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2 Executive summary

The Mekong River Basin is one of the most dynamic, productive and diverse river basins in the world. But Cambodia and Lao PDR, countries through which the Mekong River passes, are identified by the World Food Program as two of the most impoverished nations in southeast Asia.

Increasing population pressure across the region will increase the demand for food, increasing pressure on land and water resources. To meet the region's future food requirements, large improvements in agricultural productivity, and in water use productivity across the region must occur. These all need to occur across a backdrop of major production constraints including drought, and exceedingly low fertility of soils.

In this project, research was undertaken using GIS to identify areas across southern Laos and Cambodia suitable for the production of high value dry season crops and, using modelling, to simulate potential yields of these crops to determine total regional production potential and identify current yield gaps. Empirical field research was undertaken in both countries to: identify and investigate water management options to improve water productivity; identify soil physical and chemical constraints common in soils across the lowlands of both countries; and, identifying options to improve crop productivity on such soils.

Modelling undertaken by the project provided insight into the improvements in regional productivity that could be achieved in the lowlands of both southern Cambodia and Lao with dry season crops. While maize yields currently realised on lowland soils with access to supplementary irrigation, were close to simulate maximum yields, peanut productivity on farms in both countries were well beneath simulated yield potential.

Early research conducted in both countries identified poor lateral water movement from furrows of lowland soils as an important constraint limiting dry season crop productivity. Further, the hardsetting nature of soils as occur on drying, restricted the lateral growth of crop roots limiting the soil volume that roots could access for water and nutrients. Insights gained through investigations of additions of organic matter in subsequent years showed some success in enhancement of lateral growth of roots as well as reduced soil strength in the affected zone. Research into different layouts and irrigation methods showed little tangible benefit regarding crop access to water and on crop productivity.

Alleviation of chronic nutrient deficiencies as typically afflict the lowland soils was optimally achieved in farm trials through progressive applications of nutrients through the season rather than as a single application at sowing, improving productivity, reducing input costs, and resulting in less loss of nutrients to the environment. The inclusion of rice hull biochar to maize crops in multiple trials highlighted benefits from improving soil fertility by improving maize yields, well beyond modelled predictions (15-20%), identifying that scope exists to further improve yields through the removal of soil nutritional and hydrologic constraints to crop production. While evidence of the improvement in dry season crop yield following biochar amendments is clear, the mechanism is still unknown. Unveiling the mechanism by which this intervention occurs is vital as this knowledge may provide new applications to boost farm productivity a further 15-20%.

The fundamental issue of poor lateral water movement from furrows into beds on these soils is a major constraint limiting dry season crop productivity in both countries, but the solutions to solve this issue are not yet known. The project recommends that further efforts should be undertaken to investigate options and solutions to overcome this constraint accepting that if the constraints to lateral water movement could be overcome, this intervention would provide a major boost to dry season non-rice crop yields across the entire lowlands of the Mekong River Basin.

3 Background

Project background and justification of research

The Mekong River basin is one of the most dynamic, productive and diverse river basins in the world. The river passes through six countries in south east Asia and is home to 65 million people, many of which are rural based, poor and depend directly on water for food (Mekong River Commission 2003)**.** Cambodia and Lao PDR are two countries through which the Mekong River passes and the World Food Program has identified them as two of the most impoverished nations in south east Asia, with high rates of poverty, food insecurity and poor nutrition predominating, particularly amongst small landholders. Across the Mekong River basin, the climate is defined as tropical, featuring distinct annual wet and dry cycles; during the wet-season, rainfall may exceed 2000 mm per season, and due to a preponderance of saturated soils at this time, in the lowlands, few other agricultural opportunities exist other than rain-fed rice production.

Rice is a major component in the diets of people of the lower Mekong corridor, with the majority of rice grown during the wet season. Water productivity and yield of wet season rice in the region is low by global standards, attributed to a number of factors including climate variability, the lack of suitable varieties and frequent use of low yielding local varieties, nutrient-depleted soils, the lack of use of artificial fertilizers and inadequate management practices partly attributed to social circumstance. Indeed Mainuddin and Kirby (2009b), found Cambodia and Lao PDR had less than average water productivity for lowland rice and they attributed this to: low annual rainfall, longer than average dry season, poorer soil nutrition. Despite this, governments of Cambodia and Lao PDR have the ambition to increase the amount of rice produced, mainly by the expansion of the amount of rice grown during the dry-season. While irrigation infrastructure exists in Cambodia to allow for rice to be produced during the dry-season, irrigation infrastructure is uncommon in southern Lao, and where it exists, is often poorly maintained. Additionally, small scale irrigated rice production in Lao is increasingly an economically marginal activity due to rising input costs and increased labour scarcity coupled with Government interventions in the rice market to control prices. As a result, small landholders mainly produce rain-fed rice during the wet season as few other agricultural options exist, much of which is consumed locally/on-farm; dry-season irrigated rice only makes a minor contribution into the national Lao crop.

Over the next 50 years, increasing population pressures in the region will increase the demand for food, increasing pressure on land and water resources (Nesbitt 2005). To meet the region’s food requirements in the future, large improvements in agricultural water use and significant improvements in water productivity must occur in both rainfed and irrigated cropping systems (Johnston *et al.* 2010; Kirby *et al.* 2010). Growing dry season crops has the potential to significantly improve income and water productivity and food security and studies in southern Cambodia have shown double cropping rice increases household income by 25-37% with rainfed dry season rice and up to 75% where supplementary irrigation is available (Chea *et al.* 2004). However, as incomes of the general populous across the region rise, consumers will look to complement their diets with alternative foods in addition to rice. The production of dry season non-rice crops to meet these needs would likely be less water consumptive than dry-season irrigated paddy rice, producing a nutritious, high value crop. The incorporation of these crops into the rotations of smallholder farms, along with increasing the agricultural production across the region could be an important pathway for improving average household income and general standards of living. But, prior research investigating the productivity of dry-season crops in both Cambodia and Lao has indicated these systems are subject to major production constraints including drought, and low fertility of soils; these are likely to remain the key research challenges for the foreseeable future (Fukai and Ouk 2012). In this project, obstacles to adoption of non-rice dry season crops across the region were investigated. These included effective water management, soil physical and chemical constraints, and the selection of appropriate non-rice crops.

Across the region, access to water and the amount of water available is not ubiquitous. In a recent ACIAR study in southern Lao (CSE2009/04; Wade 2009), Newby classified villages in rural areas into one of six typologies. Two characteristics are used to define the typologies: elevation (highlands and lowlands) and water availability during the dry season (high, medium and low). This project focused on dry season production in the Mekong lowlands. The two typologies relevant to the project were:

- *Irrigated Lowlands*. Access to channel water during the dry season (fully irrigated; high water availability) where high water use crops such as maize, rice or melons can be grown
- *Lowlands with access to supplementary irrigation.* Access to limited amounts of surface or groundwater (supplementary irrigation; medium water availability) during the dry season where extensive lower water use crops (vegetables or grain crops) or intensive planting of higher water use crops (maize) may be grown.

The broad intent of this project was to increase community knowledge about water, soil and nutrient requirements and key soil constraints for the optimisation of yields of crops over the wet/dry season across the two lowland typologies of the Mekong floodplain.

Key issues addressed

The key issues addressed by this project were classified within two broad areas; factors affecting the availability of water to dry season crops and smallholder management interventions to improve crop access to water and; identifying soil factors impeding the performance of dry season crops and smallholder relevant management options to ameliorate soil constraints for high value, dry season crops.

Factors affecting the availability of water: Modelling research undertaken in a prior project conducted in the lowlands of southern Lao estimated that substantial amounts of residual water (e.g. 240 mm) could remain in soils at the commencement of the dry season (Wade 2009). In other regions of south east Asia, carry-over water from the previous wet season was successfully utilised to grow soybean, cowpea and mungbean crops in the dry season without supplementary irrigation (So and Ringrose-Voase 2000).

Early research in the present project investigated with collaborative farmers the feasibility of capturing residual *carry-over* water to grow suitable short-duration dry-season grain crops identified in previous research in this region (Fukai 2006a, 2006b). Subsequent research undertook:

- assessment of the water requirements of several dry season candidate crops,
- interventions to improve lateral movement of applied irrigation water to plant roots,
- irrigation methods and layouts to improve plant access to water
- better planting methods to improve plant access to applied soils water.
- use of mulches to reduce evaporation and improve water productivity

Soil factors impeding the performance of dry season crops: While access to water during the dry season is of indisputable significance (Laux *et al.* 2010; Rockstrom *et al.* 2010), the levels of agricultural production attainable during the dry season will also be constrained by soil limitations (Wade *et al.* 1999b; So and Ringrose-Voase 2000; Seng *et al.* 2001a; Seng *et al.* 2008). Typically, soils of the regions are chemically and physically hostile. Lowland soils are ubiquitously sandy in texture and prone to hardsetting, lacking in both organic matter and cation exchange capacity, acidic in the aerobic state and containing high levels of iron, manganese and aluminium (White *et al.* 1997; Bell and Seng 2004), particularly in the subsoil. Soils too across the region are in general extremely nutrient deficient, and prior research has shown that for most soils across

Cambodia, there is a strong yield response in rice to additions of N, P and K (Bell and Seng 2004).

Early work in the present project investigated in conjunction with collaborative farmers, the need for liming to correct soil acidity on the yield of a range of dry-season grain crops that were of interest to collaborative farmers. Subsequent research undertook to:

- Investigate the amount and placement of inorganic fertilizers to meet the needs of dry season crops.
- Investigate strategic uses of fertilizers to improve crop yields and reduce costs.
- the role that organic amendments could make to contribute to meeting the nutrient requirements of high production dry season crops
- organic interventions to improve the lateral development of roots of dry season crop roots in hardsetting soils

In-country consultations at the time of project development confirmed that the key issues that the project was to address matched aspirations of the respective governments' goals of alleviating rural poverty through improved productivity and diversification of rice-based farming systems, livestock and fisheries and the project was consistent with ACIAR's mandate for improving the productivity of lowland farming systems and maintaining and increasing critically important rice yields to improve food security and incomes.

4 Objectives

This project contributed to the development of diversification and intensification options for existing crop systems to improve the nutrition, profitability and sustainability of rural communities in southern Lao and Cambodia. Emphasis in the project was made to assist smallholder farms in intensifying their farm systems through the introduction of sustainable production of dry season non-rice crops by optimizing water, soil and nutrition management. The specific objectives, and activities within objectives of the project were as follows:

Objective 1 Identify of water and soil chemical constraints to the adoption of non-rice dry season crops in Lao and Cambodia.

