration of available water was the least variable measure of water security. The riskiness of transplanted rice, which depends on prolonged ponding, compared with crops requiring soil water alone, is evident in Figure 1.4.

Predicted run-off for 2006–11 varied from 0 to 568 mm (mean 213 mm; CV 0.93), and deep percolation varied between 69 and 401 mm (mean 307 mm; CV 0.39). That is, run-off did not occur every year, but deep percolation did. These predictions, based on medium-uplands and uplands, broadly agreed with the observed hydrology in the research watershed. Long-term modelling suggests that there is little or no run-off when rainfall is <1,050 mm (15% of years).

The average estimated post-harvest (residual) soil water with transplanted medium-duration rice from 2006 to 2011 was 111 mm (CV 0.62) with an average harvest date of 25 October. It rose to 193 mm (CV 0.41) after a short-duration variety harvested by 1 October.

Farmers succeeded with direct-seeded rice, even in a year when transplanted rice failed, achieving yields of 4 t/ha (Figure 1.5, left). They also grew rainfed vegetables on uplands and well-drained medium-uplands in the Kharif season, earning high prices (Figure 1.5, right).

Research into the engagement process showed that success with Kharif vegetables transformed farmers' perceptions of uplands from being their least valuable land to their most valuable when managed appropriately.

Satisfactory yields were obtained with rainfed wheat and mustard following short-duration rice using residual water, given adequate phosphorus fertiliser (Figure 1.6, left). Farmers extended vegetables into the Rabi season and even early summer if irrigation was available from shallow groundwater accessed via seepage pits

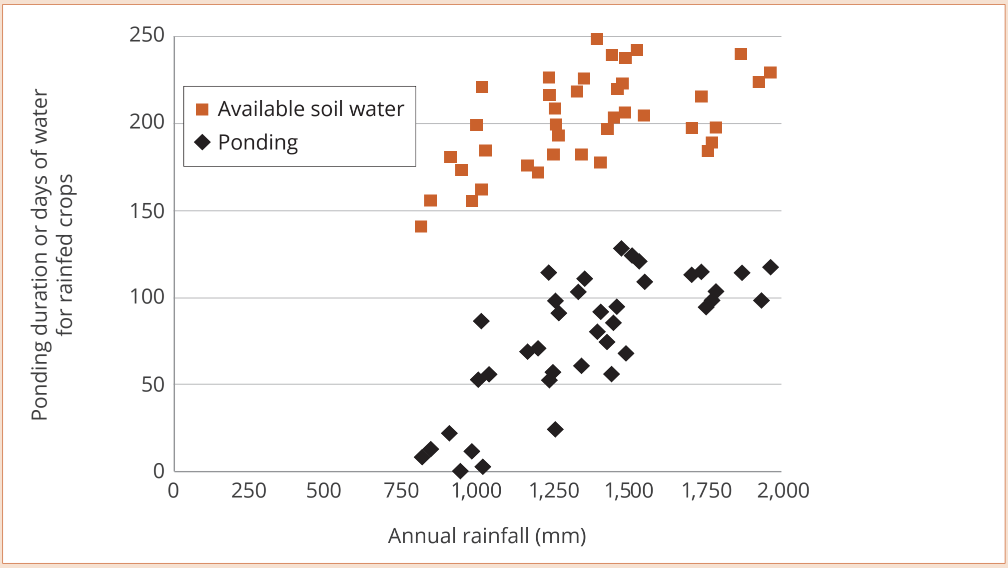


Figure 1.4 Duration of ponding and of readily available soil water in response to rainfall, from long-term modelling of medium-uplands, Purulia district (West Bengal)

or wells (Figure 1.6, right). They also grew vegetables in the pre-Kharif period if they had ponds filled by pre-monsoon rainfall with run-off from hard surfaces (e.g. roads).

Overall, farmers displayed a remarkable new capacity to identify and capitalise on opportunities offered by their land and water assets. We attributed this to the highly participatory engagement process.

The uptake of more diverse and intensive cropping over a short period in the research villages is shown in Figure 1.7. The year 2010 was a drought, which particularly affected the 2010–11 Rabi season. Recovery in 2011–12 demonstrates the resilience of the farmers and the technology. Family case studies revealed improved food security, reduced forced migration, and increased

Figure 1.5 Successful Kharif cropping during 'drought', 2010 (723 mm rainfall, compared with an average of 1240 mm). Left: Direct-seeded rice approaching harvest (foreground), with recently transplanted rice in the background, which ultimately failed (September 2010). Right: Vegetables on uplands and medium-uplands (September 2010) show that 'drought' only affected transplanted rice. There was plenty of water for other crops.

Figure 1.6 Rabi cropping. Left: Rabi cropping was possible without irrigation, if short-season crops (in this case, mustard) were sown early after rice. Plots show the large response to phosphorus. Right: Small water harvesting structures such as this 'seepage pit' allowed less risky Rabi cropping (wheat, in this case) based on residual soil water plus minimal supplementary irrigation. Farmers ultimately preferred to use any irrigation water for vegetables.

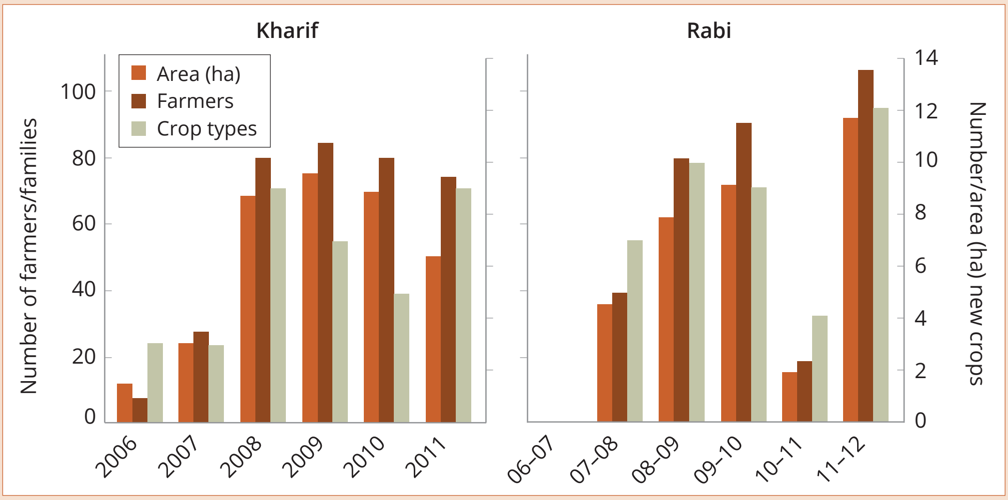


Figure 1.7 Uptake of new crops from 2006 to 2012. New crops included vegetables in both seasons and field crops in the Rabi season. The farmers growing new crops in 2006 were participants in the vegetable research.

investment in agriculture and schooling. Out-scaling in 2011–12 reached 2,374 of 3,118 families targeted; case studies in four of the villages revealed that 66% of medium-upland fields were second-cropped using a mix of no irrigation and supplementary irrigation.

Discussion

Low rice yields and recurring crop failures with transplanted rice are inevitable on the terraced and bunded hillslopes because of insufficient ponding. The same land has adequate soil water every year for crops that do not need ponding. For rice to be grown on this land, it is critical that production transitions to direct-seeded rice, with no requirement for puddling and ponding. Farmers successfully grew direct-seeded rice, even in a year when transplanted rice failed.

WSD is often claimed to drought-proof agriculture—for example, through 'rescue irrigation' to allow timely transplanting. However, our results show that there may be little or no run-off to harvest in 15% of years, and deep drainage provides water too late to save rice. The only way to remove drought risk in rice is to adopt direct seeding. The research also showed that rainfed crops other than rice, including vegetables, can be grown in the Kharif season, with low drought risk.

The amount of residual water left by rice depends on crop duration. Short-duration rice maximises the available water and minimises the risk to the second crop. In addition, direct-seeded rice is more likely to be planted on time than transplanted rice. For this reason, direct-seeded rice increases the chance of timely planting of the second crop.

The most secure water for irrigation is seepage derived from deep percolation in uplands and medium-uplands, and harvested low in the landscape. It may be used for supplementary irrigation of Rabi field crops, but in our study it was most valuable for vegetables. Run-off from hard surfaces captured early in the pre-monsoon proved useful for pre-Kharif vegetables.

Agronomic experiences built the farmers' knowledge of land and water resources, and the skills to manage them. They became adept at evaluating new options beyond those introduced by the research team. Moreover, the technology spread rapidly from the few collaborating farmers to most of the village (Figure 1.7). No subsidies were required. Out-scaling in 2011–12 showed strong adoption of second-cropping, providing further evidence that cropping intensity can be increased with little additional investment in water harvesting structures.

Run-off and drainage estimates confirm that WSD in eastern India has the potential to provide new water resources, raise agricultural production, and improve livelihoods. However, implementation of WSD has been slow. The results of this project show that farmers do not need to wait for WSD to improve their situation.

Conclusions

With very little irrigation infrastructure on the East India Plateau, improved livelihoods must come through improved rainfall productivity. This project confirms the potential for WSD to capture water for irrigation. More importantly, it establishes that major gains in rainfall productivity can be made without full WSD, the implementation of which is limited by the available funds and expertise.

Low rice yields on the terraced and bunded hillslopes (medium-uplands) that comprise 80% of the rice area result from deficient ponding for transplanted rice. The reputed ‘drought sensitivity’ of this region is a misconception based on transplanted rice. Rice yields can be improved substantially by removing the need for puddling, transplanting and ponding, by cultivating direct-seeded rice. Soil water during the Kharif season is adequate every year for direct-seeded rice, and for other rainfed crops on suitable uplands and drained medium-uplands.

Research confirms the potential for second-cropping based on residual water. The key to this is short-duration direct-seeded rice, which minimises risks and maximises yield.

Where irrigation is available from small water harvesting structures, it can increase Rabi crop area and/or yields, and allow more diverse cropping. Both run-off and deep drainage water may be harvested, but deep drainage is the more reliable. It can be accessed inexpensively by using small pits that access shallow groundwater in appropriate parts of the landscape.

Improved rice yields, and increased cropping intensity and diversity contributed to improved livelihoods in the case study watersheds. The benefits spread rapidly from the original participants to the village and beyond, without subsidies, validating the participatory process.

The NGO PRADAN was critical to achieving these outcomes. PRADAN maintained the focus on livelihoods (which made the research relevant to communities); enabled effective engagement of women as farmers; and facilitated the close interaction between the Village Core Committee, farmers and researchers that was central to the participatory approach. Their local experience also enabled them to contribute to developing practical ways of addressing the risks and opportunities identified during the project. It was also reported that the PRADAN staff learned deeply from the experience of working with the Australian scientists.

Adoption and out-scaling

Involving PRADAN paved the way for adoption of project outcomes within the research watersheds, and subsequently by almost 2,400 families in Purulia district through the PRADAN team of professionals.

Agronomic learning from the project was packaged into a climate-responsive crop planning calendar for use by farmers. The calendar has been included in PRADAN's natural resource management training for professionals (Figure 1.8).

The work on engaging women as farmers contributed to changes within PRADAN in the way women are engaged in development. The revised approach is gaining recognition within the larger movement relating to women in non-traditional public roles and in government programs. The subsequent ACIAR project LWR/2010/082 reported that, in 2016, direct-seeded rice had been adopted by more than 10,000 farmers and that the National Bank for Agriculture and Rural Development has adopted direct-seeded rice as an intervention to finance and support. As well, almost 6,000 farmers had adopted commercial vegetable production in 2016.

Figure 1.8 Crop planning calendar used by women during out-scaling in 2011–12

Acknowledgments

The project 'Water harvesting and better cropping systems for the benefit of small farmers in watersheds of the East India Plateau' (LWR/2002/100) was funded by ACIAR.

Participants included villagers from Purulia district (West Bengal), the Purulia Team of PRADAN led by Mr Avijit Choudury, the Indian Council for Agricultural Research led by Dr Shivendra Kumar, and colleagues from Western Sydney University (Dr Shane Norrish) and the Australian National University (Dr Barry Croke).

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2 Managing climate risk through participatory weather data collection and on-farm research

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Summary

Farmers in rainfed and drought-prone agricultural regions often grapple with how best to use limited (and uncertain and depleting) water resources. There is a need to improve water use efficiency for sustainable livelihoods and economic development. An ACIAR-funded project in India—'Adapting to climate change in Asia (ACCA)' (LWR/2008/019)—researched managing climate risk for smallholders using participatory approaches. This research involved a combination of participatory measurement of data such as rainfall, temperature and soil moisture; collective farmer clubs; and on-farm participatory research to test sowing and irrigation practices.

These approaches were combined with weather-based agrometeorological advisories to support farmer decision-making.

The initial research outputs were papers, posters and so on. However, with farmer feedback, the Climate Information Centre (CLIC) concept was developed. This further evolved into an ICT platform of software and hardware that integrated the ACCA project results and other agronomy data.

An evaluation of the CLICs showed that farmers benefited from access to agrometeorological bulletins, information on pests and weather forecast information. From an initial three CLICs established in ACCA project sites, 33 CLICs have been established through various Indian state and federal projects since 2015. The International Fund for Agricultural Development, through the Andhra Pradesh State Government, is funding the establishment of about 105 CLICs as part of the Andhra Pradesh Drought Mitigation Project from 2017 to 2022.

Introduction

Climate variability has been, and continues to be, the principal source of fluctuations in global food production in arid and semi-arid countries of the developing world (Sivakumar, Das & Brunini 2005). Improved knowledge about climate and skills in seasonal climate forecasting will help to manage uncertainty in farming. Learning about and using this new climate and weather knowledge is important for all involved in rural production (Banks 2004).

A number of initiatives are underway to bring ICT-enabled climate services to smallholder farmers. In this paper, we describe the outcome of the 'Adapting to climate change in Asia' (ACCA) project in India, which evolved into what we termed Climate Information Centres (CLICs). At the outset, the ACCA project team did not intend to develop CLICs. The ACCA project focused on participatory climate risk management at a village scale, and the ICT platform leading to CLICs evolved in response to demand from the in-country partners, extension staff and farmers. As a result, CLICs have a strong foundation in participatory action research. The research considered various challenges, such as:

- the need for location-specific and timely climate information
- integration with government monitoring of weather and climate events
- deep participation by the community
- customising information to appropriate climate-sensitive points in crop agronomy.

The village-scale ACCA project activities combined biophysical research with participatory action research. The case study villages are located in Telangana state in the districts of Mahbubnagar, Warangal and Nalgonda. The ACCA project was conducted over 5 years, from 2010 to 2015. The work of the CLICs was initiated in the later years of the research, building on the initial capacity building with farmers (van Wensveen, Williams & Roth 2016).