Activities:

1.1 Geographic mapping of zones in the lower Mekong region in relation to dry season water availability, soil type and soil properties.

1.2 Identification of current production constraints to dry season crop production through assessment of regional production potential as affected by soil type and water availability.

Objective 2 Develop technologies and practices for improving water and nutrient management and mitigating soil limitations across the lowlands.

Activities:

2.1 Selection of focus villages for farmer engagement, field experiments and demonstration sites within each country and zone.

2.2 Assessment of the soil, water and nutritional requirement of a range of short duration and longer growth period, dry-season non-rice crops.

2.3 Assessing water management solutions for increasing residual soil moisture and water-use efficiency of non-rice dry season crops.

2.4 Investigate options to improve crop nutrition and nutrient availability, and the fertility of soils of the Mekong region to improve dry-season crop productivity.

Objective 3 Produce and communicate appropriately packaged technical and financial information, to support the adoption of dry-season cropping

Activities:

3.1 Dissemination of technologies and knowledge to selected areas beyond the immediate study project sites.

3.2 Training for advisors and key farmers in methods to improve resource use that lead to improved agricultural productivity and profitability.

3.3 Use and dissemination of packaged tools to guide decision making to improve farm productivity and profitably.

5 Methodology

Objective one: Identification of water and soil chemical constraints to the adoption of non-rice dry season crops in Lao and Cambodia.

Work within this objective entailed using Geographic Information Systems (GIS) to develop spatial agro-hydrological maps of Champassak province in southern Lao and Takeo, Kampot and Kampong Speu provinces in southern Cambodia. The developed GIS was used to determine the geographic location of resources necessary to support the development of dry season non-rice crop agricultural industries. Following this, within each hydrological resource unit (HRU) the FAO model AquaCrop was used to determine agricultural yield production potential for a range of crops.

GIS Maps Laos. Agro-hydrological maps were produced for Champassak province in southern Lao. Maps comprised four layers: (i) Land use, three categories represented either as forest, water or agricultural; (ii) Soil texture, three different texture groupings. Clays included classes as clay and heavy clays; loams including the classes of loam and sandy loam; sands including the texture classes loamy sands and sand; (iii) Topography, four landscapes representing different terrain, as either 0-8 %; 8-16%; 16-20% or greater than 20% slope, and; (iv) Hydrogeology, three separate categories based on similar geology were represented as either alluvium including: younger alluvium and exposed older alluvium; geological material of the Jurassic period including the upper and lower Jurassic aquifers, and; basement and bedrock, aquifers associated with either Triassic, Granitic or Volcanic geological origin. Hydrogeological classifications were similar to those defined in Viossanges et al (2018).

Land use data was sourced by the Forest Inventory Planning Division (FIPD/ DOF) by using ALOS collected during 2009 – 2010 and verified by the Department of Agriculture and Land Management (DALaM), Ministry of Agriculture, Lao PDR

Soil data was accessed from sources at the National Agricultural and Forest Research Institute Lao PDR and the Soil Survey and Land Classification Centre (SSLCC) of DALaM.

Topographic data used to develop the Digital Elevation Model was developed using the NASA Shuttle Radar Topography Mission (SRTM V 3.0) using 90 metre resolution.

Hydrogeological data was downloaded from the Mekong River Commission database accessed at:
http://www.arcgis.com/home/item.html?id=e17fec08485344c18d7980a093207550#overview

Hydrological Research Units of less than 200 ha were excluded from further analysis which resulted in 20 HRU over the entire province were dry season crop production could be reasonably be expected to be practiced. Even with eliminating HRU's of less than 200 ha, the remaining HRU's represented in excess of 98 % of the calculated arable area of the province.

GIS Maps Cambodia: Agro-hydrological maps were produced for three southern provinces in Cambodia: Takeo, Kampot and Kampong Speu. Like work undertaken in Laos, agro-hydrological maps comprised four layers: (i) Land use, three categories represented either as forest, water or agricultural; (ii) Soil texture; three different texture grouping were differentiated. Clays included texture classes: Clay, Silty Clay, Sandy Clay; Loams including texture classes: Loam, Sandy loam; Silt, Clay loam, Silty clay loam and Silty loam; and Sands including the texture classes Loamy sand and Sand; (iii) Topography, four landscapes representing different terrain, as either 0-8 %; 8-16%; 16-20% or greater than 20% slope, and; (iv) Hydrogeology; five separate categories based on similar geology and represented as either alluvium including younger alluvium

(Holocene to Recent) and exposed older alluvium (Upper tertiary to Pleistocene); basement and bedrock including aquifers associated with either Triassic, Granitic or Volcanic geological material; geological material of the Lower Palaeozoic aquifer (Cambrian to Silurian); geological material of the Upper Palaeozoic aquifer (Devonian to Carboniferous); and, the Upper Jurassic aquifer.

Land use data and maps showing provincial boundary were sourced from the Cambodian Ministry of Water Resources and Meteorology (MOWRAM) Technical Services Centre (TSC).

Soil data was sourced from data bases located at the Cambodian Agricultural Research and Development Institute (CARDI).

Topographic data used to develop the Digital Elevation Model was developed using the NASA Shuttle Radar Topography Mission (SRTM V 3.0) using 90 metre resolution.

Hydrogeological data was downloaded from the Mekong River Commission database accessed at:
http://www.arcgis.com/home/item.html?id=e17fec08485344c18d7980a093207550#overview

Team involved in GIS component. Khanthavy, Thavone Inthavong, Camilla Vote GIS modelling, Data analysis and verification P Eberbach. All GIS work was conducted by staff at NAFRI, Vientiane.

Determination of potential crop yield: simulation with AquaCrop.

To assess dry season crop production potential a modelling approach was adopted. Early on in the project an evaluation of simple, freely available crop models was undertaken. The evaluation was developed into an ACIAR Technical Report 87 (Vote et al. 2015) and AquaCrop (FAO) was shown as the most appropriate model to meet project needs in data scarce environments. Early on in the project, Dr Sue Walker facilitated a workshop for project personnel at the Cambodian Institute of Technology (ITC) aimed at skilling up project participants at simulating crop production using AquaCrop.

AquaCrop was developed to simulate biomass and the yield of a range of crops based on availability of water and as affected by limitations imposed by soils. While the model had been extensively tested with regard to simulation of maize in a number of environments, crop files dealing with peanut/ground nut were unavailable and AquaCrop required calibration and validation against empirical data derived from project field sites at Phone Ngam station in southern Lao. Calibration for peanut was performed using data from the well-watered treatment at Phone Ngam station conducted over the period 2015-16 and validated using data for the two other water treatments conducted in the same year and data collected from peanut trials conducted at the same site during the 2016-17 season. AquaCrop maize crop proponent was further calibrated for Prateah Lang soil using data obtained from CARDI field station during 2015-16.

In running AquaCrop in for each HRU, input files were prepared from mainly empirical data. Crop input files were prepared or further calibrated from trial data at Phone Ngam station and the CARDI field site. Soil files were prepared for each HRU using soil and water characteristics to estimate mandatory parameters such as wilting point, field capacity and saturation. Climate files were constructed using real weather data where it existed or where no data existed weather data files were constructed for particular locations using NASA Power at https://power.larc.nasa.gov/data-access-viewer/. 21 climate data sets or stations across Champassak were constructed using 10-year data sets derived either from empirical weather data or data derived from NASA power.

On simulation of crop yield, soils maps were opened in ARCmap and then overlaid with climate data sets to see which data station was most appropriate to the polygon being used at that time. Aquacrop then simulated crop performance for each soil polygon using the appropriate climate file.

Objective two: Develop technologies and practices for improving water and nutrient management and mitigating soil limitations across the lowlands

Overview

The initial research approach proposed for SMCN2012/071 was to conduct applied field-based research, largely on-farm with participating smallholder *key* farmers. Justification for this strategy was that key farmers would learn from trials by doing; neighbours would see trial outputs and would learn by seeing, adoption using the farmer learning from farmer approach. However, experience gained by the project team in the first season (2014-15) of the trial in both countries revealed that replicated trials were too complex to reliably be undertaken and maintained by farmers, and that given that farmer’s goals in attaining profit through a commercial yield were not necessarily the same goals (hypothesis testing) as that of researchers. Instead, an alternate approach of conducting relevant yet more demanding replicated research trials at nearby research stations which were on similar soils but were better resourced regarding facilities, staff, and infrastructure. New knowledge generated at these more highly managed trials were then trialled with key farmers at main villages and communes.

Research at Phone Ngam Station (Laos) and CARDI (Cambodia)

Higher level research trials were undertaken by the project in Cambodia at the Cambodian Agricultural Research and Development Institute located on the National Road 3, Prateah Lang Commune, Kambol District approximately 18 km south west of Phnom Penh (11ºº28.6’N; 104º48.5’E), and in Laos, at the Phone Ngam Rice Research and Seed Multiplication Station (National Agricultural and Forestry Research Institute) located approximately 3 km north west of Pakse, Champassak Province (15º08.6’N; 105º47.1’E). At both sites, soils were similar to soils found typically across the alluvial lowlands of both countries. In Cambodia, soils were classified as Prateah Lang, a hardsetting sandy textured soil with negligible organic material content nor levels of clay hence exhibiting low CEC and negligible nutrient holding capacity. In Lao, soils at Phone Ngam station were hardsetting sandy textured soils, alluvial in origin exhibiting low organic matter content and CEC and were similar to those at None Yang village, the site of farmer demonstration trials.

Replicated trials commenced at research stations in both countries over the dry season of 2015-16 and were conducted for a period of three years. In Laos, the research crop of interest were peanut (*Arachis hypogaea*) while in Cambodia, the crop of interest was maize (*Zea maize L*).

In each country and in each season, similar trials were conducted aimed at answering common questions on constraints and management practices to overcome constraints.

2015-16

Over 2015-16, the purpose of the trials were to determine dry season crop water requirements for sweet corn/maize (Cambodia) and groundnut/peanut (Lao) grown on a bed/furrow system and irrigated via furrow watering. Irrigations for both crops were intended to be scheduled according to a threshold soil matric potential in the middle of the bed being achieved (-30 (W1), -60 (W2) or -90 kPa(W3)) which would trigger an irrigation event to rewater beds until water potentials of -10 kPa at 20cm were achieved. However in both countries, extremely poor lateral water movement at both sites precluded the use of the water mark sensors and instead three different irrigation treatments were modified based on frequencies, watered Monday and Friday each week (W1), on Monday each week (W2) and approximately every 10 days (W3). At each watering event, water applied to each plot were timed and the amount quantified using a water meter. As soils at each site were underlain by a puddled compacted layer, we assumed that vertical deep percolation was minimal and therefore assumed that as little rain fell during the season that water applied largely reflected evapotranspiration. In Lao, water amount was the only treatment applied where as in Cambodia, a second treatment was applied as a split plot; basal fertilizer dressing at the recommended rate (F1) and at one and a half times the recommended rate (F2).

2016-17

In the previous season at both sites, a cross-section excavation of select beds in each treatment revealed that lateral water movement from the furrow into the bed was low to almost absent, and that the hardsetting nature of the soil constrained lateral root growth in the top 30 cm, precluding crop plants from growing roots to the water source.

Over 2016-17, replicated trials in both countries sought to investigate the impact of organic interventions: either no amendment; buried (5-10 cm) rice straw; or surface applied manure/biochar as a medium to facilitate the lateral movement of water from the furrow into the beds or to affect soil strength and the lateral root development on affected crops (S), and to assess the optimal placement of inorganic fertilizers at sowing (either in the sowing row or the middle of bed) (F). At CARDI, an additional non-replicated trial was conducted to assess different levels of irrigation (100-ETc; 75-ETc; 50-ETc) from flowering to harvest on yield, and the effect of incorporated straw in maize access to water. Like in the previous year, trials plots were established in a bed/furrow system and after establishment, all crops were irrigated by furrow irrigation and unless otherwise stated, irrigated with the full amount of water as determined at each site in the 2015-16 season.

2017-18

Results from the previous season showed little change in lateral water movement but indicated enhanced lateral root growth in peanut in Lao, and reduced soil strength in Cambodia. The following research repeated the use of organic amendments to improve crop root growth and investigated alternative strategies to deliver water to overcome poor lateral transmission of water.

In the 2017-18 dry seasons, a factorial experiment was undertaken at CARDI to investigate alternative irrigation strategies to deliver water to maize including a bed furrow system using furrow irrigation, hand held sprinkle and an over-bed flood and drain system. The second factor investigated related to the use of organic amendments – similar to the previous year. In Lao, two separate experiments were conducted. The first focussing on water deliver method contrast no bed versus several different styles of bed architecture and furrow delivery versus hand held irrigation, while the second contrasted various organic amendments and their impact on lateral root growth of groundnut (see Tables below for detail).

Year	Location and crop Lao	Experimental layout and treatment structure	Trial objectives and details
2015-16	Phone Ngam Station Pakse Peanut/Groundnut (variety - local sourced)	Randomized block experiment contrasting featuring three levels of watering with three replicates. Each plot (6m x 4.2 m) established as a bed/furrow system featuring 7 beds per plot.	Crop (peanut) water requirements determined by applying same quantity of water (metered) at three frequencies (Initially watering to be triggered at threshold soil water potential then moved to frequency water@ twice per week, once per week and once per 10 days). Crops hand weeded to ensure ET was dominated by crop.
2016-17	Phone Ngam Station Pakse Peanut (variety L23)	Factorial randomized block experiment contrasting organic matter interventions (S) and fertilizer placement (F)	Impact of organic intervention in improving lateral movement of water into beds from furrows and to improve lateral growth in crop root systems. Treatments were no organic

		replicated three times. Each plot established as a bed/furrow system featuring 6 beds per plots.	matter addition, buried rice straw layer in beds (5 t/ha), surface applied animal manure (5 t/ha) Optimal banded placement of inorganic fertilizers at sowing (in-row placement or mid-bed)
2017-18	Phone Ngam Station Pakse Peanut (variety - local sourced)	Experiment 1. Randomized block experiment contrasting layout and irrigation method with three replications Experiment 2.Randomized block experiment contrasting 3 organic matter interventions with three replications	Determination of impact of bed structure and layout on water availability to peanut. Treatments normal beds/furrows - furrow irrigation, normal beds/furrows with sprinkler irrigation, narrow beds furrows – furrow irrigation and no bed/furrows with flood irrigation. Impact of organic intervention in improving lateral movement of water into beds from furrows and to improve lateral growth in crop root systems. Treatments were no organic matter addition, surface spread animal manure (5 t/ha) and buried rice straw layer in beds (5 t/ha), surface applied animal manure (5 t/ha)

Year	**Location and crop** **Cambodia**	**Experimental layout and treatment structure**	**Trial objectives and details**
2015-16	Cambodian Agricultural research and development Institute Maize/Sweetcorn (variety CM-1)	Split plot randomized block experiment contrasting as main treatment three levels of watering and with the fertilizer applied at two rates as the split plot with three replicates. Each plot (6m x 4.2 m) established as a bed/furrow system featuring 7 beds per plot.	Maize/sweetcorn water requirements determined by applying same quantity of water (metered) at three frequencies (Initially watering to be triggered at threshold soil water potential then moved to frequency water@ twice per week, once per week and once per 10 days). Crops hand weeded to ensure ET was dominated by crop. Fertilizer treatments were the standard rate recommended: 90N-60P_2O_5-30K_2O kg ha^{-1} (F1), and one and a half times the recommended rate, 135N-90P_2O_5-45K_2O kg ha^{-1} (F2).
2016-17	Cambodian Agricultural research and development Institute Maize/Sweetcorn (variety CM-1)	Experiment 1. Non-randomized experiment contrasting (3) levels of irrigation of maize growing in a bed/furrow system and furrow irrigated. Experiment 2. Factorial randomized block experiment contrasting (4) organic matter interventions (S) and two	Assessment of water availability on maize/sweetcorn biomass and yield. Water scheduling based on ET and set at either 100%-ET, 75%-ET or 50% ET. Impact of organic intervention in improving lateral movement of water into beds from furrows and to improve lateral growth in crop root systems. Treatments were no organic

		inorganic fertilizer rates (F) replicated three times. Each plot established as a bed/furrow system featuring 6 beds per plots.	matter addition, rice straw surface applied and incorporated (10 t/ha), buried rice straw layer in beds (10 t/ha), surface applied animal manure and biochar(10 t/ha) Fertilizer treatments were 90N-60P_2O_5-30K_2O kg ha^{-1} (F1) and one and a half times the recommended rate, 135N-90P_2O_5-45K_2O kg ha^{-1} (F2).
2017-18	Cambodian Agricultural research and development Institute Maize/Sweetcorn (variety CM-1)	Split plot randomized experiment contrasting three irrigation strategies as main plot and contrasting organic matter interventions (F1-3) as subplot.	Comparison of the impact of conventional (bed/furrow – furrow irrigated) and alternative layouts (over bed flood and drain irrigation) and bed/furrow sprinkler irrigation on water availability to maize yield. Within each irrigation Treatments normal beds/furrows - furrow irrigation, normal beds/furrows with sprinkler irrigation, narrow beds furrows – furrow irrigation and no bed/furrows with flood irrigation. Impact of organic intervention to improve lateral water movement and enhanced availability to maize roots. Treatments were no organic matter addition F1), banded rice intact straw (10 t/ha) and banded animal manure and biochar (10 t/ha).

Research and technology adoption with Cambodian and Lao key farmers

Collaborative farm trials with key farmers were conducted over the project duration in both Cambodia and Laos from the 2014-15 dry season until 2019-20.

Cambodia

In Cambodia, key villages were established in both Takeo (Snoa and Stueng Communes), Kampot (Chamlang Chrey and Nareay communes) and Kampong Speu (Pou Mreal commune) provinces. As each of these communes had prior experience in the growing of dry season crops including maize/sweetcorn, radish, mungbean, watermelon and a strategy to effectively water these crops, research-demonstration trials with these farmers focussed on irrigation and improving soil fertility via liming and improved fertilization strategy to improve crop yield. In later seasons, the project demonstrated optimal fertilizer strategies to improve yield and minimize input costs. In general, farmers prepared fields, sowed and fertilized crops, hand weeded, undertook pest control and harvested crops. At sowing, harvest and key events such as top dressing fertilizer Mr Lim Vanndy from CARDI was on hand to take measurements and to guide in the operation. The table below details participating key farmers, crops grown and participatory research-demonstration trials conducted over the period 2014-15 to 2019-2020.

Year	Location & Farmer	Crop	Soil type	Trial
2014-15	Stueng village, Ou Saray commune, Takeo Ms Nub Moul	Mungbean	Prateah Lang (Plinthustalfs)	Effect of irrigation, lime, and fertilizer management in a bed/furrow system
	Tadeng Thmey village, Pou Mreal commune, Kampong Speu Mr. Som Vansak	Watermelon	Prey Khmer (Psamments)	

	Snao Village, Snao Commune, Takeo Ms Soun Deou	Radish	Prateah Lang (Plinthustalfs) -hardsetting coarse sandy loam)	
	Chamlang Chrey Village, Sdach Kong Khang Lech Commune, Kampot Mr. Tob Yorn	Chinese cabbage	Kampong Siem (Gleysols) -Heavy self-mulching clay	
2015-16	Chamlang Chrey Village, Sdach Kong Khang Lech Commune, Kampot Mr. Tob Yorn	Maize	Kampong Siem (Gleysols) -Heavy self-mulching clay	Effect of irrigation, lime and fertilizer management in a bed/furrow system
	Stueng village, Ou Saray commune, Takeo Ms Nub Moul	Mungbean	Prateah Lang (Plinthustalfs)	
	Snao Village, Snao Commune, Takeo Ms Soun Deou	Radish (C1& C2)	Prateah Lang (Plinthustalfs) -hardsetting coarse sandy loam)	
2016-17	1- Chamlang Chrey Village, Sdach Kong Khang Lech Commune, Kampot Mr. Tob Yorn	Maize (Fail by heavy rain)	Kampong Siem (Gleysols) -Heavy self-mulching clay	Optimal fertilizer management to improve crop yield in a bed/furrow system
	Snao Village, Snao Commune, Takeo Ms Soun Deou	Radish (C3& C4-Farmer Field Day)	Prateah Lang (Plinthustalfs) -hardsetting coarse sandy loam)	
2017-18	Snao Village, Snao Commune, Takeo Ms Soun Deou	Radish (C5& C6)	Prateah Lang (Plinthustalfs) -hardsetting coarse sandy loam)	Optimal fertilizer management to improve yield in a bed/furrow system
	Trapeang Chrey village, Chhuk commune, Kampot 1-Mr. Moa Kam 2-Mr. Pin Khim	Maize	Prey Khmer (Psamments)	
2018-19	Snao Village, Snao Commune, Takeo Ms Soun Deou	Radish (C7& C8)	Prateah Lang (Plinthustalfs hardsetting coarse sandy loam)	Optimal fertilizer management to improve yield in bed furrow systems
	Prey Sbov village, Nareay commune, Kampot 1-Mr. Ouch Chevon 2-Ms Glen Sop heap 3-Mr. Ouch Mom	Maize (Farmer Field Day)	Prey Khmer (Psamments)	Optimal irrigation and fertiliser treatments to improve yield in bed furrow system