Methods

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

The participatory action research approach (Carberry et al. 2002) was core to building capacity among the farming community to observe and act on climate and weather information. The approach we used combined field-based on-farm research, climate modelling and participatory engagement at every stage of the project. The approach comprised five linked components:

- village-level weather data recording and reporting
- formation and development of village or farmer climate clubs
- on-farm participatory research to test a range of sowing and irrigation practices in response to weather patterns
- preparation and dissemination of agrometeorological advisories
- participatory development of a seasonal rainfall visualisation tool.

In the first step, researchers from the Professor Jayashankar Telangana State Agricultural University (PJTSAU) established a manual weather station, and trained a local farmer in each village to maintain and record daily temperatures and rainfall. At the same time, we formed 'farmer climate clubs' through the Watershed Support Services and Activity Network (WASSAN), a non-government organisation (NGO). WASSAN enlisted a local NGO for each village to establish and support these clubs. At fortnightly farmer climate club meetings, typically involving 20–30 farmers, farmers discussed the weather data they had collected, crop progress and agronomy issues. Additional meetings were held in which participating scientists were also involved to co-design and evaluate the results of trials to test improved sowing and more efficient irrigation rules (Hochman et al. 2017).

As well as facilitating the fortnightly meetings, the local NGOs delivered agrometeorological advisory bulletins to their villages for public display twice weekly. The bulletins were produced by the research partner from PJTSAU, adding local agricultural context to information supplied by the Indian Meteorology Department (IMD).

Finally, a rainfall visualisation tool was developed to facilitate the charting and interpretation of the rainfall data. The tool allowed comparison of cumulative in-season rainfall with the rainfall in the previous Kharif season (monsoon rainy season, June–October), as well as locally selected years representing wet and dry seasons from the past 10 years of local weather station records (Hochman et al. 2017).

Formation of the farmer climate clubs in the villages was the critical step in bringing the community of farmers together for collective learning with the researchers, as part of the participatory action research (Figure 2.1).

Based on the successful conduct of the farmer climate clubs, there was demand from farmers and local partner research institutions to consolidate the outcomes and outputs of the project in a way that would enable farmers to consult on various farm management activities. This demand catalysed the development of the CLIC concept, which evolved into the development of an ICT platform of software and hardware that integrated the project results, and included other static data

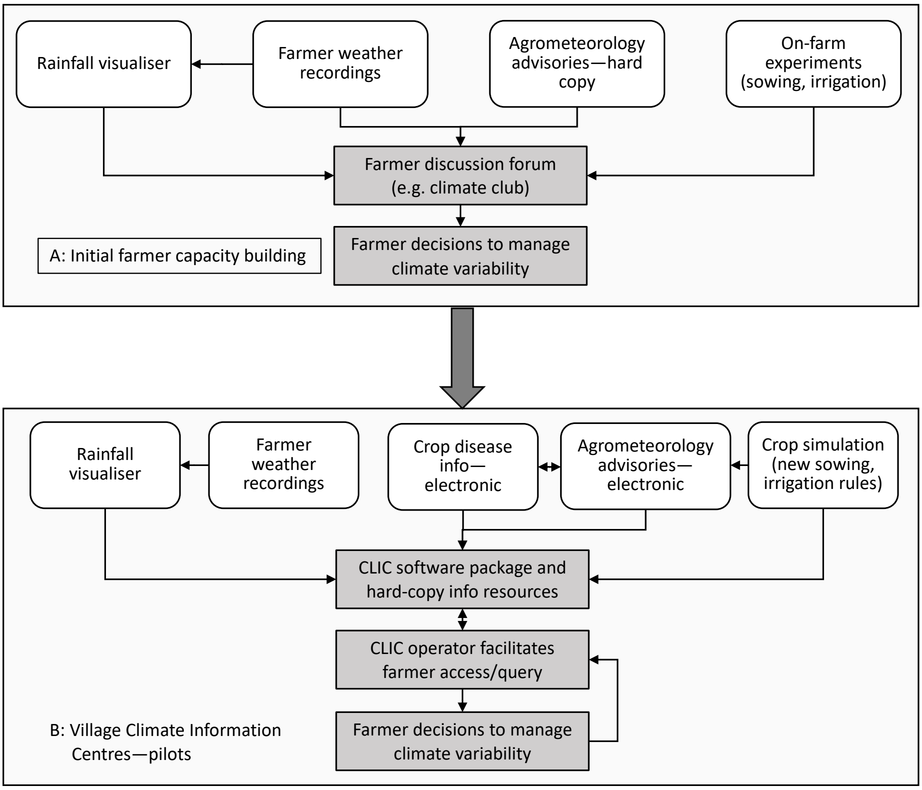

Figure 2.1 Components and evolution of initial farmer capacity building centred on (a) farmer climate clubs, leading to (b) generation of Climate Information Centres (CLICs)

to enrich the existing data and research outputs (Figure 2.1).

The CLIC in each study village was developed as a one-stop information centre that consolidates information from a range of sources (Figure 2.1). It is a computer-based, offline (with links to online) information system that displays agrometeorological advisory bulletins and generates the rainfall visualiser plots (described below). It also maintains a database of information relating to agriculture, livestock, fisheries and machinery, packaged for easy access. The CLIC system started with just the outputs from the ACCA project but has grown to be a wider repository of information—with visuals, videos, narrations and animations on varied subjects relating to agriculture that are easily accessible to farmers.

Key information components of the pilot CLICs comprised the following:

- An agrometeorological advisory. This was a 3–5-day weather forecast from the IMD processed by PJTSAU into a locally relevant, agriculture-oriented advisory. The advisory was provided to the local NGOs twice a week. The NGOs delivered them to the villages for public display, and facilitated fortnightly meetings to discuss the results and agricultural issues.
- A 'rainfall visualiser', which is a graphical presentation of the cumulative rainfall measured locally (from the rain gauge

installed in the village) and plotted on a graph. This enables farmers to view rainfall data in terms of emerging season scenarios and compare them with seasons in the near past (Figures 2.2 and 2.3).

The rainfall visualiser shows:

- a plot of the current and accumulated rainfall to date; rainfall in the village was measured from a rain gauge set up in the village, and measurements were recorded by a dedicated NGO facilitator (farmer) identified and trained for the purpose
- contrasts between the current season's rainfall with recent 'wet (90th percentile)' and 'dry (10th percentile)' seasons, and their trajectories over the season from the past 10 years of rainfall data from the IMD
- the probability of 'finish'—that is, the final total rainfall to be expected in the season (highest and lowest) based on gridded long-term historical data
- information on the optimal time for sowing to help farmers decide when to sow to minimise the risk of early crop failure; agronomic data obtained from the participatory on-farm trials suggested that, for the soils in the region, a cumulative rainfall of 50–75 mm was required before planting to ensure that seedlings can survive a dry period immediately after sowing
- advice on the timing of 'critical irrigation', which is a targeted irrigation to ensure the survival of crops during drought spells in the course of the growing season
- information on management of pests and diseases, which links weather observations to the incidence of pests and diseases; this helps farmers to be prepared and to take appropriate remedial actions, supporting judicious use of chemicals.

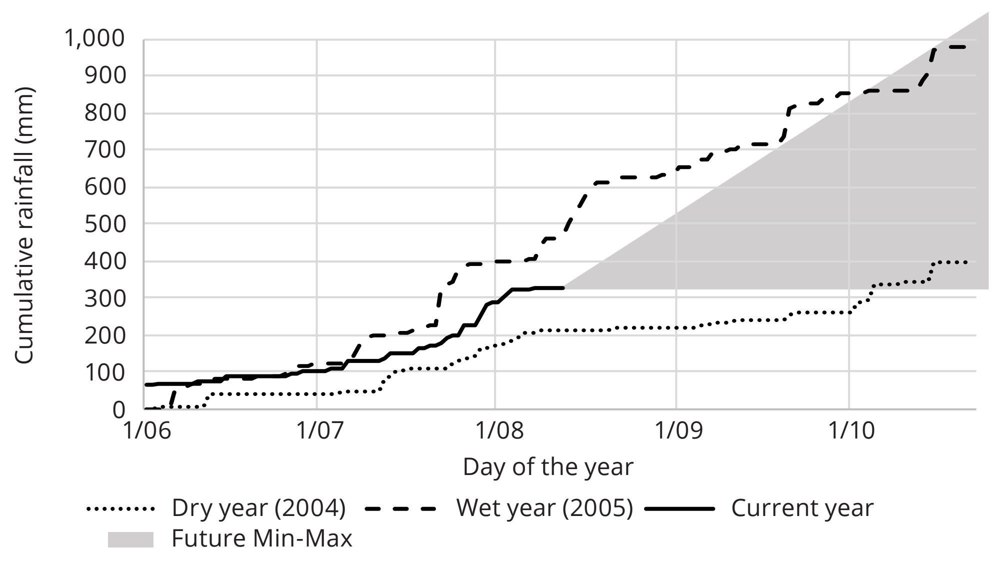

Figure 2.2 Rainfall visualiser for Gorita village, showing the cumulative rainfall for the 2011 season in comparison with the driest and wettest seasons in that decade

Figure 2.3 Climate Information Centres in action: a non-government organisation team discussing the rainfall visualiser with farmers in Gorita village

Results

An evaluation of the CLICs was undertaken in 2015, based on a survey of 330 farmers and qualitative focus group discussions in eight villages with CLICs. These comprised two ACCA project case study villages and six non-ACCA project case study villages that were established through other projects.

The ACCA project villages had the benefit of CLICs being run by experienced volunteers (involved closely with ACCA project activities from its inception), as well as the farmers having exposure to scientific discussions and explorations. The CLICs in non-ACCA project villages were run by operators with no exposure to the project but trained specifically for running CLICs.

Comparison of results for these two types of implementation provided guidance for out-scaling CLICs. Performance of CLICs in the different villages was evaluated using a number of criteria: number of farmers who have visited CLICs, frequency of visits during the Kharif season and the Rabi season (post-monsoon dry season), rating of usefulness of CLIC content, change in level of knowledge in various areas covered by CLICs, percentage of farmers aware of the existence of CLICs and their services, percentage of farmers accessing CLICs for one or more of their services, extent to which farmers' expectations were met and CLIC operator performance.

On average, 80% of the surveyed farmers had visited CLICs during the period, with no significant difference between ACCA project and non-ACCA project villages. Among the socially disadvantaged sections of the farming community, 50% had visited CLICs. A larger percentage of farmers with higher education levels were aware of CLICs. The results varied across the villages, as well as across the source of benefit. Out of a number of sources, farmers highlighted four sources as important contributors to various types of benefits they derived: the videos they watched, access to agrometeorological advisories, information on pests and weather forecast information.

Although it may not be possible to estimate total benefits based on the above data, within the short period of 6–8 months of operation, CLICs in various villages had observable benefits as reported by the farmers. The average cost savings reported were US$4–64/ha per year. Using the CLICs as our primary dissemination mechanism, 5% adoption after 5 years would result in economic benefits shared by at least 400 households in the study districts of Telangana (van Wensveen, Williams & Roth 2016).

The intangible benefits measured in terms of an increase in farmers' knowledge on various topics seem to be more widespread. Farmers across the villages perceived an increase in their knowledge on key topics of interest, such as pests, pesticides and weather. A majority of respondents in ACCA and non-ACCA project villages rated CLICs as a primary source of climate information.

Knowledge levels before and after CLICs were rated by the farmers on a scale of 0–5. Farmers who reported an increase in their knowledge on a particular topic mostly moved up one level, but some farmers moved up two levels. Weather and pesticides were the major areas in which a large number of farmers gained knowledge across the villages.

Discussion and key findings

One of the main reasons for the limited acceptance of climate-based advisories is that the information is mostly generated externally at different scales, and may not suit or match the village requirements. Engaging stakeholders is an essential ingredient in the application of any science to real-world problems, and the case has been strongly made for stakeholder participation in the application of climate science to agriculture (Cash & Buzier 2005; Cash et al. 2003; Meinke et al. 2006; Sivakumar, Das & Brunini 2005). To engage with end users, translation of climate information requires three essential components: relevance (including social, cultural and gender), credibility (the perceived technical quality of the information) and legitimacy (the perceived objectivity of the process for sharing the information) (Cash & Buzier 2005).

Up-to-date, local and spatially relevant agrometeorological information (short-term weather and seasonal climate forecasts) and related agricultural decision support tools are not readily available to a wide range of actors. Combined with limited access to traditional extension services, this leads to uninformed or underinformed decision-making at a farm level.

Climate and allied agro-advisory information delivered through web platforms (e.g. provided by agribusiness) or village CLICs enable a shared quantitative understanding of climatology at the village level. As a consequence, communities are empowered with locale-specific climate data (measured and monitored by them) and simple tools (underpinned by robust science) to increase awareness and effectively manage climate risks. Incorporating advances in digital technology and communications, CLICs complement and add value to traditional extension services (Figure 2.4). CLICs are therefore a more efficient agrometeorological advisory option for farming communities.

Figure 2.4 Digital capacity in the latest Climate Information Centres in Naskal village

Conclusions

Timely and locally relevant climate information that supports agricultural decision-making is critical for smallholders to manage climate risk. CLICs evolved from this need in the project case study locations. They were designed to complement and contribute to national agrometeorological services and the traditional extension service, increasing the reach and impact of these existing services by providing locally relevant climate information.

CLICs have been developed for capacity building among farming communities, NGOs and practitioners at village level to record, observe, interpret and act on climate information, leading to improved climate risk management and agricultural decision-making.

Although the current version of CLICs has shown promise and relevance for smallholders, CLICs need to be developed as small business centres that are knowledge and provision hubs for various agriculture inputs, providing climate information as an important service. CLICs will then have a self-sustaining financial model, rather than just providing climate information as the only service.

Adoption and out-scaling

The CLICs were developed over a 3-year period, and were first launched in 2013 in each of the three ACCA project villages. Focus group discussions were held in July–October 2013 to capture initial feedback on the suite of practices described above and the general approach taken by the CLICs. This feedback was used to refine the approach and information provided. It also provided a basis for engagement with policymakers, resulting in their growing interest to build on these initial pilots. As a result, in the following years, CLICs were established in 16 villages that were not part of the ACCA project through a watershed project managed by the NGO WASSAN. Subsequently, a further 12 CLICs were established under an Indian federal program for agriculture development through PJTSAU.

A key challenge that emerged from the pilots, as well as the next generation of CLICs, was the sustainability of the CLICs beyond the life of the project. Accordingly, the NGO partner WASSAN focused on options to mainstream CLICs into existing institutional and policy frameworks. Ultimately, the conclusion was that CLICs need to be embedded in local institutions that have a political and administrative mandate; at the village level, these are the village councils, or Gram Panchayats.

A significant next phase of out-scaling of CLICs will be achieved through a new International Fund for Agricultural Development and Andhra Pradesh State Government project titled 'Andhra Pradesh drought mitigation project (APDMP)', which will operate during 2017–22. APDMP has a total outlay of about US$145 million and will be implemented in the most drought-affected areas of Andhra Pradesh. The goal of the project is to improve the incomes and strengthen the drought resilience of 165,000 farm households over a period of 5 years. CLICs, based on the model described in this paper, are an important component of this new project (IFAD 2017).