Laos

In Laos, focus villages were established in Sukumar District, Champassak Province of Laos PDR along a transect perpendicular to the Mekong, commencing at Ban Beoung Keo near the Mekong river and heading west towards the Thailand border. The strategy was to work with villages that wanted to intensify/produce dry season non-rice crops who had the potential to market their produce both locally and at nearby markets at the Thailand border. In early years of the project, trials included water melon at Ban Beoung Keo which had access to irrigation water through its close proximity with the Mekong and a Lao Government Ministry of Water irrigation scheme. However, due to greater farmer interest in dry-season crop production in the district surrounding Ban NoneYang, good access to groundwater, and good exposure of key farms to traffic along the Sukumar-Thailand road which bisects the village, our later work with farmers concentrated mainly about the NoneYang region.

Early collaborative work with farmers (2014/15, 2015/16 and 2016/17) focussed on the production of longbean, cucumber, maize and watermelon with limited success due largely to farmer inexperience. To improve farmer skills in dry season crop production, visits were arranged in 2017 for key Ban NoneYang farmers (Mr Som, Lon Keo, and Khamchane) to inspect maize and long bean crops grown by experienced farmers in Phontong village near Pakse, employing the *Farmer Training Farmer* principle. Following these visits Ban NoneYang farmer trials were greatly improved in subsequent seasons. In these later seasons, farmers' trialled project concepts including alternate crop sowing positions in the bed/furrow system to improve access to water, the use of rice straw mulch to reduce weed incidence and improve crop water productivity, and the use of animal manures in furrows, in conjunction with inorganic NPK fertilizers to improve soil fertility and crop nutrition.

Crops were sown in a bed/furrow system and except in one incidence, all crops were furrow irrigated. In general, farmers prepared fields, sowed and fertilized crops, hand weeded, undertook pest control and harvested crops. At soil preparation and sowing, Mr Keosouvanh and Mr Bunnao from Phone Ngam Rice Breeding and Multiplication station, Pakse provided farmers with crop establishment and as well as assisted in trial establishment. During the period of crop growth, Mr Kaison from the Sukumar District Agriculture and Forestry Office (DAFO) and Provincial Agriculture and Forestry Office (PAFO) provide farmers with critical advice regarding pest control and fertilization, and participated in sampling and data collection at harvest. The table below details participating key farmers, crops grown and participatory research-demonstration trials conducted over the period 2014-15 to 2019-2020.

Year	Location and farmer	Crop(s) grown	Soil type	Trial
2014-15	Ban ParkXang (Mr Heow)	Long bean, cucumber	Coarse textured sandy loam	Crop water requirement and influence of lime. Bed sown crops watered via furrow irrigation.
	Ban NoneYang (Mr Keep)	Long bean, corn, cucumber	Sandy loam	
	Ban Beoung Keo (Mr Vipot)	Water melon	Alluvial, sandy loam	
2015-16	Ban NoneYang (Mr Keep)	Long bean,	Sandy loam	Crop water requirement and comparison between farmer method using organic fertilizer compared to

	Ban NoneYang (Mr Som)	Long bean	Sandy loam	inorganic fertilizer. Bed sown crops watered via furrow irrigation
	Ban Beoung Keo (Mr Vipot)	Long bean, cucumber	Alluvial, sandy loam	
2016-17	Ban NoneYang (Mr Som)	Maize, Long Bean, Cucumber	Sandy loam	Crop water requirement and comparison between farmer method using organic fertilizer compared to inorganic fertilizer. Bed sown crops watered with furrows
	Ban NoneYang (Ms Wat)	Maize, Long Bean, Cucumber	Sandy loam	
2017-18	Ban NoneYang (Mr Som)	Maize, Long Bean, Peanut	Sandy loam	Farmer fertilizer management compared to inorganic fertilizers and manures and rice straw mulch to reduce weed pressure and water loss. Assessment of crop sowing position in furrow in bed/furrow system in access to water.
	Ban NoneYang (Mr Lon Keo)	Maize, Long Bean,	Sandy loam	
	Ban NoneYang (Mr Khamchane)	Maize. Long bean	Sandy loam	
2018-19	Ban NoneYang (Mr Som)	Maize, Long Bean, Peanut	Sandy loam	Farmer fertilizer management compared to inorganic fertilizers and manures and rice straw mulch to reduce weed pressure and water loss. Assessment of crop sowing position in furrow in bed/furrow system in access to water.
	Ban NoneYang (Mr Lon Keo)	Maize, Long Bean,	Sandy loam	
	Ban NoneYang (Mr Khamchane)	Maize. Long bean	Sandy loam	
2019-20	Ban NoneYang (Mr Som)	Maize, Long Bean, Peanut	Sandy loam	Contrast between crops fertilized only with organic manures compared to crops sown with inorganic nutrient fertilizers at sowing.
	Ban NoneYang (Mr Phan) New farmer	Maize, Long Bean,	Sandy loam	
	Ban NoneYang (Mr Khamchane)	Long bean	Sandy loam	
	Ban NoneYang (Ms Peng) New farmer	Maize, Long bean, peanut	Sandy loam	
	Ban NoneYang (Mr Lone Keo)	Peanut	Sandy loam	

Objective 3 Produce and communicate appropriately packaged technical and financial information, to support the adoption of dry-season cropping

Under objective 3, the Projects intention was to effectively disseminate technological information developed by the project and support systems to farmers and advisors to assist in the adoption of new and more profitable methods of system intensification.

Field days & workshops:

The project used village field days as a mechanism to broadly disseminate new concepts to local and regional interest groups. Multiple field days were conducted in each country, and farmers and district advisors were invited to attend and learn new crop establishment techniques, the roles and uses of organic materials, the use of improved genetics, strategies to expediently meet plant nutrient needs, best management of pests and diseases, and best management practices.

In Lao, farm field days were held in Ban NoneYang and farmers from the district and DAFO and PAFO advisors servicing the district were invited. The early focus of farm field days was in the dissemination of the concept of dry season non-rice crop production to farmers with little or no experience, using the concept of *Farmers Training Farmers*. Project experience indicated this approach was effective in introducing new farmers to what well managed crop looks like and provided an opportunity for these farmers to learn from other farmers the most salient techniques to achieve highly productive and profitable crops. At these field days farmers inspected crops and discussed the production of the crops of key farmers. In subsequent years project concepts such as in furrow planting to improve plant access to water, and use of organic manures to improve nutrition and water productivity were concepts of emphasis. The final field days at Lao moved from learning techniques to growing highly productive crops to consider the productivity and financial returns associated with dry season non-rice crops.

In Cambodia, many farmers had prior experience in growing dry season crops, so the purpose of these field days here were less on *Farmer Training Farmers* and instead to investigate methods to improve resource use that lead to improved agricultural productivity and profitability. Earlier trials in Cambodia aimed at considering irrigation methods to most effectively apply irrigation water, and the need for lime to address low soil pH’s. Later trials contrasted farmer methods to meet the nutritional needs of crops with alternative approaches that were developed in conjunction with the project. This approach trialled the two fertilization strategies over a period of eight radish (four seasons) and two maize crops and illustrated productivity differences and analysed financial implications associated with the two approaches. The Cambodian field days were designed both for farmers across the district and for department of Agriculture advisors and were held in most seasons.

A one-day advisor training workshop was held in February 2020 at DAFO in Sukumar in Lao. DAFO and PAFO agricultural advisors from across the Sukumar district were invited to attend to hear presentations of four project participants. The purpose of these presentations were to aid in upskilling advisors so that they could provide best practice advice to farmers of dry season’s crops:

John Hornbuckle – discussing crop seasonal water requirement and scheduling irrigation to maximise productivity.

Jeff McCormick – discussing key growth stages and the agronomy of groundnut/peanut and sweetcorn

Phil Eberbach – discussing soil fertility, crop nutrient requirements and the role of fertilizers in dry season crop production.

Khanthavy Souliyavongsa – using GIS discussed the potential areas within the province were resources were available to support the production of dry season crop and allow for farm intensification.

Tools and resources

To support advisors, the project has undertaken to produce a manual to support the production of maize in the irrigated lowlands. Despite the existence of an Upland Maize Production Guide (Martin 2015), the rationale behind producing a second guide was that despite some similarities, a significant departure exists in growing lowland maize in contrast to its production in the uplands. Key points of departure include:

- vastly different soils – in general soil of very low fertility (Prateah Lang),
- the need for different options in soil/field preparation to deal with poorer soils,
- the need for irrigation,
- probable different varieties,
- the production of a maize destined for fresh human consumption (green) rather than as animal feed and,
- different harvest and post-harvest requirements.

6 Achievements against activities and outputs/milestones

Objective 1: Identify water and chemical constraints to the adoption of non-rice dry season crops in Lao PDR and Cambodia

No.	Activity	Outputs/ milestones	Completion date	Comments
1.1	*Geographic mapping of zones in the lower Mekong region in relation to dry season water availability, soil type and soil properties.*	Zones in southern Lao PDR and Cambodia identified and mapped in digital format.	Sept 2015 Completed Lao & Cambodia	Agro-hydrological zones in Champasak and in the provinces of Takeo, Kampot and Kampong Speu, Cambodia have been delineated using a combination of SWAT model and GIS tools.
		Hydrology maps overlain with regional soil maps including texture, pH, OC and total N & P produced and published.	March 2019 Lao & Cambodia	This has been incorporated into the agro-hydrological model through the identification of HRU's using the SWAT model (see above).

1.2	*Regional determination of the dry season crop production potential as affected by soil type and water availability, and the identification of constraints to current production.*	A comparative assessment of crop models (CropWat, AquaCrop, Ecocrop, SWBM) produced and published	Sept. 2015. Completed	This document was finalised and published online in Dec 2015 as ACIAR Technical Report No. 87 available at http://aciar.gov.au/publication/tr87 The model has been successfully calibrated and validated to local conditions using data from 2015/16, 2016/17 and 2017-18 AquaCrop modelling has been completed and a conference paper has been developed and accepted for the 18th Australian Agronomy Conference in October, 2017 and the 22nd International Congress on Modelling and Simulation (MODSIM2017) in Tasmania December 2017
		Simple matrix assessment of gap between current and potential production capacity completed for zones / countries	Feb 2020. Completed	AquaCrop modelling has been completed for HRU's in both countries. Gaps between simulated yield and actual yield made for maize and peanut. In both countries, simulated yield and actual yields were similar for maize but actual yields of peanut in both countries were about 50% lower than simulated yields
		AquaCrop and EcoCrop modelling completed to assess production gaps and constraints as effect current crops, and to guide in the selection of viable alternate crops suited to the region and climate.	Feb 2020 Completed	Aquacrop modelling has been completed and a monograph comparing models has been published and 2 conference papers have been delivered. Ecocrop, an FAO model which matches climate to particular crops was not used in this project as a diverse range of crops suitable for each ecotype was already well known for which markets had already been established.
		Production gaps and constraints for major zone modelled and combined with relevant previous work in this area. Production and market risk analysed and assessed. Preliminary report produced and forwarded to stakeholders and NGOs.	February 2020 Complete	Production gaps have been identified and constraints to production identified. Edaphic limitations restricting lateral water movement as well as hardsetting of soils constraining lateral root growth are identified as key constraints and require further research. Further, higher yields of maize associated with some organic amendments beyond simulated values indicate scope for further yield increase using strategic additions of biochars – the mechanism of yield increases have not been clarified. Staff associated with NGO's initially flagged as collaborators have moved on and were not replaced by NGO's. NGO's sent delegates to project updates but did not collaborate further.

		A reflective evaluation of the integration of activities associated with Objective 1 complete and reported.	Feb 2020	An evaluation of milestone one indicated activities to be well integrated as reported in the present document

PC = partner country, A = Australia

Objective 2: Develop technologies and practices for improving water and nutrient management and mitigating soil limitations across the lowlands …

No.	Activity	Outputs/ milestones	Completion date	Comments

2.1	Selection of focus villages for farmer engagement, field experiments and demonstration sites within each country and agro-hydrological zone	Select and establish six focus villages across the region, (two per hydrological zones and each on contrasting soils)	Mar 2015 Completed	A total of five villages (four in the Takeo, Kampot provinces of Cambodia and three in the Sukhuma district, Champasak province in southern Laos) have been selected based on their soil characteristics, water availability and willingness of the farmer to perform demonstration field trials. Crops grown in the demonstration trials (maize, radish, mung bean and Chinese kale in Cambodia; long bean and cucumber in Laos) were selected based on farmers' preferences.
		Village meetings held to identify key soil and water constraints for the 6 focus villages)	Mar 2015 Completed	Meeting with participatory farmers, village officials and regional agricultural staff were held to identify soil problems and constraints to dry season production. Soil pH, poor chemical fertility and poor structure and lack of access to water for irrigation (Lao) identified.
		Showcasing "best bet" results of village trials of alternative crops and optimal management at IDE and SNV demonstration sites in other areas (PADEE project sites)	Feb 2020 Completed	This has been completed in part through the development and delivery of a 'travelling roadshow' which was designed and developed to disseminate generalised information related to best practice management including fertiliser and water management, transferring knowledge through school children and other youth. This road show was delivered in two districts at three schools to an audience of > 1000 school children, teacher's advisers and government officials. A series of workshops have been undertaken by CARDI to showcase results in provinces based on farmer field trials. In 2017, Radish were showcased in Snoaw village Takeo, In 2017/18 and 2018/19 maize was showcased in Kampot province in Trapeung village and Prey Sbov village respectively. In Ban NoneYang in Lao, trials and field days have demonstrated alternative planting methods, and mulch in improving soil fertility and water use efficiency on maize, long-bean and peanut production in 2018,2019 & 2020.

2.2		Report reviewing literature and previous research options for alternative dry season crops in Mekong lowlands produced	Feb 2016 Completed in part	More recently a brief review of crop physiology and known constraints of growing alternative dry season crops including peanut, long bean, cucumber, maize, radish and mung bean in the Mekong sub region has been prepared for project modelling purposes only; this has not been published.
		In each hydrological zone seed for cropping at least two short duration grain / pulse or forage crops sourced	Nov 2015 Completed	Reputable suppliers of viable seed have been sourced.
		In each focus village trials of at least two short-duration dry season crop alternatives completed	May 2016 Completed	In Laos, three alternative crop species (long bean, sweet corn and cucumber) were grown at each farm demonstration trial location. In Cambodia, demonstration cropping trials for Maize, Radish have been conducted. In later trials peanut was substituted for cucumber due to the propensity of cucumber for disease in southern Lao.
		In each focus village trials varying inputs (water and nitrogen) on short-duration dry season crop alternatives completed and reported	May 2016 Completed	Multi farm replicate trials have been conducted in all the selected villages aiming to compare farmer practices regarding water and fertiliser management against less frequent irrigations or project fertiliser recommendations for each specific crop. Crop production has been monitored and results reported in 2015-16, 2016-17 and 2017-18 annual reports and in this report.

2.3	*Investigation of options to improve the amount of water available for dry season crops and the water use efficiency of non-rice dry season crops.*	AquaCrop modelling investigating impact of short season crops and early sowing on residual soil moisture at end of wet season completed and reported	Aug 2016 Completed	The AquaCrop model has been successfully calibrated to local conditions for maize and groundnut production in Cambodia and Laos, respectively. Two papers have been published (18th Australian Agronomy Conference) & (22nd International Congress on Modelling and Simulation (MODSIM2017). Three student theses have been produced with a focus on groundnut and maize production response to irrigation treatments and the prediction of maize yield under different climate change scenarios. Several further papers are currently being prepared for publication.
		Trials addressing key constraints to effective water management of dry season cropping for each focus village (six test sites) and data complied, constraints and losses identified and reported	Feb 2020 Completed	This was an iterative process with continued through the duration of the project with subsequent work fine tuned, based on findings from previous DS field trials associated with project activities. These inclusions included improved soil structure or interventions to overcome root growth restriction due to physically hostile soils. Final farmer demonstration trials were conducted over the final 2018-19 dry season in Cambodia and in 2018-19 and 2019-2020 in Lao demonstrating key project findings aimed at better management of soil to improve dry season crop performance
		Guidelines on dry season crop water requirements developed and distributed to farmers and stakeholders (NGO's)	March 2019 Completed	Guidelines developed from the data collected during the 2015/2016, 2016/17 and 2017-18 dry seasons and distributed to farmers at field day events as either project leaflets or as crop production guides in the form of crop calendars.
		Soil water management tool evaluated and report published	Feb 2020 Completed	Simple tools for improving crop access to soil moisture were developed over 2015/16, 2016/17, 2017/18. Poor lateral water use, was identified during the 2015/16 dry season. Reports of soil organic matter interventions, irrigation layout and furrow bed configuration designed to improve crop access to water were researched in 2017-18 and guides detailing pertinent results were reported in project reports and disseminated to farmers at field days on demonstration farms.

2.3 (cont)		Tables establishing relationships between end of season residual soil moisture and potential crop productivity developed and disseminated to NGO's and stakeholders	Nov 2016 Achieved	Initial intentions were to develop tables that would show across the different soil types stored residual soil moisture and indicate potential crop productivity based on residual soils water. Knowledge attained early in the project indicate that except in exceptional circumstances, carryover water is negligible and the project recommends that only farmers with access to an appreciable supply of water such as a groundwater bore be encouraged to grow dry season crops. Hence tables have not been produced
		Management options for improving irrigation efficiency and increasing residual soil water for dry season crops investigated and reported. Extension guide prepared and disseminated.	Mar 2019 Complete	Early results in the project emphasised specific properties of soil requiring improved methods to facilitate crop access to water. Interventions trialled to improve crop access to water have been successfully demonstrated in on-farm trials. These methods don't solve the water impediment imposed by these soils necessitating further research. None the less these interventions are recommended practice promoted by the project and have been incorporated as part of the crop calendar guide for farmers and extension staff.

2.4	*Investigate options to improve crop nutrition and nutrient delivery, and the fertility of soils of the Mekong region to improve dry-season crop productivity*	Key soil and nutrient constraints identified for each focus village	Dec 2015 Complete	Based on previous studies in the focus areas, the broad soil and nutrient constraints were acknowledged and quantified at some key site where analysis has be performed. Samples from other sites have been collected and have been analysed. However, we recognise that no analysis for S has as yet occurred – but as to date no fertilizer treatment has included S, and the soils lack organic matter, we recognise that S deficiency is highly likely and this needs research in the coming dry season.
		Trials completed testing potential solutions (multi-factorial experiments with irrigation rate, organic and artificial fertiliser and lime) to key soil and nutrient constraints for each focus village	Feb 2020 Complete	Trials have been conducted in all the selected villages aiming to compare farmer practices regarding water and fertiliser (organic and artificial) management against project recommended irrigation schedules and fertiliser recommended strategies for each specific crop. Crop production has been evaluated and reported in annual reports. The financial implications of these contrasts has been evaluated and are reported in annual reports and here.
		Model of N, P, S cycle between components of rotation (aerobic / anaerobic) developed and reported in the scientific literature	Feb 2020 Complete	This work has been completed in association with a PhD research run in parallel with this project
		Feasibility study (sources/costs) completed for using organic manures and artificial fertilizers to meet crop needs. Data analysed and reports produced.	Feb 2020 Complete	Farmer and research trials investigating the use of fertilizer and animal manures have been conducted in both Lao and Cambodia. Yield data showing the benefit of organic amendments has been produced in the 2017-18 annual report and in the present report and presented to farmers at field days. Sources of organic material have been identified
		Nutrient supplementation schedules for particular crops and organic substrates produced	Feb 2020 Completed	Crop fertilization and organic amendment schedules have been produced and are incorporated in the crop grower guide and calendars for maize in Cambodia and maize, peanut and longbean in Lao