Encouragingly, the CLICs being designed in the APDMP are next generation, with a wider scope of information to be delivered to farmers, including advisories on livestock management (e.g. in relation to weather), market prices, and government services and contacts.

The governance and mainstreaming of CLICs is also evolving towards CLICs being embedded locally within Farmer Producer Organisations, in close association with the village administration (IFAD 2017).

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3 Transforming small-scale irrigation in southern Africa

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Summary

Small-scale irrigation schemes are complex socioecological systems that require multiple interventions at various scales to address the diversity of constraints that limit their performance. ACIAR's 'Transforming small-scale irrigation in southern Africa' (TISA project; LWR/2016/137)) project achieves this through a two-pronged approach that facilitates farmer-centred learning and participatory problem solving by introducing:

- soil moisture and nutrient monitoring tools that are sophisticated, but simple to use, and stimulate farmer learning about irrigation water management to enhance decision-making, reduce water use and increase yields
- agricultural innovation platforms (AIPs) as multi-stakeholder forums that bring key stakeholders together to develop solutions to the barriers preventing farmers turning increased yield into improved profitability.

The tools and AIPs provide two simultaneous, synergistic entry points to transition underperforming irrigation schemes to being more sustainable and profitable. This occurs by increasing yields through more efficient use of water and fertiliser, and also investing in the famers, institutions and value-chain network.

Through the project, farmers have learned from the tools and each other. As a result, irrigation has been reduced (frequency and duration of irrigation events), soil nutrients have been retained and yields have improved. The AIPs have also facilitated further learning from the tools, which has resulted in a deeper understanding of water–nutrient dynamics. Through the AIPs, farmers have established and strengthened their links to suppliers, output markets and irrigation departments. The farmers have also been able to address priority constraints and progress towards the community vision for each scheme.

Introduction

Irrigation development is a priority in southern Africa for poverty alleviation, food security, and economic growth and development. Continued expansion of irrigation will take place, even though existing small-scale communal irrigation schemes have not realised returns on investment (Stirzaker & Pittock 2014). Many farmers and schemes are trapped in unprofitable farming as a result of policies that have restricted plot sizes and required farmers to focus on crops for food security. The impact of these policies is amplified by a lack of agronomic and irrigation knowledge, low soil fertility and poor market integration. This has led to insufficient investment in scheme maintenance, resulting in failed or degrading infrastructure (Bjornlund, van Rooyen & Stirzaker 2017). The end result is low crop production and low income, inefficient use of water and land, and increased conflict over access to water.

Conventional irrigation scheme development has focused on infrastructure and irrigation application, which is not sufficient to improve poorly functioning systems. Traditionally, it has been easier to obtain funding for engineering works; little funding has been available for 'soft' issues, such as institutional development and integrating farmers into the agricultural value chain. The rationale for the ACIAR project 'Transforming small-scale irrigation in southern Africa' (LWR/2016/137) argues that there is no single solution to improving yield and profitability. The soft barriers must be addressed in conjunction with infrastructure issues.

The project initially operated on five schemes in three countries: Mozambique, Tanzania and Zimbabwe. It is now out-scaling these approaches.

Methods

The project introduced:

- soil moisture and nutrient monitoring tools that are sophisticated, but simple to use, and stimulate farmer learning about irrigation water management to enhance decision-making, reduce water use and increase yields
- agricultural innovation platforms (AIPs), which are multi-stakeholder forums that bring key stakeholders together to develop solutions to the barriers preventing farmers turning increased yield into improved profitability.

The tools and AIPs simultaneously aim to develop two complementary learning loops to overcome the challenges faced by small-scale irrigation schemes. These are described more fully in Pittock et al. (2018) and Bjornlund et al. (2018). A critical underpinning of both approaches is that new knowledge and solutions must be generated locally.

Soil monitoring tools[1]

The tools were designed to provide farmers with critical information about moisture and nutrient dynamics in the soil, and to facilitate farmer learning for more informed decision-making. The tools are simple to use (circumventing low literacy and numeracy issues) and provide the least amount of information needed for improved irrigation decision-making (Stirzaker, Mbakwe & Mziray 2017).

The Chameleon™ soil water sensors and reader (Figure 3.1) monitor soil moisture by measuring soil tension. A sensor 'array' comprises three sensors, which are

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[1] Tools were developed by CSIRO with support from the South African Water Research Commission and ACIAR.

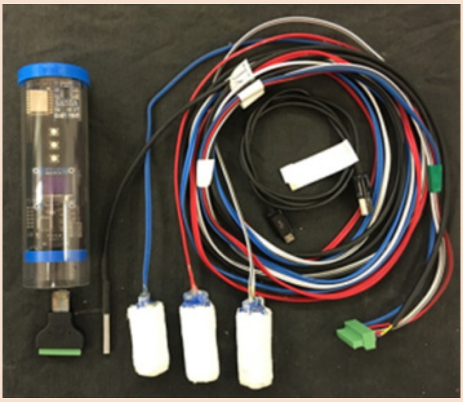

Figure 3.1 Chameleon reader and sensors

permanently buried, to monitor the top, middle and bottom areas of the root zone.

The reader connects to the array and displays the soil moisture levels through coloured LED lights: blue, green and red, denoting wet, moist and dry soil, respectively. Farmers use this information to decide when to irrigate. The reader is moved between arrays and shared by several farmers. The farmers record the Chameleon readings and relevant agronomic data in a field book. The wi-fi-enabled reader also allows data to be uploaded to an online database for storage and visualisation of soil moisture over time.[1]

The FullStop™ wetting front detector comprises two funnel-shaped devices to collect soil water samples at two depths (one-third and two-thirds of a crop's root depth). The water samples are assessed for nitrates using nitrate test strips, and salt levels using an electrical conductivity meter. The FullStop provides farmers with information about the depth of water penetration, from irrigation or rainfall, and how nitrates are moving through the profile and leaching beyond the root zone. This provides information to farmers about how much to irrigate and how to manage fertiliser.

The combination of information on soil moisture, soil nitrate status and water movement stimulates learning about irrigation and nutrient management. The tools were supplied to 20 farmers on four irrigation schemes.[2]

Agricultural innovation platform process

AIPs were established for each of the irrigation schemes. These platforms are particularly suited to identifying constraints and prioritising interventions in complex systems. AIPs have many additional benefits, such as fostering empowerment, respect and self-organisation (van Rooyen et al. 2017). Establishment of AIPs on each scheme required the selection of a facilitator with local knowledge and, critically, the skills to ensure inclusivity and ownership (van Rooyen et al. 2017). Once established, the AIPs were used to:[3]

- identify value-chain stakeholders with the skills to bring about change, and their incentives for engaging in input and output markets
- undertake a community visioning exercise to create a shared vision of a desired and achievable future state of the scheme and community
- identify a scheme's constraints and opportunities, with emphasis on gaining a deep understanding of root causes and viable solutions
- foster innovation to identify the most suitable strategies to address the prioritised constraints; implementation of activities took place outside the AIP meetings.

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[1] https://via.farm

[2] The tools were not deployed on the Magozi scheme in Tanzania, where rice is the main crop.

[3] Different AIPs may undertake the steps in a different order.

AIP participants learn to think critically about constraints, solutions and interpretation of the soil monitoring results. Experimentation, including failure, is valued as an integral part of the learning process that leads to successful implementation. Importantly, the AIP functions as a catalyst to bring people and organisations together. Through the process, relationships are strengthened and formalised.

Results

Within a few months of the tools being deployed, project staff observed that farmers were starting to learn from the tools. Surveys undertaken 3 years after deployment showed that most households surveyed were aware of the tools (Table 3.1). Many farmers had made changes to their irrigation and fertiliser management in response to the monitoring, which had resulted in improved yields and income. A diversity of AIP-facilitated activities were implemented, with each responding to local context and constraints. Some major issues, such as crippling water debts, needed an early resolution; if left unaddressed, they would have undermined all other farmer and project efforts.

The AIPs also fostered on-farm changes, and improved market linkages and business skills. Additional indirect benefits of the AIP process include reduced conflict over water, which has resulted in an increased willingness to participate in collective actions, such as scheme maintenance and payment of water fees.

Table 3.1 includes examples of systemic changes brought about by the two-pronged approach at the farm, household and scheme scales. Critical changes are as follows:

- Irrigation has been reduced, crop diversification has commenced, main crop yields have increased, and more money is invested in inputs and equipment.
- Prices received have improved, income diversification is occurring, many households' farm and off-farm incomes have improved, and household conflict has decreased.
- There is more willingness for collective action, and scheme-scale conflict has decreased.

The relationships between these changes are complex and positively synergistic, with one change often producing several flow-on effects (Figure 3.2). Previously, crops were greatly overwatered, and nitrates were rapidly leached past the root zone. Reduced irrigation is a positive from a crop production and environmental perspective, and improves supply reliability for tail-end water users. Reduced frequency and duration of irrigation also reduce the time spent irrigating, which releases time for additional on- and off-farm activities. This was seen as one of the most important benefits of monitoring soil moisture and nutrient levels. The income increases are encouraging and critical, because the yield increases must be translated into improved income for schemes to become profitable and sustainable.

There are encouraging signs of equity improvements with respect to the involvement of women and youth in farming. Women have been the most rapid adopters of high-value crops, which has increased household income and investment in food, education and health. Reflecting this, there has been a substantial shift from male-dominated to joint decision-making and more female decision-making. With increased profitability, there is evidence of young people returning to the schemes; in one scheme, the community has decided to allocate unused land to young farmers.

Table 3.1 Key outcomes

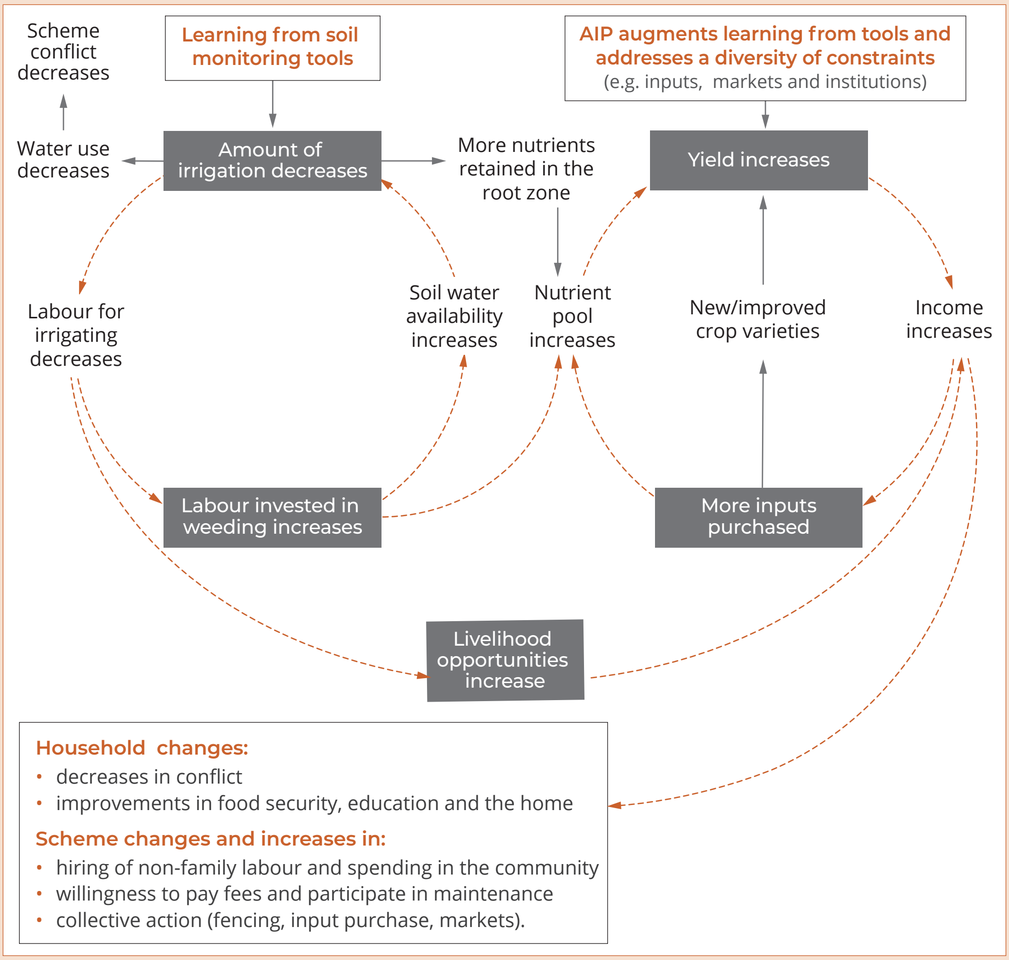
Outcome type	Evidence examples (% figures are for households surveyed)
Learning from tools	• Across the schemes, 24–68% had the tools, and 89% or more were aware of them. • Of those who were aware of the tools, 50–93% and 26–68% made changes due to learning from the Chameleon and FullStop, respectively. • There is strong evidence that learning from those with the tools spread widely among other farmers in the scheme. At the Sililatshani Scheme in Zimbabwe, while 23% had the tools, 55% reported changing their irrigation practices as a result of the data from the Chameleon. • Of those making a change due to learning from the tools, 77–93% increased yield and 43–94% increased their income.
Learning and innovations through agricultural innovation programs	• Capacity building: farm record keeping, gross margin analysis and group management. • Farm management: crop diversification, levelling and fertiliser/manure management. • Input supplies: collective negotiation with suppliers. • Financial: water payment arrears addressed, increased willingness to pay fees and improved credit access. • Markets and marketing: high-value crops and buyers identified, and crop storages built. Floor prices agreed for crops. • Scheme maintenance: collective payment for new fencing, new/repaired infrastructure. • Governance: plot mapping, business planning, plot reallocation to youth and revision of irrigator associations' constitutions.
On-farm	• The interval between irrigation events increased by about twofold, and the duration of each event was reduced by about half. • Water used by irrigators decreased, supply for downstream users increased, and less time was spent irrigating. The latter has released time for other farm work and income-earning activities. • Increases in yield of 25% or more occurred for the main irrigated crop in 43–81% of households. • 18–60% of households grew new crops, and there was more spending on irrigation and farm inputs (61–73% of households), and farm implements (31–66% of households).
Household	• Income sources have changed (11–66%). • Income has increased: farm income by 21–83% and off-farm income by 39–60%. • Households perceive an improvement in food security (58–70%), health (42–75%) and education (31–61%). • Household conflict has decreased (44–89%).
Irrigation scheme	• Improved willingness to support collective action through participation in maintenance (89–100%) and payment for water (64–100%). • Improved ability to pay for water (69–99%). • Reduced conflict between upstream and tail-end farmers (35–83%).

Source: Bjornlund et al. (2018)

Key findings

Survey evidence and the influence model (Figure 3.2) suggest that households have moved into a positive and self-reinforcing cycle of learning and development, which should continue unless external factors significantly change. This has been made possible by the dual entry points of the tools and AIPs, which generate two feedback loops for ongoing learning about soil moisture–nutrient dynamics and addressing constraints to profitability. This is shown in Figure 3.3, where bold arrows indicate direct influences of the tools and AIPs on increasing profitability, while the other arrows show the learning feedback loops that reinforce the impact.