			Feb 2018	
		Rates of acidification with systems intensification calculated, and lime required for correction of acidification determined and reported.	Oct 2017 Completed	Sampling and soil analysis conducted in 2015/16 confirmed the acidic nature of the soils prevailing in the study areas and ratified the need for liming and the effectiveness of lime in reducing the availability of exchangeable aluminium. These findings have been reported in the Annual Reports for this project
		Lime sources and logistics of supply chain investigated. Guides to acidification and soil amelioration including costs and benefits prepared and distributed	Feb 2018 Completed	In southern Laos, lime can be easily sourced from local agronomic supply stores @ 50 000 LAK 50 kg^{-1}. In Cambodia, this is not as readily accessible. However, rock phosphate can be locally sourced from Banteay Meanchey Province which is reported to be 25 % P with an unknown proportion of Ca.
		A reflective analysis of the activities associated with Objective 2, their synthesis and an evaluation of their impact completed and reported.	June 2018 Achieved	A reflective analysis of performance of the project has been undertaken regularly throughout the term of the project and has been instrumental in influence the direction of elements of the project at key points. Reflective writing has been formally reported through appropriate sections of trip reports

PC = partner country, A = Australia

Objective 3: Produce and communicate appropriately packaged technical and financial information, to support the adoption of dry season crop production

No.	Activity	Outputs/ milestones	Completion date	Comments
3.1	*Dissemination of technologies and knowledge to selected areas beyond the immediate study project sites*	Project team workshop on Impact Pathways and the development of a plan	Dec 2015 Completed	An initial IPA was conducted at the project inception meeting in May 2014.
		Demonstration trials established on participatory farms in each focal villages) to demonstrate farm interventions to enable dry season production	Feb 2020 Completed	A total of thirty four demonstration trials have been performed in villages within Champasak province (Lao) and Takeo, and Kampot provinces of Cambodia where a variety of dry season crops have been tested under different water and fertilisation practices. Seven field days have been conducted which provided farmers from the regions an opportunity to review and learn new farming methods from other farmers. Also at field days, an analysis of the framing methods has been provided including the impact of new systems on farm finances
		i Crop comparison demonstration	Dec 2016 Completed	Simple on farm trials have been conducted to evaluate and demonstrate methods of irrigation, water conserving interventions and fertilization methods over the duration of the project for a range of dry season crops.
		ii Crop water – irrigation demonstration	Dec 2017 Completed	
		ii Crop nutrient fertilizer (organic/inorganic) & soil liming demonstration	Dec 2017 Completed	
		Crop calendar produced for use across the region which details particular key development and operational dates sowing, pests for an array of crops, and disseminated	Mar 2019 & Feb 2020 Completed	In the two final years of the project, crop calendars were developed by NAFRI which detailed the key steps required by farmers to prepare land, plant, irrigated and manage dry season crops. These calendars included sections on weed and pest control strategies for each of the three main crops promoted by the project. This approach was also adopted by CARDI in Cambodia for maize.

3.2	*Training for advisors and key farmers in methods to improve resource use that lead to improved agricultural productivity and profitability.*	Courses to inform farmers about crop water and nutrient use developed and conducted by project team and DAEC in Lao PDR at three locations	March 2019	Several workshops and field days have been organised by NAFRI to inform farmers about crop water and nutrient requirements, methods to improve water use, and improve plant access to water and options to improve the availability of nutrients to dry season crops. These programs were conducted at Ban NoneYang and involved iexcess of 65 farmers from across the Sukumar district.
		Courses to inform farmers about crop water and nutrient use developed and conducted by project team and DAE in Cambodia at three locations	Mar 2019 Completed	Numerous farmer field days have been organised by the in country Cambodian partners to inform farmers in Takeo and Kampot province about crop water and nutrient requirements, and options to improve the availability of nutrients to dry season crops and reduce input costs. These programs were conducted at Snoaw village in Takeo and in Kampot province at Trapeung Chey and Prey Sbov villages and involved in excess of 80 farmers
		Regional programs to demonstrate methods to intensify farming systems and produce more income established consistent with 3.1	Feb 2020 Completed	Programs to inform farmers of new more intensive farming systems to improve farm productivity and profitability have been developed and conducted by incountry partners. A workshop was also delivered to DAFO and PAFO in Sukumar to specifically train advisors about dry season crops, their water and nutrient requirements and their fit into the farming system to enable them in giving correct and timely guidance to farmers.

3.3	*Use and dissemination of packaged tools to guide decision making to improve farm productivity and profitably*	Guide on water and nutrient management produced	Mar 2019 Complete	Water and nutrient requirement data collected over the duration of the project has been synthesised into a farmer ready format. Crop calendars advising crop water requirement/irrigation scheduling and fertilizer management have been prepared produced for maize, long bean and peanut prepared and distributed to regional small land holder/farmers at regional field days and to district crop advisors.
		Phone based app and/or calendar chart for assessing potential crop area based on water storage produced		Experience gained by the project indicated that farm ponds are invariably small and of which most farmers rely for aquaculture. For the purpose of growing DS crops, ponds are rarely and sparingly used as most farmers' access alternate water supplies e.g. ground or channel water for crop irrigation. Therefore the project recognised the need to make conversion tables of water requirement for crop area to volumes of pond water available was relegated low priority status. This output has not been completed.
		Phone based app and/or chart based tool for recommending nitrogen application based on crop colour/ crop reflectance produced	Mar 2019 Completed	This achievement was an aspiration target. We originally intended staff and students at ITC to take on the role of app development but ITC lacked staff to undertake this role. But recognising its importance, the project have trained farmers as part of farmer training of indicators of nitrogen deficiencies-enabling them to schedule topdressing with urea. Also the project has trained farmers to look for nodules on the roots of developing pulse crops.
		Simple tool and knowledge package for soil water monitoring for irrigation scheduling produced	Mar 2019 Completed	We initially proposed using of a cheap soil water traffic light tool as developed by CSIRO. However despite the cost coming down, it still is too expensive for farmers and there for we need to reconsider what tools were available and to develop knowledge package as appropriate. As part of farmer training, crop water requirement and crop and irrigation scheduling were well covered and are detailed in crop calendars.

7 Key results and discussion

Objective one: Identification water and soil chemical constraints to the adoption of non-rice dry season crops in Lao and Cambodia.

Agro-hydrological modelling of Champassak province, Lao PDR

The concept of hydrological response units (HRU) as described by Flügel (1995 & 1996) provided the basis for the development of agro-hydrological map of southern Lao. Built on land use, soil texture, and topography, ArcSWAT was used to distinguish HRU's within the watershed boundaries of each region. Land use was based on three discrete types: forest, comprising about 75.6% of the total land area; water comprising 2.88% total area; and, agriculture comprising 21.4% of the total area. Soil textures were demarcated into either of three main classes using the following rationale: clays comprise an amalgamation of texture classes featuring a predominance of clay and having a predisposing effect on CEC, water holding, fluid movement and possibly structural stability. Sands represented an amalgamation of two principal texture classes dominated by sands and representing soils with negligible nutrient retention and water holding capacity. Loams comprised soils with a high potential load of silts or sands, but with sufficient clay to allow for moderate CEC and structural characteristics including stability. Basic hydrogeological data (Mekong River Commission) was incorporated into the model to demarcate areas where groundwater irrigation access would be likely to facilitate supplementary irrigation of smallholder dry season crops. Like texture, these systems were clustered into common units based on related geology and similar hydrogeology e.g. units designated as Younger Alluvium Aquifer and Exposed older Alluvium Aquifer were cluster into a single unit representing alluvial aquifers. Earlier stages of modelling where textural classes and hydrogeological units hadn't been clustered produced up to 48 HRU's but by clustering textures and like hydrogeological units and the elimination of HRU's comprising a land area of less than 200 ha, reduced the total number of HRU's of agricultural potential to 22 while still representing the majority (99.5%) of agricultural land. The agro-hydrological model, in its final form is illustrated in Figure 7.1

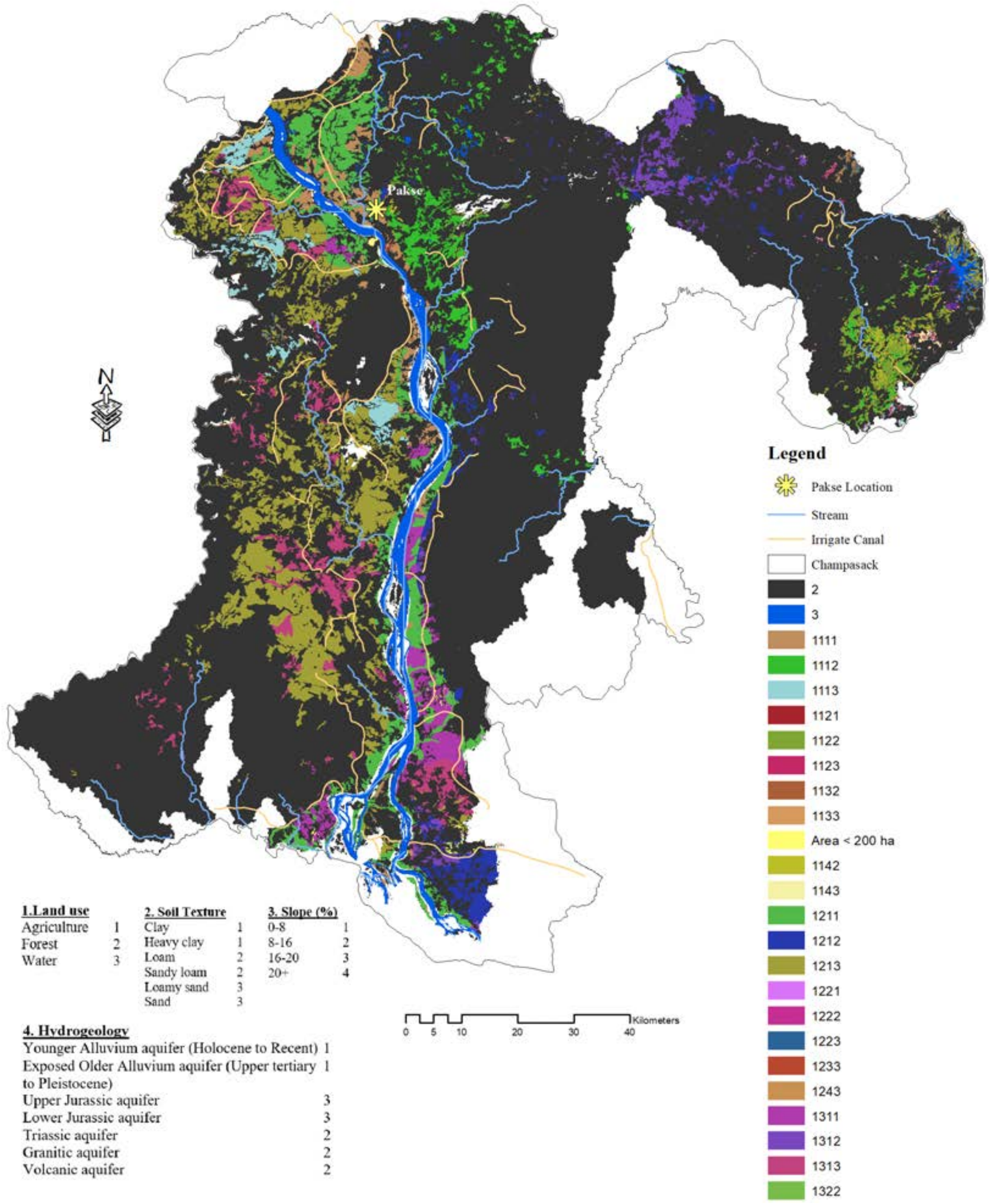

Figure 7.1: Agro-hydrological map of Champassak based on land use, soil texture, topography and underlying hydrogeology. Note each HRU, represents an area of the agriculture landscape exceeding 200 ha in size.

An agro-hydrological map of three key provinces in southern Cambodia (Takeo, Kampot and Kampong Speu) were also produced using ArcSWAT to distinguish HRU's within the watershed boundaries across the provinces. A similar approach to that used in Lao was also employed here with regard to soil texture and geological units except that rather than three, the Cambodian map featured five hydrogeological systems. Additionally, given the extensive irrigation canal network that has been developed in southern Cambodia, the location of irrigation canals was included in the map. The agro-hydrological model in its final form is illustrated in Figure 7.2

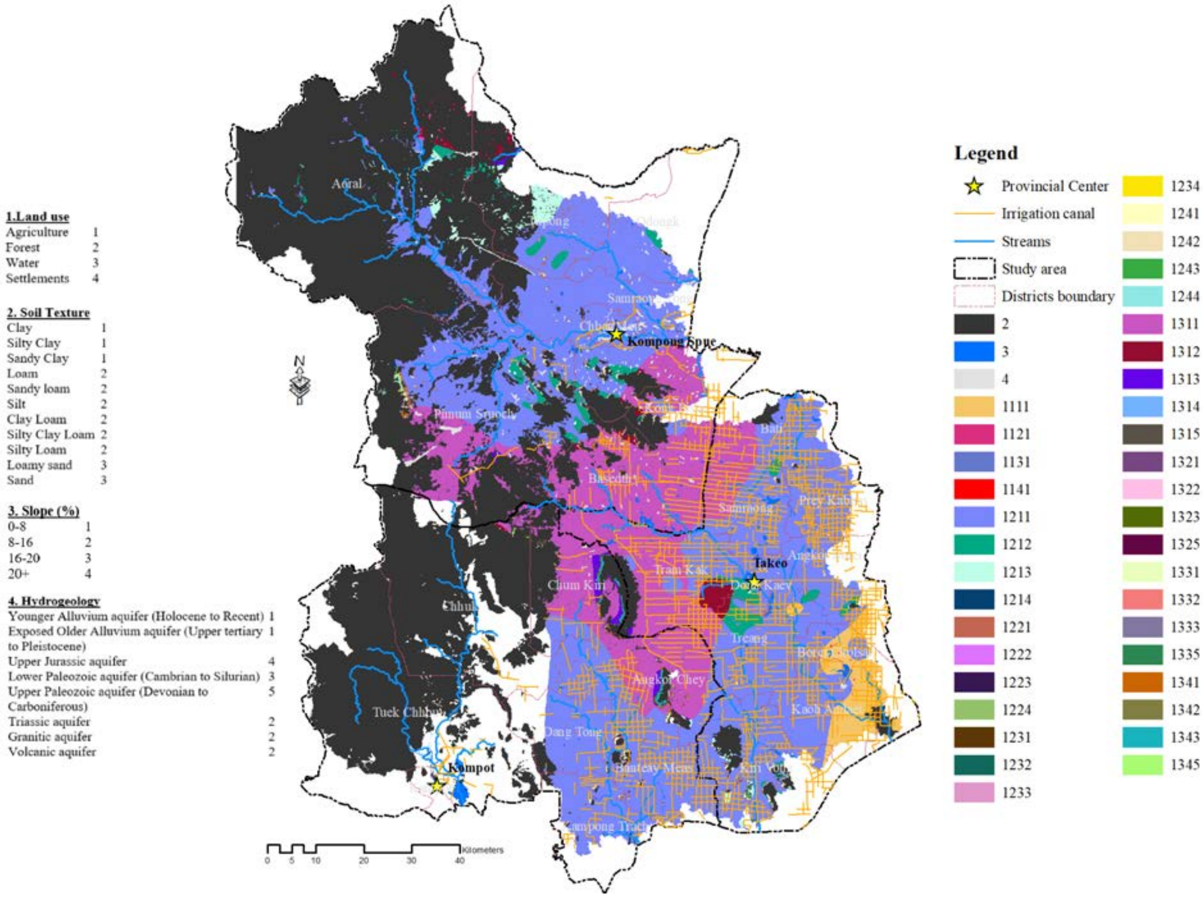

Figure 7.2 Agro-hydrological map of three provinces (Takeo, Kampot & Kampong speu) in southern Cambodia based on land use, soil texture, topography and underlying hydrogeology.

Determination of potential crop yield: simulation with AquaCrop.

To assess dry season crop production potential a crop simulation modelling approach was adopted using the FAO crop-water availability model AquaCrop.

Following development of the GIS maps for both countries, AquaCrop was applied in each polygon to simulate crop yield. In both countries, the potential yields of both maize and peanut were simulated across each region.

The simulated potential yield of peanut and maize for each HRU in Champassak province in Lao PDR is given in the Table 7.1 below. Across the entire region, simulated potential peanut grain yield ranged from 3.15 to 4.11 t/ha. There was little difference in simulated peanut grain yield across the three textural types (clays 3.8 t/ha, loam 3.73 t/ha and sands 3.72 t/ha) which we speculate was due to the fact that irrigation in the simulation ensured that water was not limiting and therefore the superior water holding capacity of clays were not apparent in these simulations. Interestingly, simulated peanut yields were lower, in the lowest topographic zone (0-8% slope 3.67 t/ha) and increased as the slope increased up until 16-20% (3.92 t/ha). While the reason for this is not entirely clear, it would appear that higher slopes in Champassak province are associated with the Bolvean Plateau which along with having better soils, has a more favourable climate for the growing of crops. Research undertaken during 2015-16 at Phone Ngam station in southern Lao, showed local variety of peanut in an irrigated bed/furrow system with optimal water and best agronomic management to achieve an average yield of 1.75 t/ha. AquaCrop modelling indicated that peanut growing in this HRU had a maximum yield potential of 3.66 t/ha which indicating that at this stage empirical yields of peanut are less than 50% of potential yields.

Across the region, the range in simulated maize yield was less than for peanut and varied between 2.128-2.133 t/ha. There was practically no difference in simulated maize yield across the three textural types (clays 2.13 t/ha, loam 2.18 t/ha and sands 2.19 t/ha) indicating that texture in isolation is not a major determinant of maize yield. Interestingly, there was negligible difference in maize yield across the four topographic zones: simulated maize yields were lower, in the lowest topographic zone (0-8% slope 2.185 t/ha) and increased slightly in all zones with a slope greater than 8 % (2.195 t/ha).

The simulated total potential yield for peanut and maize across the province is estimated at 906748 and 531354 t, respectively. These figures only estimate potential production of each crop and likely, greatly exceeds real production potential across the region due to assumptions made as part of the analysis. Primarily, the analysis assumes all land designated agricultural is available for production; not taking into account non-productive zones such as dwellings, villages, fences or roadways. Additionally, the analysis assumed infinite labour supply. Surveys of others (e.g. Lyall 2017) have indicated that labour limitations and lack of available finance to farmers is likely to be a severe limitation to the uptake and production dry season crops by smallholder farmers.

Table 7.1 Simulated potential peanut and maize crop yields (AquaCrop) across 23 Hydrological Resource Units of Champassak province in Lao PDR.

HRU Code	Land Area per HRU (km^2)	Simulate peanut grain yield per HRU (t/ha)	Simulate maize grain yield per HRU (t/ha)	Potential yield of peanut crops in each HRU (t)	Potential yield by maize crops in each HRU (t grain)
2	8789.407				
3	335.502				
1111	123.800	3.46	2.128	42834.8	26344.6
1112	187.637	3.93	2.129	73741.34	39947.9
1113	110.144	3.54	2.128	38990.98	23438.6
1121	2.300	3.15	2.133	724.5	490.6
1122	66.290	3.94	2.130	26118.26	14119.8
1123	7.112	4.03	2.130	2866.136	1514.2
1132	19.837	4.06	2.130	8053.822	4224.3
1133	2.049	4.01	2.129	821.649	436.23
1141	12.101	3.73	2.129	4513.673	2576.3
1142	31.809	4.04	2.130	12850.84	6775.3
1143	5.435	3.92	2.129	2130.52	1157.1
1211	423.484	3.58	2.128	151607.3	90117.4

1212	147.955	4.01	2.129	59329.96	31499.6
1213	808.267	3.52	2.128	284510	171999.2
1221	3.102	3.53	2.128	1095.006	660.1
1222	7.995	4.11	2.129	3285.945	1702.1
1223	19.302	3.76	2.129	7257.552	4109.4
1233	4.698	3.68	2.128	1728.864	999.7
1243	14.936	3.65	2.128	5451.64	3178.4
1311	153.365	3.68	2.129	56438.32	32651.4
1312	120.771	3.96	2.130	47825.32	25724.2
1313	220.790	3.32	2.128	73302.28	46984
1322	3.305	3.95	2.128	1305.475	703.3
Total (HRU code 1)	2496.48	3.76	2.129	906784.1	531353.7

The simulated potential yield of peanut and maize for each HRU in the three provinces modelled across southern Cambodia are given in the following table (7.2). Across the entire region, potential peanut grain yield ranged from 2.157 to 3.239 t/ha. From highest to lowest, there was more than 1000 kg difference in peanut grain yield per hectare. Interestingly, in general simulated peanut yields were lower in the three provinces of Cambodia than in Champassak in Lao where the maximum potential yield was modelled to be 4.11 t/ha. This could reflect the fact that Aquacrop model calibration for peanut as undertaken in this study was modelled mainly using Lao input data. However, unlike Lao there was marked difference in simulated peanut grain yield across the three textural types with simulated yields on clays soils (3.22 t/ha) considerably out yielding simulated peanut yield growing on sands (2.32 t/ha) with yields on loams (2.94 t/ha) only slightly inferior to yield on clays. We speculate that yield differences between the two texture types may be due to a poorer fertility index being assigned to sands in Cambodia than clays, therefore suppressing simulated yield potential on these soils. There was practically no difference in simulated peanut yield as a function of topographic zone with average yields of each zone ranging from 2.68 – 2.69 t/ha.