For irrigation schemes to be sustainable, a paradigm shift is needed from subsistence farming to commercially oriented farming, to generate sufficient will and income to maintain the infrastructure and pay for water. This shift needs to take place at the farm household level and within all levels of government, and possibly most critically within government support services and non-government organisations. At the household level, there has been significant



Household changes:

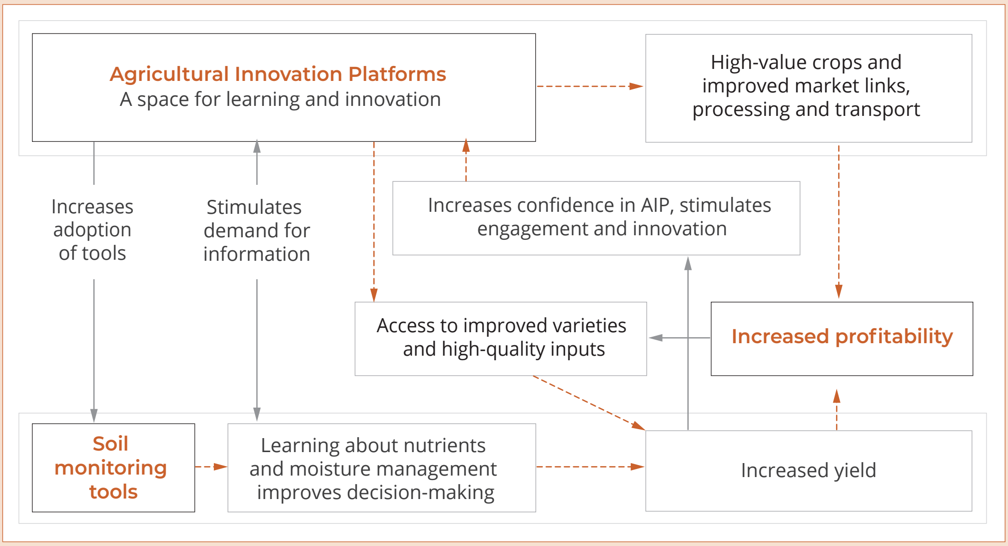
- decreases in conflict
- improvements in food security, education and the home

Scheme changes and increases in:

- hiring of non-family labour and spending in the community
- willingness to pay fees and participate in maintenance
- collective action (fencing, input purchase, markets).

Source: Adapted from Bjornlund et al. (2018)

Figure 3.2 Influence model of key changes



Source: Adapted from Bjornlund et al. (2018)

Figure 3.3 How the two-pronged approach influences profitability

evidence that this process is taking place, with the adoption of higher-value crops, increased farm and household income, and reduced conflict over water. This has resulted in an increased willingness to participate in collective action, such as paying for water, system maintenance, and collective bargaining with buyers and input suppliers.

Conclusions

Small scale-irrigation schemes are complex systems. For schemes to become sustainable, investment is required in institutional and other human capacity, as well as physical infrastructure.

The tools plus AIP approach constitutes two broad interventions. The AIP facilitates a multi-stakeholder forum to generate context-specific solutions to diverse challenges, thus increasing farmer profitability and scheme sustainability. The tools provide critical information about complex soil moisture–nutrient dynamics, and the AIP facilitates the process of learning from the tools. This has led to improved water and nutrient management, improved yield and increased farm profitability.

The flow-on effect from these two interventions has produced on-farm, household and scheme-scale changes, including reduced conflicts within households and among irrigators. This has resulted in increased trust and willingness to participate in collective action, such as fee payment, scheme maintenance, and collective bargaining in both input and output markets. Gender dynamics are changing positively at the household and scheme levels, and participation of youth in irrigation has increased. There is early evidence of flow-on contributions to local economic development through households having greater income and household enterprise activity.

Out-scaling

A second phase of the project commenced in 2017 and will continue until 2021. The focus is on developing sustainable up- and out-scaling processes of the tools plus AIP approach. This will foster innovation at higher political scales, embed new practices in existing governance institutions, and spread the learning across more schemes. Successful phase 1 innovations are being given greater prominence, including plot-level mapping, revision of irrigator associations' constitutions and farmer record keeping.

The momentum and credibility gained in phase 1 have transferred into phase 2, with significant progress made in the first year. The approach is being adopted in donor-funded small-scale irrigation scheme developments, and national and local governments are taking up the approach across whole provinces.

Acknowledgments

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4

Participatory groundwater management: making the invisible resource visible and giving ownership of its sustainability to villagers

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Summary

The MARVI project, 'Managing aquifer recharge and sustaining groundwater use through village-level intervention' (LWR/2010/015), is about a village-level participatory approach to measuring groundwater levels and improving groundwater productivity. The overall aim of the MARVI project was to improve cooperative decision-making for sustainable groundwater use. It focused on two multi-village watersheds: the Meghraj watershed in Aravali district of Gujarat, India, and the Dharta watershed in Udaipur district of Rajasthan, India. Both watersheds have hardrock aquifers.

The MARVI project focused on developing a village-level participatory approach, models and tools to help improve groundwater supplies and reduce groundwater demand. Farmers and other affected stakeholders, including local schools, were directly involved. A unique feature of MARVI was the collection of scientific data by citizens through the engagement of Bhujal Jankaars (BJs), a Hindi word meaning 'groundwater informed' volunteers. With appropriate training and capacity building, BJs monitored groundwater levels and quality, giving a village perspective on what was happening to village groundwater availability. BJs conveyed this information to farmers and others in their own language.

Watertable fluctuations in 110 wells in the Meghraj watershed and 250 wells in the Dharta watershed were monitored by BJs and groundwater sensors over 4 years. A number of check dams were monitored to understand their groundwater recharge performance and effects on groundwater availability in nearby wells. An SMS-based data collection system and a smart phone app called MyWell, for both Android and iOS platforms, were developed to assist in the easy collection of data on watertable depth and rainfall, and to visualise data and make them available on the web. A detailed socioeconomic study—along with crop demonstrations, engagement through Photo Voice and community forums—was conducted to understand farmers' needs and capacities, and explore what changes will work for future groundwater management strategies.

In the MARVI approach, we found that having local farmers (BJs) monitoring their groundwater resources and sharing this information with the community was the first step in villagers talking about their groundwater situation in a more objective way. This led to serious dialogue and seeing a better future through cooperative management of the resource. A significant finding from MARVI is that community-based local-level groundwater monitoring can open pathways for ownership of the problem, and solutions involving sharing and using groundwater sustainably. It is also important to note that non-government organisations (NGOs), along with university and research institution partners, play an important role in research for development through effective engagement and change at the grassroots level for livelihood improvement.

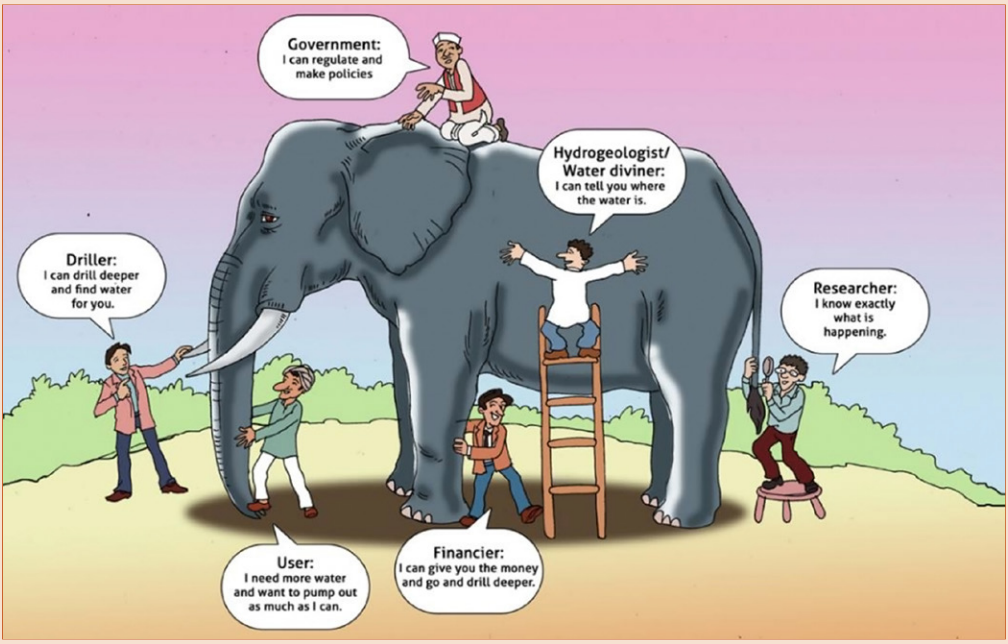
The training resources and technical tools developed have been well tested and refined during the past 5 years, and are now available for out-scaling to other areas. In general, the groundwater monitoring, data collection and analysis, and demystification of the data in a participatory manner with active involvement of the community motivated farmers to change their irrigation methods and grow crops that use less water. The work of MARVI culminated in farmers coming together and forming village groundwater cooperatives.

Introduction

More than half of India and other countries in the region are undergoing serious water stress. The accelerating and alarming rate of groundwater depletion continues unabated. In rural communities, reduced availability of groundwater constrains food production, jeopardises farm incomes, catalyses increased urban migration, and fractures community cohesion and harmony. Rural women and girls spend more time carrying water, the cost of pumping is increasing, groundwater quality is declining, and surface streams and dependent aquatic ecosystems are struggling. The future of many villages is very much linked to the future of groundwater.

In many parts of India, including the watersheds targeted in this study, groundwater tables are declining. The management of groundwater has become quite complex as a result of the range of actors involved in its development and use (Figure 4.1). The MARVI project, 'Managing aquifer recharge and sustaining groundwater use through village-level intervention', had an overall aim of improving cooperative decision-making for sustainable groundwater use. This required the development of a village-level participatory approach to measuring groundwater levels and improving water use efficiency in groundwater-stressed regions of India (Maheshwari et al. 2014).

A unique feature of MARVI is the engagement of Bhujal Jankaars (BJs) (Jadeja et al. 2018), a Hindi word meaning 'groundwater informed'. These are volunteers who, with appropriate training and capacity building, monitor rainfall, groundwater levels and quality, and water levels of managed aquifer recharge infiltration basins (called check dams). They also make sense of the data from a village perspective, and infer what can be done to improve the groundwater situation and thus household livelihoods; this is often based on growing crops with groundwater irrigation. Importantly, they function to inform and guide their village communities on the groundwater situation and how best to use groundwater in response to seasonal or long-term variability in resources.



Source: B Maheshwari, Western Sydney University

Figure 4.1 The complexity of the 'groundwater elephant'

Methods

The MARVI project focused on two watersheds: the Dharta watershed in Rajasthan and the Meghraj watershed in Gujarat, India. In total, 11 villages were involved. Both watersheds have hardrock aquifers, implying that they have low groundwater storage capacity and deplete relatively quickly.

The main activities in MARVI were to design and implement participatory processes to assist village-level discovery and application of solutions for sustained groundwater use and improved livelihoods. Some of the solutions explored were creating awareness about the extent of the problem; building the capacity of the local people to monitor, quantify and manage groundwater resources; and piloting village groundwater cooperatives. Overall, the focus of the activities was to improve cooperative decision-making for sustainable groundwater use at the village level.

Watertable fluctuations in 250 hand-dug wells in the Dharta watershed and 110 in the Meghraj watershed were monitored weekly, over 5 years, by BJs using a simple 50-m measuring tape and a 15 cm diameter wooden circular float (Figure 4.2).

BJs also monitored rainfall and water levels in a number of check dams (Dashora et al. 2017). The monitoring built

Source: B Maheshwari, Western Sydney University

Figure 4.2 A Bhujal Jankaar measuring groundwater levels manually understanding of the groundwater recharge performance of the local check dams and their effects on groundwater availability in nearby wells. Thus, the monitoring by BJs enabled the establishment of a comprehensive database, which enabled village communities and other stakeholders to understand the village groundwater situation and explore options for sharing groundwater resources. The project developed the MyWell app (available on Android and iOS platforms), which particularly helps in crowdsourcing groundwater measurements over SMS. The app enables anyone across India to participate in the collection of data on watertable, rainfall and check dam water levels, which are shared publicly on the web.

The transformation of the local villager BJs into local groundwater champions required undertaking technical capacity building of the BJs, as well as nurturing their confidence in what they can achieve for their villages (Figure 4.3). Incentives for the BJs to continue in the MARVI project were a small financial reward (Rs1,000 per month, which is about A$40 per month), and their pride in being groundwater informed and gaining respect within their community on groundwater matters.

Linked to this work, capacity-building activities were implemented to advance groundwater knowledge and understanding of farmers, local communities, schools and decision-makers (Figure 4.4). A number of tools, protocols and approaches were developed and integrated to assist in collecting and analysing biophysical and socioeconomic data; the aims were to understand aspects of annual groundwater recharge, water availability for irrigation, crop water demand, cropping area, and socioeconomic parameters that affect the sustainability of groundwater use and interventions (Varua et al. 2016; Ward et al 2016).

Source: B Maheshwari, Western Sydney University

Figure 4.3 Hand-dug well site used for monitoring groundwater level using automatic sensor

Source: J Ward, Mekong Region Futures Institute

Figure 4.4 Engaging with future groundwater managers of villages (i.e. children)

Results

The project developed an approach to community-based, participatory groundwater monitoring and management, through close collaboration between research and development agencies and village communities. Data monitored by BJs and water level sensors have enabled the validated estimation of local hydrogeological parameters, and the development of simple groundwater balances for villages and their surrounding landscapes (Chinnasamy et al. 2018) (Figure 4.5). The SMS system and

Source: Y Jadeja, Arid Communities and Technologies

Figure 4.5 Classroom training workshop for Bhujal Jankaars

MyWell App developed during the project have helped with easy collection, sharing and analysis of village water data.

The 36 BJs are proving to be significant change agents through their high-quality measurements, understanding of the groundwater situation and communication with the village communities in the two watersheds. They are also an important interface between researchers and the communities. Effective engagement of village communities and local data collected during the past 5 years indicate that farmers now better understand their local groundwater system. This includes accepting that groundwater is limited, and that the falling watertable is not an individual farm-level issue but a village-level issue, which needs to be tackled at the village level. This process requires time, and needs the continuous efforts of the BJs and follow-up by the project team for sustaining change in village communities.

The MARVI project developed a simple method, involving farmers monitoring water levels in check dams during the rainy season, that can provide reliable estimates of local groundwater recharge. Monitoring can also be used to determine the need for desilting of check dams in the following dry season and to provide essential data to allow quantification of recharge from check dams. More check dams monitored over longer periods using this method would provide quantitative data to inform decisions on the size and placement of check dams—taking into account local benefits, capital and maintenance costs, and downstream impacts—and thereby inform future investment in check dams for groundwater recharge.

The MARVI project influenced more than 3,700 farmer families in 18 villages to make changes to cope with groundwater scarcity. In general, the project has brought the issue of groundwater scarcity to the forefront of the minds of farmers, school communities and government agencies working in the study areas. There is evidence that, in the last 2 years of the project, 56 farmers in the Meghraj watershed converted their irrigation method from surface to drip irrigation, and adopted crop varieties and agronomic practices that use less water. In the Dharta watershed, there is evidence that some farmers have changed their traditional crop that requires five or six irrigations (e.g. wheat) to some medicinal crops—isabgol (psyllium) and kaali tulsi (*Ocimum sanctum* Linn.)—that require only three irrigations. These changes in farming practices are mainly due to groundwater community forums, field trial demonstrations, groundwater monitoring and the constant presence of project staff in the study area.

One of the important achievements of the MARVI approach is the farmer-established village groundwater cooperatives (VGCs), of which three were formed in the Dharta watershed and two in the Meghraj watershed. Each VGC consisted of 14–20 farmers and represented an agricultural land area of 18–40 ha. The groundwater in some of these VGCs was traditionally shared through a barter system, in which the farmer who provided groundwater to the neighbours through access to their private well received one-third of produce from the land in exchange for the water provided. Farmers who formed VGCs felt that the current barter system of selling water was not fair, created equity issues and did not support groundwater sustainability. The VGCs aimed to raise these issues and discuss more equitable access to the groundwater, based on the tools developed under the MARVI project. For instance, the groundwater level data revealed that deepening wells or installing deeper tubewells is like stealing another person's groundwater, and overall no extra water is to be gained by drilling deeper. As a result, the farmers have already taken agreed measures to stop drilling deeper and to remove sediment from recharge structures to enhance recharge and so increase the amount of water available. The farmers also worked to manage the demand for groundwater by determining the maximum possible Rabi (winter) crop areas from post-monsoon groundwater levels, improving soil mulching and water use efficiency, and diversifying crop types depending on water availability. Some of these solutions are being supported by follow-up work in the study villages and beyond.

Discussion and key findings

The MARVI experience has amply demonstrated that directly engaging villagers, and empowering them with knowledge and local data can create a cooperative environment for sustainable groundwater use. The understanding developed by village communities about groundwater level fluctuations, rainfall and groundwater quality can help in more effective dialogue and agreeing on a common vision among different stakeholders.

Since groundwater sustainability is multisectorial (water, land, agriculture) and multisegmental (farmers, women, children, pastoralists), holistic and inclusive approaches are required for community mobilisation. Further, success in sustainability of groundwater will come if there is collective action at the village level, which is supported by the Gram Panchayat (village council), and is then further linked to the regional or aquifer level.

There are some challenges with the MARVI approach—in particular, it requires patience from government agencies and NGOs that work with village communities. Further, training BJs and empowering village communities takes at least 6–9 months. BJs and associated farmers need to be appropriately identified and trained, and 'hand holding' support is required for at least 1–2 years to ensure proper implementation of the program. However, these aspects can be managed by providing adequate resources and proper training of facilitators.

It is important to mention that this project involved three non-government organisations (NGOs), along with two universities and two research institutions. The engagement of farmers and village communities was at the centre of the project design and was critical to success of the project. The grassroots nature of the NGOs brought particular strengths to the success of MARVI in championing the project at a grassroots level. In particular, the NGOs contributed by building local capacity to monitor groundwater, promoting the role of women and the less privileged, and assisting farmers to change irrigation practices and crop type to reduce groundwater use.

The NGOs were also crucial in helping the project through engagement and awareness processes based in local cultural beliefs, values and practices. Further, the NGOs helped to bridge the gap between university and research institution partners and the community, through their particular skills in local engagement, focus, commitment to helping their local communities and ability to operate flexibly in implementing project activities.

It is quite clear from this project that technical intervention or government initiatives alone cannot solve the complex and 'wicked' problem of groundwater management. NGOs play an essential role in 'research for development' projects such as MARVI.

There is still some level of reluctance among staff in government agencies due to their lack of appreciation for participatory approaches and empowerment, and fear of the unknown—they are more used to technical interventions and building infrastructure.

Also, the need for agreement among groundwater users on a sustainable level of extraction, effective coordination and collaboration for equity and access, and the mechanisms for monitoring and self-regulation of the resource use cannot be overemphasised.

Norms relating to use of groundwater should be formed, practised and enforced at the village level. Voluntary restrictions are helpful, but difficult to enforce. Thus, if practices for sharing and use of groundwater are to be scaled up, some institutional mechanism will be required. Therefore, there should be incentives and disincentives at the policy level for appropriate use of groundwater.

Despite the above challenges, the MARVI experience has amply demonstrated that directly engaging villagers and empowering them with knowledge and local data can create a cooperative environment for sustainable groundwater use.

Conclusions

The groundwater level represents the integration of recharge, pumping and flow processes, and is a direct measure of groundwater availability and the success of any collective management practices. BJs are an effective, trusted and valuable interface between village communities and government agencies, NGOs and researchers. Overall, the experience from the MARVI project indicates that a transdisciplinary and participatory approach is likely to be more effective in enabling farmers, other village community members and NGOs to work together with researchers and government agencies to understand the groundwater situation, and design holistic interventions that have wider ownership at the village and Gram Panchayat levels. Also, such an approach is expected to deliver longer-term sustainability of groundwater at a regional or basin scale. However, it will require substantial external and prolonged support.

Adoption and out-scaling

The MARVI approach has been tested in two watersheds in Rajasthan and Gujarat over 5 years, and it is now ready for upscaling to other areas in the two states and beyond. As well, further trials of VGCs as a means to achieve sustainable groundwater recharge and use are required. Key outcomes from the MARVI project include a BJ training program, a MARVI implementation manual and MyWell for out-scaling beyond the study areas. Future investments are required by the central and state governments, and corporate social responsibility funds are needed to nurture, refine and adapt the approach to local conditions in other parts of India.

A number of MARVI outputs have attracted significant interest from the Ministry of Water Resources, River Development and Ganga Rejuvenation, the Government of India, the state water resources ministries and the World Bank. In particular, the BJ training program and a participatory process to help develop village water security plans are now being incorporated into the

National Groundwater Management and Improvement Program (the Atal Bhujal Yojana) in hundreds of villages across seven states of India, with significant technical and financial support from the World Bank. The MARVI project team, with the support of ACIAR and the Australian Water Partnership, is working with relevant state and central government agencies, NGOs and other stakeholders to out-scale MARVI through the Atal Bhujal Yojana and other initiatives. In particular, the team will assist in out-scaling through further developing and adapting BJ training resources, the methodology for estimating groundwater recharge from simple measurements, and a smart phone app (MyWell) for collecting and visualising groundwater, rainfall and check dam data.

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5 Making the best of watershed development in India

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Summary

Approximately 70% of agriculture in India is rainfed. The rainfall is variable in time and space, often leading to unreliable cropping and low yields. To counter this and assist sustainable rainfed agriculture, watershed development (WSD) is used to capture water through surface water dams and managed aquifer recharge. It is an approach adopted in many developing countries, where dependence on rainfed agriculture is extensive. To date, WSD has largely relied on village-level implementation with the ongoing involvement of local communities. Three significant problems have occurred:

- On many occasions, hydrological and hydrogeological knowledge on which WSD has been based has been too generic, sometimes leading to unsustainable water use and inappropriate land use.
- Ongoing commitment by local communities has been sporadic once external support has been withdrawn.
- Water capture by WSD in some villages has led to less water in downstream locations.

This project investigated each of these issues by evaluating the potential for WSD to be implemented at a meso rather than micro level—that is, at an area that is characterised by a hydrological unit in which the hydrogeology and the behaviour of surface water are defined and discrete. This would generally be an area of approximately 10,000 ha and incorporate a number of villages. This means that WSD can be planned without detriment to downstream villages.

However, water management is just one input into determining the livelihoods of the community. It needs to be matched to land use and socioeconomic characteristics of those living in the catchment to produce the best effects on livelihoods and consequently resilience to drought.

The project developed an integrated planning process to assess meso-level WSD administration, with the goal of creating greater resilience to drought. The staged process begins with simple hydrological modelling to plan for site selection for potential meso-level implementation over the wider catchment. It then shows a step-by-step process for assessing alternatives for land and water management, and their subsequent livelihoods outcomes. The tool is targeted for regional government and non-government organisation implementers, and is accompanied by a manual to guide the planning process in a participative manner.

Introduction

Watershed development (WSD) has been an approach widely adopted throughout the developing world to assist with sustainable development of rainfed agriculture in supporting resilient livelihoods, through integrated planning. In general, WSD has been planned and administered at the micro or village level. The reasons for this are obvious: existing community structures can be used to enhance involvement, and the local land-use and water issues are well understood by the community.

Evaluations of this micro-level approach have revealed that unintended consequences for other villages in the catchment can occur through overcapture of surface water resources and overexploitation of groundwater. Although a whole-of-basin approach seems a logical response, it can be prohibitively complex.

In this project, we examined the potential for meso-level (up to 10,000 ha) implementation of WSD. We used a sustainable livelihoods model to provide the context for integrating a series of biophysical and socioeconomic studies, to provide a planning and evaluation tool for meso-level implementation of WSD.

Methods

A series of biophysical, economic and social studies were undertaken. Details of the methods for each are provided in Reddy and Syme (2015). Improved resilience in terms of the number of years a household could survive drought was chosen as the indicator of the success of WSD.

Two areas with contrasting rainfalls that had experienced earlier WSD interventions at the micro level were chosen for the study. The study areas were chosen to have clear hydrological boundaries (hydrological units—HUNs). These areas incorporated a number of villages and were identified as the boundary for identifying meso catchments. Thus the study was a planning one, providing baseline information for the evaluation of future meso-level delivery. The overall design divided the villages into three meso areas over the HUN: upstream, midstream and downstream. Each subarea contained about 14 villages. In addition, two villages in the same HUN that had not experienced micro-level WSD were chosen for comparison.

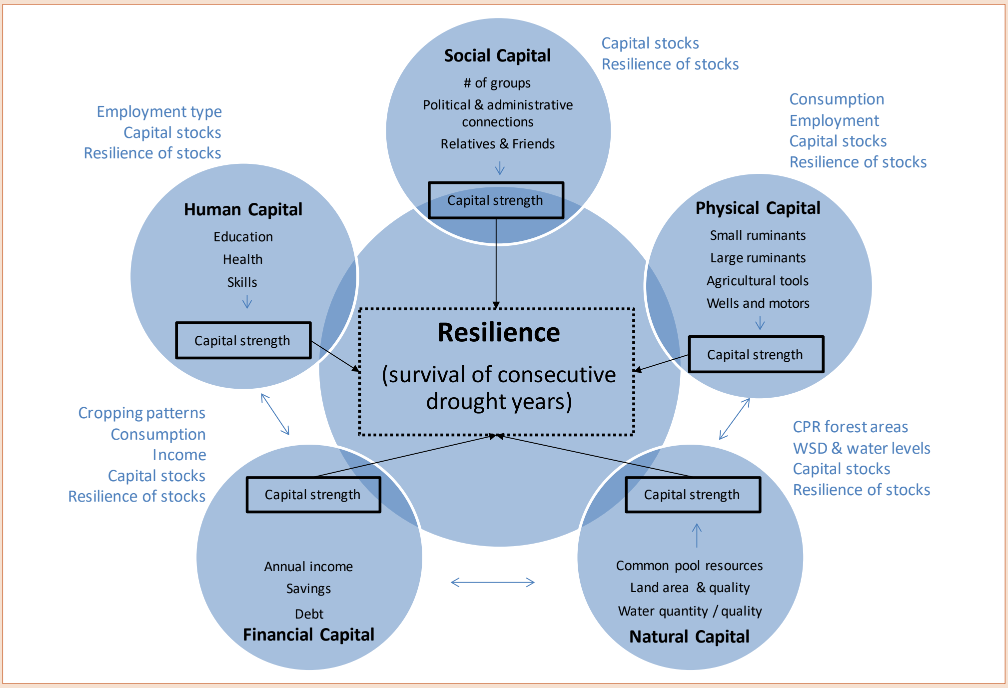
Hydrogeological data on the two HUNs were collected through monitoring wells—collecting long-term rainfall data and geo-referencing the water bodies—and watershed interventions. Modelling was used to capture the rainfall–groundwater recharge relationship and groundwater–surface water linkages. The socioeconomic data were collected using quantitative surveys and representative sampling methods, complemented by qualitative research. A wide variety of data was collected pertaining to household structure, age, level of education, debt, current land-use practices, crop selection, off-farm income and so on.

Hydrogeological investigations were undertaken using resistivity surveys and bore drilling to understand and map the aquifers, and allow selection of suitable WSD sites for rainwater harvesting. Quantitative estimates of recharge and changes in groundwater storage were derived using the lithologically constrained rainfall method (Sreedevi et al. 2015).

Social data collected both quantitatively and in interactive group discussions included satisfaction with local institutions, community quality of life and equity issues. The questions were asked in the context of current circumstances but also in the context of meso-level WSD.

To provide a combined perspective of water resources management for WSD, including surface water and groundwater, a simple integrated surface water and groundwater water balance model was devised as a basis for regional planning of WSD meso-level implementation (Yen, Pavelic & Brindha 2015).

The Sustainable Rural Livelihoods framework (five capitals: natural, physical, human, financial and social) was adopted, along with a separate resilience survey, to assess the resilience of the farming households to drought in the upstream, midstream and downstream areas of the two HUNs. Resilience was modelled using Bayesian networks. This approach allowed investigation of alternative scenarios for WSD and related policies (Merritt et al. 2015). The conceptual design is shown in Figure 5.1.



CPR = common property rights; WSD = watershed development
Source: Reddy & Syme (2015)

Figure 5.1 Overall structure of the Bayesian network model of resilience, including each of the five livelihood capitals and their components

An ongoing stakeholder engagement process was adopted to communicate the findings at the policy, implementation and community levels, and to receive feedback. Workshops were used to develop a training program for meso-level WSD development and evaluation with regional non-government organisations (NGOs) and government officers. A training manual has been prepared, detailing a scenario-based planning approach for WSD (Reddy 2018).

Results

A regression analysis predicting resilience was undertaken after grouping data at the meso level, using the five capitals, the HUN location and location on the HUN as dummy variables. The analysis of the predictive capacity of the five capitals for resilience showed a small, but statistically significant, relationship for four capitals in terms of predicting resilience. Only social capital was not statistically related.

An ordered probit model showed that resilience, measured in terms of reported household capacity to withstand a number of droughts, is positively associated with rainfall, the location (downstream) and the area treated by WSD in the past. That is, a catchment with better rainfall is more resilient than one with lower rainfall; downstream locations are more resilient than upstream and midstream locations;[1] and villages previously treated with watershed interventions are more resilient than untreated villages. These variables interact, and therefore planning must reflect the conditions at the meso-WSD site.

For example, the project showed extremely poor performance in the upstream locations in the low-rainfall catchment, despite these locations being acclaimed as a best-implemented WSD area. It also showed an unexpectedly poor performance in a WSD program in the relatively better rainfall catchment and midstream location, despite shifts to high-value horticultural crops.

The explanation for these deviations lies in the hydrogeology of the locations. The hydrogeology of the upstream location in the low-rainfall zone is a very shallow aquifer, and therefore the location does not benefit from on-stream interventions for groundwater recharge. As a result, despite well-constructed and well-maintained check dams, this area could not benefit much from groundwater recharge.

The other exceptional case of a midstream location in the better rainfall catchment is characterised by a moderately shallow aquifer with limited groundwater potential. The nature of the aquifer means that groundwater rises and falls faster than in other locations during good as well as bad rainfall years. As a result of the absence of this hydrogeological information, horticultural crops were promoted, and, when the demand for water surpassed supply, the wells started failing and crops dried up. This was because groundwater was unknowingly exploited beyond its potential.

These two cases clearly demonstrate the role and importance of hydrogeology and land-use practices in explaining and understanding WSD impacts. In the absence of such information, the impacts are often attributed to the quality of WSD implementation or to rainfall variations. This clearly indicates the need to consider all the biophysical aspects before designing and implementing WSD. In monitoring groundwater, we have found that voluntary data collected at the micro level for variables such as depth to groundwater may not be sufficiently reliable in the absence of hydrogeological understanding.

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[1] This was because the upstream villages were located on mountainous slopes that were not amenable to water capture, and the downstream locations drained into significant water bodies or streams.

The performance of WSD differed between locations. Village-level water capture was clearly associated with some negative-equity water management externalities, affecting downstream communities. This has been shown in other micro-level studies (Pavelic et al. 2015). These negative effects were largely accepted as being a representation of 'karma', as local village arrangements were tolerated. This may be why social capital was not a predictor of resilience. However, combining up to 14 villages (meso-level WSD) was seen to create less tolerable inequity issues because some villages were seen as currently more influential than others, which may lead to domination of the meso process. To anticipate these equity issues, a simple meso-level conjunctive water management model was derived as an aid to planning and to enable discussion on how water should be shared.

The project has created an improved approach for developing practice through a user-friendly planning process, derived from the findings. Ongoing implementation will depend on the development of policy and practice at regional, state and local levels.

Discussion and key findings

The project demonstrated that meso-level administration of WSD has the potential to improve on the performance of micro-level WSD because it can be better targeted to a definable HUN and can allow more sustainable administration of WSD. There were a number of demonstrations at the micro level that WSD was inappropriately applied, given the actual state of available surface water and groundwater. These led to inappropriate crop choice and land use, and to problems in maintaining adequate equity for upstream and downstream users. The meso-level hydrogeological analysis allowed the development of clear sustainable water management guidelines from which realistic plans for agriculture can be made.

The project also demonstrated that, by adopting an integrated sustainable livelihoods approach, the socioeconomic data could be interpreted in conjunction with the hydrological modelling to assess the effects of meso-level WSD on resilience to drought. Application of this technique allows scenario planning to occur in a collaborative way with the community. The data collection is relatively simple, and can be implemented by the community itself with some guidance from NGOs or regional government officers. Most importantly, the planning process starts with defining the water resource and thus preventing its diminution.

The simple conjunctive water modelling tool developed in the project identifies the preferred direction for WSD and the potential equity issues in terms of water resources. In combination with the capitals data, this will allow people to see how different groups in the community will benefit or lose. In cases where WSD is inappropriate for a village or particular groups in the meso catchment, compensatory policies or implementation roles can be planned in advance to prevent conflict as much as possible.

Conclusion

Meso-level administration of WSD has the potential to improve outcomes from WSD if it is planned based on knowledge of the relationship between surface water and groundwater resources, and their sustainable conjunctive management. Current micro applications of WSD from this research seem to have a varied outcome because interventions do not relate to defined HUNs and are therefore sometimes inappropriate for sustainable management.

The simple surface water–groundwater modelling designed and implemented for this project is useful for meso-level planning to select appropriate sites for WSD. With integration of hydrogeology, land use and understanding of community resilience, meso-level WSD planning and assessment becomes convenient and comprehensive.

Relatively simple methods for mapping aquifers and surface water flows, including their depth and their relationship, can aid planning for appropriate interventions, land use and appropriate crop selection.

A simple measure of social resilience—estimation of the number of years of drought a landholder could survive—was devised as a key indicator of long-term social sustainability. The means for improving resilience can be interpreted through a livelihoods perspective.

Planning challenges will need to be considered if the meso-level approach is to be successful on an ongoing basis for WSD. These relate to the institutions that may need to be developed on a catchment basis, as opposed to a village basis.

Surveys and discussions showed that there were perceptions of inequity with micro-level WSD, and these could be exacerbated by meso-level application. Perceptions of inequity may occur in meso-level WSD if some villages are seen to be more powerful in terms of garnering resources. Conflict may occur if some areas are immediate winners in terms of crop yield improvements, while others are not included in the program for sustainability and public good reasons. This may require more sophisticated and socially based property rights, and the coordination of social welfare–based programs with WSD interventions.

The major output from the project has been a training manual that moves systematically through the WSD planning process. It is suitable for state- and regional-level WSD planners (Reddy 2018).

Adoption

The project was conducted in close collaboration with the Andhra Pradesh Department of Rural Development. The project was represented on an Andhra Pradesh Government committee for coordinating water resources management. Workshops based on the findings were conducted with regional members of the Andhra Pradesh Government and key NGOs. A course for teaching, understanding, planning and implementing WSD was developed. The project also provided input as part of the membership of the World Bank Catchment Assessment and Planning for Watershed Management project team.

Acknowledgments

We thank ACIAR and the Andhra Pradesh Department of Rural Development for their active involvement throughout the ACIAR-funded project ‘Impacts of meso-scale Watershed Development in Andhra Pradesh (India) and their implications for designing and implementing improved WSD policies and programs’ (LWR/2006/072).

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6 The realities of water ‘saving’ in rice–wheat systems in north-west India

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Summary

The rice–wheat (RW) cropping system of north-west India is critical for food security, but is unsustainable as currently practised. Critical among the threats to sustainability are increasing labour scarcity, increasing cost of production, resource degradation and groundwater depletion.

To address these threats, a range of technologies that reduce irrigation and labour requirements, tillage intensity and straw burning have been developed over the past two decades. These include:

- changing from puddled transplanted rice (PTR; manually transplanted) to mechanised planting of dry-seeded rice (DSR)
- use of alternate wetting and drying (AWD) water management for rice instead of continuous flooding
- use of zero-till wheat (ZTW) instead of conventional-till wheat (CTW)
- use of permanent raised beds
- surface retention of rice residues.

A literature review showed that the RW systems of north-west India rely on a huge unconfined aquifer, where groundwater levels have declined alarmingly since the 1970s.

From 2002 to 2013, ACIAR supported three projects in Ludhiana, north-west India, and one project with multiple sites across south Asia that investigated the use of permanent raised beds, zero tillage, rice straw mulch and DSR in the RW system. At the time the projects commenced, most of these technologies had been shown, or were believed, to reduce irrigation water input. However, whether and to what degree they resulted in ‘real’ water savings had not been considered.

Using a combination of field experimentation and crop modelling, the ACIAR projects enabled a systematic assessment of the types and magnitude of water savings that result from changing from conventional practice (PTR–CTW) to reduced or zero-till RW systems with surface retention of rice residues.

The research confirmed that AWD results in large reductions in irrigation input to rice, and that changing from PTR to DSR with the same AWD water management further reduces irrigation input. Changing to AWD reduced irrigation input, largely by reducing drainage below the root zone. However, drainage below the root zone returns to the aquifer from which the water was pumped, and therefore reducing drainage does not result in real water savings. Reduction in crop evapotranspiration (ET) is needed to reduce groundwater depletion, while maintaining (or increasing) yield, thus decreasing the amount of water consumed ('lost') per unit of crop production.

Mulching reduced the number of irrigations in ZTW by one in about 50% of years, due to suppression of soil evaporation. However, ET of the mulched and non-mulched wheat crops was similar.

The results of the field and modelling studies suggest that there is little scope for reducing ET by changing from conventional PTR–CTW systems to conservation agriculture systems incorporating DSR, zero tillage and surface retention of rice residues.

The modelling studies suggest that by far the greatest opportunity for reducing ET in RW systems is to change from long- and medium- to short-duration rice varieties. However, changing to short-duration varieties comes at the cost of grain yield. Therefore, increasing the yield of short-duration varieties should be a major research objective to sustain yield while reducing groundwater depletion.

Introduction

The irrigated rice–wheat (RW) cropping system of north-west India is fundamental to India's food security (Timsina & Connor 2001). Current practice involves intensive tillage for both crops, and puddling and manual transplanting of rice. This is followed by prolonged periods of continuous flooding for rice, burning of rice residues, removal of wheat straw for fodder, and a 2–3-month fallow period between wheat harvest and rice establishment.

Most of the RW areas of north-west India rely on irrigation from the huge aquifer system underlying the Indo-Gangetic Plain (Humphreys et al. 2010). Since the early 1970s, there has been a steady decline in groundwater levels in the major RW areas of north-west India (Ambast, Tyagi & Raul 2006), increasing the energy requirement and cost of pumping. Of even greater concern, a continuing decline in groundwater levels will eventually lead to salinisation of the aquifer (Hira 2009). Humphreys et al. (2010) estimated that a reduction in evapotranspiration (ET) from the RW system of about 150 mm per year was needed to halt the groundwater decline.

Over the past two decades, a wide range of technologies have been developed with the goals of increasing the profitability and productivity of RW systems while reducing their water, energy and labour requirements, and adverse environmental impacts. The technologies include laser levelling, reduced or zero tillage for both rice and wheat, rice residue retention, raised beds, dry-seeded rice (DSR), and alternate wetting and drying (AWD) water management for rice (Humphreys et al. 2010).

Many of these technologies give small to large reductions in irrigation amount compared with conventional practice, and there has been a general belief that widespread adoption of such technologies will 'save' water and reduce the rate of decline of groundwater levels. However, determining the impacts of the technologies on the groundwater requires water accounting at a range of temporal and spatial scales up to the river basin scale (Molden 1997; Molden et al. 2003). This is required to distinguish between 'real' water savings for the whole aquifer system and farmer field irrigation water savings that have no effect on groundwater depletion at the system scale. This paper analyses how some agronomic and irrigation management practices for RW systems may (or may not) affect overall groundwater depletion.

Methods

Permanent raised beds

Flat and bed RW systems were compared in small plots on two soil types (sandy loam, silty loam) in central Punjab (Ludhiana and Phillaur), India, over 4 years (eight crops). The sites, treatments and management are described in detail by Yadvinder-Singh et al. (2009).

The treatments on the flat grew puddled transplanted rice (PTR) followed by conventional-till wheat (CTW) or zero-till wheat (ZTW). The treatments on beds grew DSR or transplanted rice, followed by ZTW. There were two irrigation treatments for the PTR: continuous flooding and recommended AWD water management (irrigate 2 days after the floodwater has dissipated). Irrigation of the wheat was scheduled according to recommended practice based on cumulative pan evaporation (CPE) following irrigation at the crown root initiation stage (irrigate when the ratio of irrigation amount (I) at the previous irrigation to CPE minus rainfall decreases to 0.9—that is, I/(CPE – rain) = 0.9; Prihar, Gajri & Narang 1974).

Fresh and 'permanent' beds (up to six crops) were also compared with conventional tillage in large, unreplicated blocks running the full length (~60 m) of a farmer's field on the silty loam soil. Conventional PTR–CTW on the flat was compared with transplanted rice on fresh or permanent beds followed by ZTW on the beds. Water management of the PTR included continuous flooding and AWD, and AWD was used on the beds with the furrows filled to the top of the beds or halfway up the beds. Irrigation of the wheat was scheduled using recommended practice. Details of the treatments in the large blocks can be found in Kukal et al. (2010).

Irrigation water was pumped from the groundwater (depth about 10 m) at both sites and measured to each plot using a flowmeter. Soil water status was monitored in a range of ways in the small plots, including neutron probe and granular matrix sensors (logged). Dry-down of the soil profile after rice was monitored. Details of the monitoring can be found in Humphreys et al. (2008).

Mulch

A replicated small plot experiment was conducted over 2 years on a clay loam soil at Punjab Agricultural University, Ludhiana. There were two mulch treatments (0 and 7 t/ha) in main plots, and six irrigation treatments in subplots (12 m × 6 m). Irrigations were scheduled in several ways:

- according to soil matric potential (–40 kPa at 15–20 cm)
- using recommended practice based on pan evaporation (i.e. I/(CPE – rain) = 0.9)
- using a range of deficit irrigation treatments based on lower I/(CPE – rain) ratios.

Rainfall was measured manually at the experimental site. Irrigation water was pumped from the groundwater (depth about 10 m), and the volume applied was measured using a flowmeter. Soil matric potential was determined using tensiometers installed at depths of 20–180 cm in 20 cm increments. Soil profile water content was determined from neutron probe counts. Tensiometer and neutron probe readings were made shortly before irrigation, and otherwise twice weekly. ET was calculated from the decrease in soil profile water content during each dry-down period. Soil evaporation was measured using mini-lysimeters between the plant rows. The full experimental details are in Balwinder-Singh et al. (2011a, b).

Using the field data, the Agriculture Production System Simulator (APSIM)–Wheat model was parameterised, calibrated and validated (Balwinder-Singh et al. 2011c). The model was run for 40 years of historical weather data to investigate the effects of mulch, irrigation schedule, sowing date and soil type on yield and components of the water balance (Balwinder-Singh et al. 2016).

Dry-seeded rice

A small plot replicated experiment was conducted on a clay loam soil at Ludhiana over 2 years of contrasting rainfall incidence and amount. DSR and PTR were compared in main plots, with the seedbed for the PTR sown on the same day as the DSR main plots. There were four irrigation treatments in subplots (9 m × 7 m). Irrigations were scheduled when soil matric potential at 18–20 cm soil depth had decreased to thresholds of –20, –40 and –70 kPa, and there was also a daily-irrigated treatment (which remained continuously flooded in PTR, but not always in DSR).

Irrigations were from the groundwater (~10 m depth) and were measured using a flowmeter. Rainfall was measured manually at the site, and water depth was measured daily using millimetre scales (ruler) installed in each plot. Tritium tracing was used to determine drainage below 60 cm. The change in water content of the soil profile to 60 cm was determined using soil samples collected shortly before crop establishment and after harvest. ET was calculated from the water balance equation. Full details are in Sudhir-Yadav et al. (2011a, b).

From the field data, the ORYZA2000 crop model was parameterised, calibrated and validated for PTR and DSR (Sudhir-Yadav et al. 2011c, 2012). Model simulations for 40 years of historical weather data at Ludhiana were run using irrigation thresholds ranging from 0 kPa (continuous flooding) to –70 kPa soil matric potential (20 cm soil depth) in 10 kPa increments.

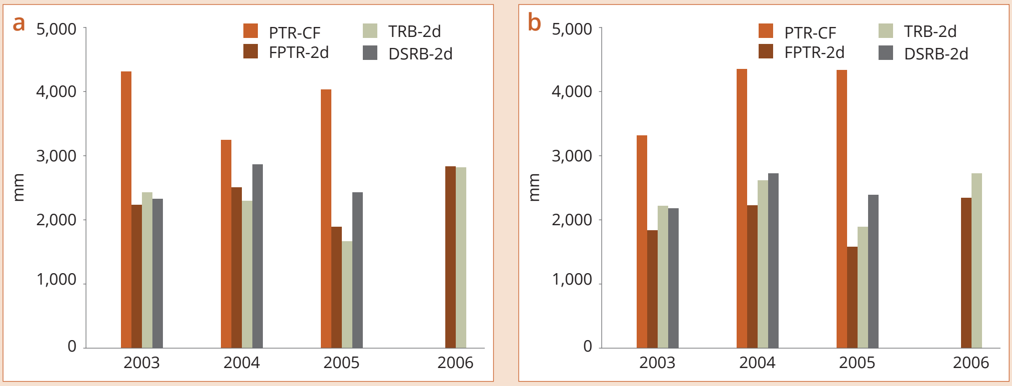
Results

Beds

Irrigation for rice was greatly reduced with AWD in PTR on the flat, and in both transplanted rice and DSR on the beds, compared with PTR on the flat with continuous flooding.

With the same (recommended) AWD practice in both the PTR and beds, irrigation input to the beds was the same as the input to PTR on each soil type, in both the small plots and the farmer's field (Figure 6.1; table 3 in Humphreys et al. [2008], Kukal et al. [2010]). In fact, on the silty loam soil, irrigation input to the permanent beds was higher than to PTR.

The data on soil profile volumetric water content indicated a large increase in volumetric water content to the depth of measurement (180 cm) during the rice season (Humphreys et al. 2008). There was considerable drying of the soil profile to depth between the time ponding of the rice ceased and the time of wheat sowing,



DSRB-2d = dry-seeded rice on beds with alternate wetting and drying (AWD); PTR-CF = puddled transplanted rice with continuous flooding; PTR-2d = PTR with AWD (irrigate 2 days after the floodwater has dissipated); TRB-2d = transplanted rice on beds with AWD
Source: Humphreys et al. (2008)

Figure 6.1 Irrigation input on (a) sandy loam and (b) silty loam soils, 2003–06

indicating drainage through the profile and beyond the root zone. At each irrigation, the amount of water applied to the beds was less than that to the flats. However, total irrigation input to the beds and flats was similar; the beds were irrigated more frequently because the same formula (based on CPE and the amount of water applied at the previous irrigation) was used to schedule irrigations on beds and flats (Kukal et al. 2010).

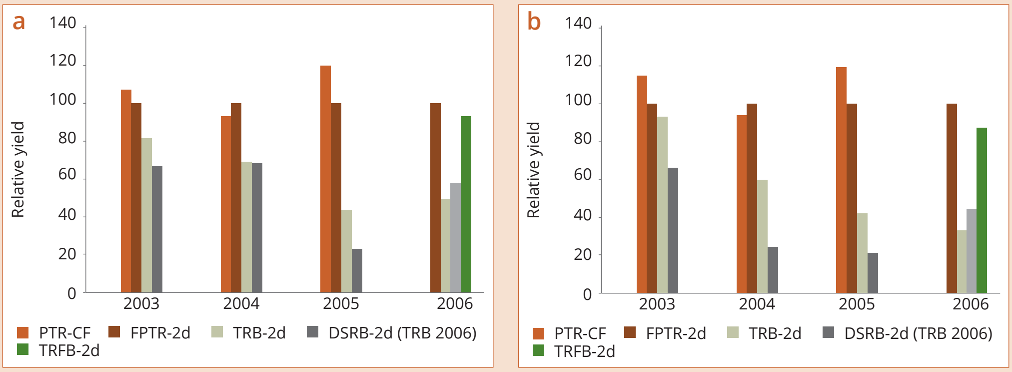
Over 4 years, there was no consistent effect of permanent beds on yield of wheat in comparison with CTW grown in rotation with PTR in the small plots (Yadvinder-Singh et al. 2009). In PTR, there was no consistent effect of changing from continuous flooding to AWD on the yield of rice. However, yield of rice on beds was lower than that of PTR with the same AWD water management (Figure 6.2). In the last year, when fresh beds were formed in one treatment, yield of rice was comparable to that of PTR.

In the farmer's field, rice yield on permanent beds was consistently about half that of PTR regardless of the age of the beds or irrigation management, while yield of wheat on beds and flats was similar (Kukal et al. 2010).

Mulch

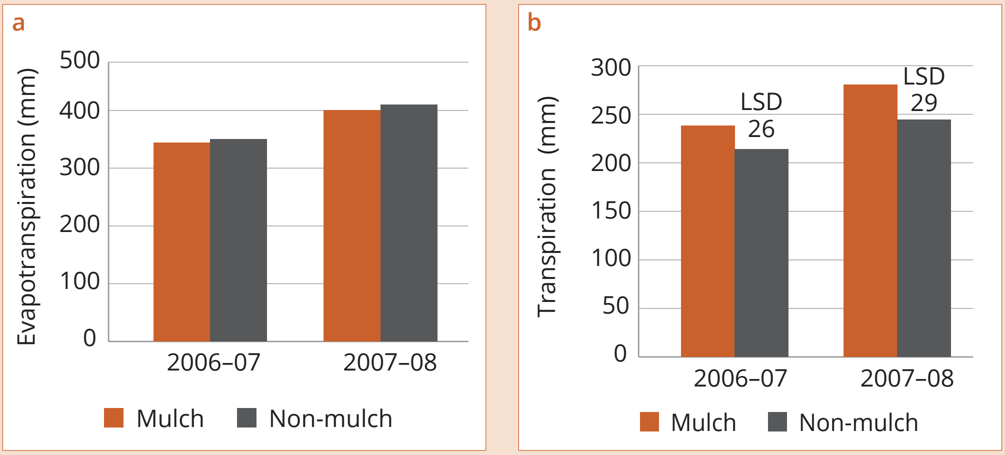
Mulch reduced the number of irrigations by one, while maintaining grain yield, in 2 years of contrasting rainfall amount and distribution (Balwinder-Singh et al. 2011a). The APSIM model simulations showed that mulch decreased the number of irrigations by one in almost 50% of years for wheat sown at the optimum time and irrigated when the soil water deficit reached 50% (Balwinder-Singh et al. 2016). In these years, this was equivalent to a reduction in irrigation amount of about 50 mm on the sandy loam soil and 60 mm on a clay loam soil, for average total irrigation of 250–300 mm. The reduction was mainly due to reduced soil evaporation (Es). In the field experiments, mulch reduced Es by 35–40 mm (Balwinder-Singh et al. 2011b). However, there was no effect of mulch on ET (Figure 6.3a), indicating higher transpiration of the mulched wheat (Figure 6.3b).

In the field experiments, with irrigations scheduled according to soil matric potential,



DSRB-2d = dry-seeded rice on beds with alternate wetting and drying (AWD); PTR-CF = puddled transplanted rice with continuous flooding; PTR-2d = PTR with AWD (irrigate 2 days after the floodwater has dissipated); TRB-2d = transplanted rice on beds with AWD; TRFB = transplanted rice on fresh beds
Source: Kukal et al. (2008)

Figure 6.2 Relative yield of rice (compared with puddled transplanted rice—PTR) on (a) sandy loam and (b) silty loam soils, 2003–06



LSD = least significant difference

Figure 6.3 Effect of mulch on (a) evapotranspiration and (b) transpiration of wheat, with irrigation scheduled according to I/(CPE – rain) = 0.9

mulch had no effect on yield or biomass (Balwinder-Singh et al. 2011a). The model simulations suggested that mulch increased grain yield by an average of 0.3 t/ha on the sandy loam, and by 0.5 t/ha on the clay loam, with irrigations scheduled at 50% soil water deficit for wheat sown at the optimum time (Balwinder-Singh et al. 2016).

Dry-seeded rice

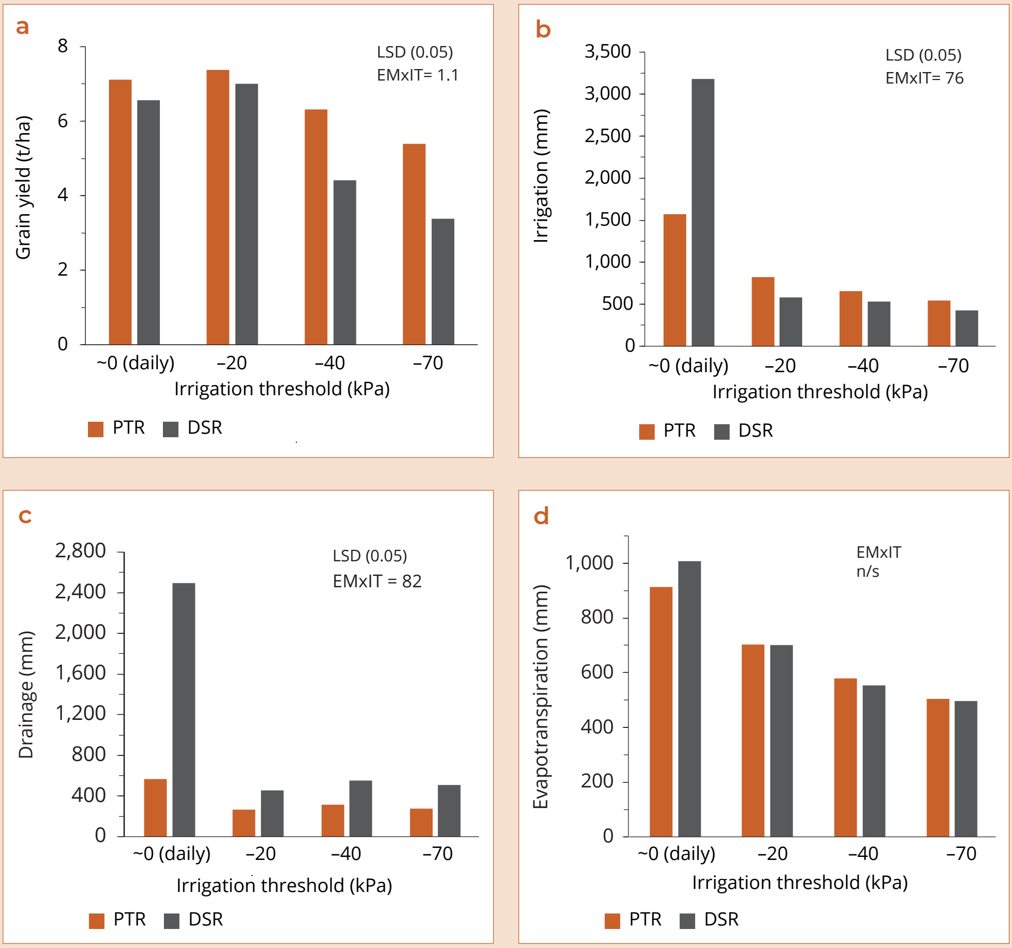
In the field experiments, grain yields of PTR and DSR were similar and high (7–8 t/ha) with daily irrigation and with an irrigation threshold of –20 kPa (Figure 6.4a; Sudhir-Yadav et al. 2011a). The threshold of –20 kPa resulted in irrigations 2–3 days after the floodwater had dissipated, and was thus similar to the recommended AWD water management for rice in north-west India.

Yields of both PTR and DSR declined as the irrigation threshold declined below –20 kPa, but with a steeper decline in DSR.

Shifting from daily irrigation to AWD greatly reduced irrigation input in both PTR and DSR, but more so in DSR (Figure 6.4b). Thus, there was a 30% reduction in irrigation amount in DSR compared with PTR within the same AWD treatment. Decreasing the irrigation threshold from –20 to –40 and –70 kPa had a relatively small effect on irrigation input in both DSR and PTR.

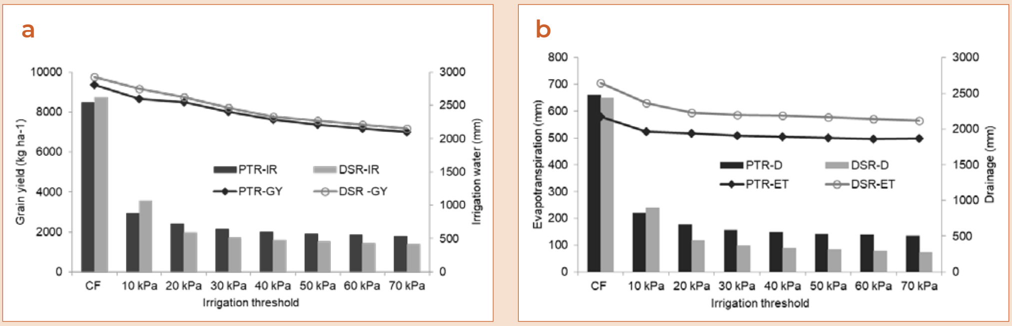
The net result was higher irrigation water productivity (kg grain/m^3 irrigation water) in DSR with an irrigation threshold of –20 kPa than in all other treatment combinations.

With the AWD treatment, the reduction in irrigation to DSR was due to reduced seepage into and through the bunds and run-off, which more than offset the higher drainage in DSR (Figure 6.4c). ET was similar for both establishment methods when using the same AWD schedule (Figure 6.4d; Sudhir-Yadav et al. 2011b). It should be



DSR = dry-seeded rice; EM = establishment method; ET = evapotranspiration; IT = irrigation threshold; LSD = least significant difference; PTR = puddled transplanted rice

Figure 6.4 (a) Grain yield, (b) irrigation input, (c) drainage and (d) evapotranspiration of rice establishment methods as affected by irrigation threshold in 2009



CF = continuous flooding; D = drainage; DSR = dry-seeded rice; ET = evapotranspiration; GY = grain yield; IR = irrigation; PTR = puddled transplanted rice
Source: Sudhir-Yadav et al. (2012)

Figure 6.5 Effect of irrigation threshold (soil water tension) on (a) yield and irrigation water requirement, and (b) evapotranspiration and drainage of puddled transplanted rice and dry-seeded rice—means of results of ORYZA simulations for 40 years of weather data

noted that drainage determinations based on point measurements from within a plot underestimate total drainage from the plot as a result of seepage into the bunds, which becomes drainage.

The modelling studies of Sudhir-Yadav et al. (2011c, 2012) supported the findings of the field studies for both PTR and DSR—large reductions in irrigation input (~60% reduction) when changing from continuous flooding to AWD due to large reductions in drainage below the root zone—and suggested relatively small reductions in ET (Figure 6.5). There were only small changes in irrigation input as the AWD irrigation threshold decreased below –20 kPa.

Discussion

Beds

The beds research showed that whether irrigation input to rice decreases on beds compared with PTR depends on the water management used in each approach, whether the beds are freshly formed or permanent, and the soil type. The higher irrigation input to rice on the permanent beds than to PTR on the loam soil—with the same AWD water management in both—was probably because of greater macroporosity (worm and rat holes, old root channels, cracks) at the time of rice establishment, despite reshaping of the beds before sowing or transplanting in the beds. The research also provided evidence of large amounts of drainage beyond the root zone of the deepest rooting crop (wheat) during the rice crop, and few signs of drainage from wheat.

Yield of rice on the permanent beds declined over time, similar to the findings of others in the region (Jat et al. 2008; Yadvinder-Singh et al. 2008).

Overall, it is not likely that the permanent beds achieved a reduction in ET in either wheat or rice, nor did they increase water consumed per unit of crop production (WPet; kg grain/m^3). Given the decline in rice yield, it is likely that WPet of the rice decreased. It is likely that the increased surface area (by approximately 16%) as a result of forming the narrow beds increased Es of the beds, consistent with the more rapid drying of the beds than the flats after sowing (Kukal et al. 2008). The modelling study of Cook et al. (2009) also suggests higher Es from beds. The generally similar biomass and yield of the wheat on beds and flats suggests that transpiration would be similar. In the case of rice, although crop growth was poorer on the beds, reducing transpiration, the topsoil was always saturated or close to saturated as a result of frequent irrigation or rain. Any reduction in transpiration was likely partially compensated for by increased Es from the wet soil. This indicates that there is little likelihood of increasing WPet or reducing groundwater depletion by changing to permanent raised beds.

Mulch

The field and modelling studies found that mulch reduced Es when growing wheat, and can potentially reduce the number of irrigations by one in 50% of years, equivalent to an average irrigation reduction of 50–60 mm in these years. For farmers to achieve this reduction, they need to be able to schedule irrigation according to soil dryness. How well farmers can do this based on visual observation is not known.

The field studies found that mulch did not reduce ET, as the water saved by supressing Es in the early growth period was transpired by the crop later in the season. However, there was no clear effect on biomass and no real water saving, because of longer crop duration and lower transpiration efficiency.

Dry-seeded rice

Large reductions in irrigation were found when changing from continuous flooding to frequent AWD in both DSR and PTR. There was similar (first year) or higher (second year) irrigation input to non-puddled rice (DSR) than to PTR with continuous flooding or daily irrigation. The higher input to DSR in the second year was probably due to soil cracking in the DSR plots under the hot, dry conditions between rice crops; the cracks were partially sealed by puddling in the PTR. Consistent with this, deep drainage was higher in all treatments in the second crop. Irrigation input to DSR was about 30% lower than to PTR within each AWD schedule each year. This was mainly due to the need for ponding for 2 weeks after transplanting, and partly due to the need for more frequent irrigation of the PTR plots once the AWD commenced (because of more rapid soil cracking and thus faster soil drying in the puddled soil).

Drainage below the root zone was higher under DSR than PTR in the AWD treatments, while ET was similar in the field experiments. However, the model simulations suggested higher ET and lower drainage below the root zone in DSR than PTR, with AWD at thresholds of –20 kPa and lower, and similar yield of PTR and DSR within each threshold. As a result, simulated ET of DSR was higher than for PTR, due to similar biomass production and longer in-field duration.

Both the field and modelling studies show similar yields of PTR and DSR when grown with optimum AWD water management. The field studies provide no evidence of reduced ET in DSR, while the modelling studies suggest higher ET.

Thus, although there may be some economic benefits of using DSR, in that less irrigation water has to be pumped, use of DSR will not overall reduce the amount of groundwater depleted per unit of rice produced.

RW cropping system modelling

Systems approaches for RW are needed because management of each crop has consequences for subsequent crops, such as the ability to plant on time, and effects of changes in soil physical properties, residual soil water and nutrient availability on crop growth, yield and water productivity.

The goal of the RW system model simulations was to identify cropping system options with the potential to reduce ET and increase WPet. A question of particular interest was whether conversion from the RW system using recommended farmer practice to a conservation agriculture RW system would reduce ET and increase WPet.

Methods

The APSIM cropping system model was parameterised, calibrated and validated for the RW system in north-west India using the data from the above three studies (Balwinder-Singh et al. 2015a). The model was used to determine the effects (on crop performance, components of the water balance and water productivity) of rice variety (duration), rice sowing date, rice water management and inclusion of a legume (mungbean) in the conventional PTR–CTW cropping system. The model was then used to explore the effects of conversion from a PTR–CTW system with recommended AWD water management to a conservation agriculture RW system with zero tillage for both crops, replacement of PTR with DSR, full retention of rice residues, and the inclusion of mungbean (Balwinder-Singh et al. 2015b).

For both the conventional and conservation agriculture RW systems, three rice varieties (long, medium and short duration), and four sowing dates at 3-week intervals from mid May to mid July were considered. The scenarios were run for 40 years of historical weather data for Ludhiana. Grain yield, components of the water balance, irrigation water productivity (WPi; kg grain/m^3 irrigation input) and crop water productivity were determined both for individual crops and the total system.

Annual system yield was determined as rice equivalent yield (REY). REY of the non-rice crops (wheat, mungbean) was calculated as follows:

$$\text{REY (t/ha)} = Yc \times Pc/Pr,$$

where

Yc is yield of crop c (t/ha)
Pc is price of crop c (US\$/t)
Pr is price of rice (US\$/t).

Annual system REY was calculated from the sum of REY of individual crops grown over each 12-month cycle.

Results

The simulations showed large variation in all measures of RW system performance as affected by seasonal weather conditions. Superimposed on this were large effects of rice variety duration, rice sowing date, and tillage or establishment method (PTR–CTW versus conservation agriculture; Table 6.1). Trends in system REY, irrigation input, ET and drainage largely reflected trends in these parameters in rice, and most of the system drainage occurred during the rice phase.

Maximum REY for rice and the RW system occurred in systems with early June sowing of the long-duration rice variety, with similar yield for the conventional and conservation agriculture RW systems (Table 6.1). However, the conservation agriculture system was superior, with a 25% reduction in irrigation input and a 50% increase in irrigation water productivity, slightly lower ET (~55 mm) and slightly higher WPet. The higher irrigation input in the conventional system was due to the need to pond the PTR for the first 2 weeks after transplanting.

Yield of the long- and medium-duration rice varieties declined as sowing was delayed beyond early or late June, respectively, as a result of the reproductive stage being pushed into colder weather. Otherwise,

Table 6.1 Rice–wheat systems with maximum and minimum mean system yield, irrigation input, ET, drainage, and water productivity with respect to irrigation input and ET

Duration	Sowing date	System	REY (t/ha)	Irrigation (mm)	ET (mm)	Drainage (mm)	Run-off (mm)	WPi (kg/mm/ha)	WPet (kg/ha/mm)
Long[a]	5 June	rFP	14.6	1,350	1,295	550	40	10.9	11.3
Long	5 June	CA	14.5	960	1,240	450	51	15.7	11.7
Long	5 June	rFP + mungbean	18.0[b]	1,700[c]	1,530[c]	495	40	10.7	11.8
Long	5 June	CA + mungbean	17.7	1,240	1,500	420	40	14.5	11.8
Short	5 June	CA	12.7	560[b]	955[b]	330	45	23.9[b]	13.2[b]
Short	5 June	CA + mungbean	15.6	860	1,255	320[b]	34	18.5	12.4
Short	15 July	CA + mungbean	15.7	930	1,190	365	35	17.3	13.2[b]
Long	15 July	rFP	5.7	1,510	1,250	830	31	3.7	4.5

CA = conservation agriculture—zero tillage for all crops, dry seeded rice, surface retention of rice residues and 30% of wheat residues (i.e. ZTDSR–ZTW with AWD for rice); ET = evapotranspiration; REY = rice equivalent yield; rFP = recommended farmer practice—puddled transplanted rice, conventional-till wheat, removal of all crop residues, alternate wetting and drying water management (i.e. PTR–CTW with AWD for rice); WPet = water consumed per unit of crop production; WPi = water productivity

a This system is commonly practised by farmers, and can be regarded as a 'control' for comparison.

b Best value

c Worst value

Source: After Balwinder-Singh et al. (2015b)

the effect of sowing date on yield was relatively small. For earlier sowings, yield increased with variety duration.

Irrigation input and ET of rice and of the RW system decreased with a decrease in rice variety duration, but this came at the expense of yield. Within rice varieties, the effect of sowing date on system ET was relatively small. Minimum system irrigation input and ET, and maximum WPet occurred with 5 June sowing of the short-duration variety in the conservation agriculture system, but the trade-off was much lower REY than that of the highest-yielding systems (Table 6.1).

Inclusion of mungbean increased REY of the highest-yielding RW systems by more than 3 t/ha, but this required, on average, an additional 280–350 mm of irrigation and increased ET by averages of around 250 mm (Table 6.1). Inclusion of mungbean increased REY of the systems with short-duration varieties sown in June and July to means of around 15 t/ha. The 15 July sowing of the short-duration variety in the RW–mungbean system resulted in equal highest WPet, a 45% reduction in irrigation input compared with the highest-yielding system, and only a 13% loss in REY.

Discussion

The only way to achieve a substantial reduction in ET in comparison with popular practice (5 June sowing of long-duration rice varieties) was by growing short-duration varieties in either the conventional PTR–CTW system or the conservation agriculture RW system. However, with current short-duration varieties, this came at the cost of both rice and system yields. With short-duration varieties, there was considerable flexibility in rice sowing date, with similar system yields for sowings from 5 June to 15 July. This points to the need to focus breeding efforts on raising the yield potential of short-duration varieties.

Conclusions

Irrigation input was reduced in DSR compared with PTR using optimum AWD water management, and mulch reduced the number of irrigations in wheat in about 50% of years, and also average irrigation input. The research into beds and DSR provided evidence of substantial drainage beyond the root zone of the RW system during the rice season. The results of both the beds and mulching research suggested little drainage during the wheat season itself. There was no evidence of reduced ET from DSR or mulching of wheat when the crops were irrigated using recommended practice.

Although technologies that reduce irrigation input by redu drainage below the root zone will not reduce overall water abstraction from the aquifer, they will, most importantly, save energy and labour, reduce production costs, and reduce groundwater and air pollution (smoke, greenhouse gases). The only way to reduce groundwater depletion is to reduce ET. The question is how to do this without sacrificing yield, as biomass production is directly related to transpiration. Hence the goal of reducing evaporation.

Mulch reduced soil evaporation from irrigated wheat by 35–40 mm. However, mulch had no effect on ET, as a result of reduced transpiration efficiency and/or longer crop duration.

Both the field and modelling studies suggested that changing from continuous ponding or daily irrigation of rice to frequent AWD reduced ET (by around 100 mm) from both PTR and DSR without loss of yield.

The results of the field and modelling studies suggested little scope for reducing RW system ET by changing from conventional PTR–CTW systems to conservation agriculture RW systems using recommended irrigation management for both crops. The modelling studies suggested that by far the biggest opportunity for reducing ET is to shift from long- and medium- to short-duration rice varieties.

However, changing to short-duration varieties comes at the cost of yield. Therefore, increasing the yield of short-duration varieties should be a major research objective. The use of alternative crops to rice and wheat should also be considered.

Because of the critical importance of reducing ET to reduce the rate of groundwater depletion, there is an urgent need for accurate determination of ET for a range of cropping system options (crops and management), for use in validation or refinement of crop models.

Cropping system simulations need to be performed for a range of alternative crops to rice and wheat to provide a range of options for reducing ET. Spatial hydrological studies are also needed to determine the sustainable level of water depletion from agriculture and other land uses across the landscape, to identify cropping system options that will allow matching of groundwater depletion and recharge.

Adoption and out-scaling

Considerable effort has been put into out-scaling DSR and the Happy Seeder (direct drilling of wheat into rice residues) in north-west India during the past decade. Early support has been provided by ACIAR and the CGIAR Cereal Systems Initiative for South Asia, the latter funded by the Bill and Melinda Gates Foundation. Punjab Agricultural University and the Borlaug Institute for South Asia/CIMMYT (International Maize and Wheat Improvement Center) have been strongly promoting DSR and the Happy Seeder through participatory on-farm demonstrations in Punjab and Haryana for several years.

At the same time, state governments have supported subsidies for farmers to purchase Happy Seeders and improved seed drills for DSR. The Punjab and Haryana state governments have made it mandatory for all self-propelled combine harvesters to have a 'Super Straw Management System' (Super SMS), which chops and spreads the straw from the harvester. This uniform spreading of the loose residues is essential for good crop establishment using the Happy Seeder.

Although a ban on straw burning in Punjab and Haryana has been in place for some years, the political will to enforce the ban has been lacking until now. Enforcement is currently proceeding in parallel with promotion of the Happy Seeder. Starting in 2018, the Government of India has provided Rs11.5 billion (approximately A$220 million) to subsidise the price of Happy Seeders and other straw management machinery (e.g. straw mulcher, baler, mould board plough).

The number of manufacturers of Happy Seeders listed with Punjab state for the subsidy increased from 6 in 2017 to 16 in 2018, and there are many other manufacturers. About 11,000 Happy Seeders have been manufactured to date (HS Sidhu, pers. comm.). It is expected that 20% of the RW area (approximately 0.4 million ha) in Punjab will be planted by sowing wheat into full rice residues using the Happy Seeder, and other systems of straw management will be used on another approximately 0.1 million ha in the 2018–19 season. The proportion of the RW area using improved straw management is expected to increase to more than 60% in 2019–20.

Initial adoption rates of DSR were very encouraging. In 2015, the area of DSR in Punjab was estimated to be 160,000 ha, but this had declined to 5,000 ha by 2018. The likely reasons for the decline are multiple (MS Bhullar, pers. comm.):[1]

- The date when farmers may start transplanting was delayed to 20 June—closer to the start of the monsoon rains, to reduce the demand for electricity, which is used for pumping groundwater. (Electricity is only available for 2 hours/day before that date, and thereafter for 8 hours/day; electricity for farmers is highly subsidised.).
- There is a lack of suitable varieties for late-planted DSR.
- In 2017, the rains started in early June, with further rains in the following weeks, so the soil was too wet for dry seeding.
- Weed problems in 2017 led to some crops being ploughed in.

Given the poor performance of permanent raised bed RW systems in north-west India, there have been few attempts to out-scale

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[1] May 2020 update. The area of DSR is expected to increase to 200,000–250,000 ha in Punjab in 2020 due to labour shortage as a result of the lock down in India in response to the Coronavirus (SARS-CoV-2) pandemic, resulting in millions of labourers returning to their villages in other parts of the country.

the technology, and virtually no adoption in this region. However, a few farmers have adopted permanent raised bed RW systems in the eastern Indo-Gangetic Plain in Bangladesh and India.

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