Across the three provinces, the range in simulated maize yield was less than for peanut and varied between 1.987-2.129 t/ha. Research undertaken within this project at CARDI show that for maize variety CM1 grown in an irrigated bed/furrow system with optimal water and best agronomic management could achieve an average grain yields ranging between 2.0 and 2.4 t/ha. This data indicates that AquaCrop modelling here is simulating quite closely maize yields as typically seen in field trials on these soils. But, there was a difference in simulated maize yield across the three textural types with average simulated yields decreasing from 2.130 t/ha for clays, to 2.127 t/ha-loams to 2.062 t/ha for sands reflecting a reduction of approximately 70 kg reduction in simulated maize yield per ha. Interestingly, there was negligible difference in maize yield across the four topographic zones, ranging from 2.095 – 2.099 t/ha.

The simulated total potential yield for peanut and maize across the three provinces were estimated 1939386 and 1450123 t respectively. Despite Cambodia having a lower yield potential t/ha for peanut, figures presented here represent a considerable greater yield potential for these two crops in Cambodia than Lao, mainly as there is great arable land available for dry season crop production in Cambodia compared to Champassak province in Lao. Note, these figures also only estimate potential production of each crop and are likely to greatly exceed real production potential across the region for reasons similar to those ascribed for Lao in the section above.

Table 7.2 Simulated potential peanut and maize crop yields (AquaCrop) across 38 Hydrological Resource Units across Takeo, Kampot and Kampong Speu in southern Cambodia.

HRU Code	Land Area per HRU (km^2)	Simulate peanut grain yield per HRU ($t\ ha^{-1}$)	Simulate maize grain yield per HRU ($t\ ha^{-1}$)	Potential yield of peanut crops in each HRU (t)	Potential yield by maize crops in each HRU (t grain)
2	5279.531				
3	75.103				
4	81.203	t/ha	t/ha		
1111	203.318	3.229	2.129	65648.68	43289.49
1121	1.183	3.233	2.129	382.3321	251.7969
1131	0.041	3.214	2.129	13.01838	8.623811
1141	0.073	3.212	2.129	23.41635	15.52292
1211	4336.870	3.060	2.126	1326938	921922.2
1212	181.805	2.957	2.123	53767.09	38600.52
1213	72.924	2.910	2.129	21224.54	15525.29
1214	4.909	2.921	2.129	1433.65	1045.091
1221	57.947	3.024	2.124	17520.73	12305.42
1222	9.339	2.928	2.125	2734.671	1984.635
1223	6.156	2.945	2.129	1812.717	1310.613
1224	1.806	2.769	2.129	500.1738	384.5279
1231	6.602	3.003	2.122	1982.233	1400.958
1232	2.147	2.982	2.128	640.0813	456.7989
1233	0.745	3.001	2.129	223.6342	158.6576

1234	0.972	2.767	2.129	268.91	206.9199
1241	15.325	2.996	2.123	4590.816	3254.139
1242	7.679	2.974	2.128	2283.652	1634.15
1243	2.932	3.014	2.129	883.8644	624.3048
1244	2.049	2.765	2.129	566.7198	436.2546
1311	1778.987	2.200	2.056	391314.9	365821
1312	75.500	2.377	2.118	17947.59	15994.54
1313	32.416	2.457	2.102	7964.005	6812.743
1314	0.049	2.649	2.088	12.87459	10.14741
1315	2.876	2.157	1.987	620.2032	571.3181
1321	39.585	2.230	2.034	8828.679	8050.997
1322	3.451	2.329	2.092	803.4769	721.7695
1323	6.359	2.460	2.101	1564.401	1335.657
1325	1.337	2.177	1.992	290.9774	266.1977
1331	3.888	2.360	2.060	917.4406	800.8996
1332	0.591	2.180	2.073	128.8869	122.6034
1333	1.895	2.480	2.101	469.9957	398.1855
1335	0.300	2.188	1.994	65.56684	59.7722
1341	9.137	2.355	2.060	2151.814	1882.319
1342	1.742	2.183	2.081	380.1414	362.3427
1343	9.218	2.519	2.114	2322.058	1948.264
1345	0.745	2.194	1.995	163.4628	148.6602
Total	6882			1,939,386	1,450,123

Simulated crop yield data produced here for specific locations based on soil type, climate and access to ground water for supplementary irrigation reveal a number of critical points. Where access to water is assured, crop simulation indicates dry season crop production can have a superlative impact on the diets and incomes of rural small holders - particularly on those who only produce a single crop of rice during the wet seasons. Regionally too, a huge potential financial benefit may occur as a result of the multiplier effect, associated with increased regional spending derived from improved farm incomes.

This data too may benefit the formulation of policy by regional and national governments of the two countries in guiding future development, and in guiding research. Research conducted in the present project reveals locations where maximal dry season crop production may be anticipated, aiding in the prioritization of investments regarding enhancing access to key resources, as well as developing rules to ensure sustainable long term resource use. Also, simulated yields here identify that while maize yields reflect biophysical constraints, production of peanut and possible other crops are well below their potential, justifying strategic investment in research to address current yield gaps and in developing new methods that enhance farm productivity, reduce input costs and increase farm profits.

Objective two: Develop technologies and practices for improving water and nutrient management and mitigating soil limitations across the lowlands

Two research sites were established for the purpose of undertaking intensive replicated research aimed at applied knowledge generation with output to be transferred and tested in the field on key farms.

In southern Lao, research trials were established at Phone Ngam Rice Research and Multiplication Centre (PNG) (15^{o} 08' 14.97" N, 105^{o} 47' 13.78" E, elevation 101 m) 3 km to the north west of Pakse, Champassak Province. Phone Ngam station was selected as soils were very similar to soils endemic across the region, particularly those of NoneYang district. Key soil properties at the site are given in Table 7.3. Soil testing prior to trial establishment indicated that the soils were moderately to strongly acidic with comparatively moderate levels of exchangeable Al. Soil testing following liming showed liming had corrected pH in the 0-20 cm layer and reduced exchangeable Al to a level where it was unlikely to inhibit biological activity. Typical of soils across the region, levels of OM and CEC were miniscule indicating that the soils had little capacity to retain nutrients. Levels of inorganic NH_4^+ and P were very low and responded positively to basal fertilization at sowing.

Table 7.3 Key soil properties at trial site at Phone Ngam station in December 2015-16, pre- and post-liming and basal application of NPK fertilizer. Soil properties with prefix $_i$ were assessed prior to addition establishment of the research trials, and properties with prefix $_{ps}$ were analysed after mechanical preparation of the site, following incorporation of agricultural lime and after application of NPK fertilizer.

Depth (cm)	pH_i	pH_{ps}	OM %	$NH_4^+{}_i$ ppm	$NH_4^+{}_{ps}$ ppm	$NO_3^-{}_i$ ppm	$NO_3^-{}_{ps}$ ppm	P_i mg/kg	P_{ps} mg/kg	Ex Al_i Meq/100g	$ExAl_{ps}$ Meq/100g	CEC Meq/100g	BD g/cm^3	Texture
0-20	4.7	5.9	0.51	8.3	35.3	0.07	0.09	2.59	13.48	0.26	0.02	1.62	1.53	SL
20-40	5.1	-	0.28	5.7	-	0.08	-	.77	-	0.28		1.84	1.8	SL
40-60	5.25	-	0.23	3.7	-	0.07	-	0.8	-	1.38		3.5	1.78	SL

pH – soil pH 1:2.5 deionized water; P – Olsen P; CEC Cation Exchange Capacity; BD Bulk Density.

Research trials in Cambodia were established at the Cambodian Agricultural and Research and Development Institute (CARDI) located in Dangkor District, Phnom Penh

Province. Soils at CARDI were typical of the majority of rice growing soils across the region (Prateah Lang). Key soil properties at the site are given in Table 7.4. Soil testing prior to trial establishment indicated that the soils were slightly acidic necessitating lime incorporation prior to sowing. Like Lao, soils at CARDI had low levels of OM and negligible CEC and hence no capacity to retain nutrients. Levels of total N were low reflecting low levels of OM but levels of P prior to basal fertilizer addition were modest reflecting prior fertilizer applications at this site. Like Lao, soils at CARDI (0 – 40 cm) were sandy loam but had a higher bulk density close to the limit where plant roots were likely to be physically restrained.

Table 7.4 Key soil properties at research trial sites at CARDI station. Soil properties with prefix $_1$ were assessed prior to establishment of the research trials, and properties with prefix $_2$ were analysed post basal and topdressing fertilizer application and at the maize flowering stage.

Depth (cm)	pH_1	pH_2	OM %	OM %	TN_1 %	TN_2 %	P_i mg/kg	P_{ps} mg/kg	CEC Meq/ 100g	BD g/cm^3	Texture
0-20	5.3	5.7	0.9	0.75	0.05	0.03	7.33	19.13	1.15	1.66	SL
20-40	8.5	7.0	0.13	0.26	0.04	0.01	.52	1.17	0.84		SL
40-60	-	-8.2	-	0.18	-	0.01		0.5			
60-80	-	8.5	-	0.21	-	0.01		0.48			

P – Olsen P; CEC - Cation Exchange Capacity; BD- Bulk density.

At both sites, local climatic data was monitored and collected using automated weather stations. Daily reference evapotranspiration (ETo) was calculated at both sites using the FAO ETo calculator. Daily ETo in conjunction with crop coefficients (Kc), were used to calculate crop water use (ET) which was then used to calculate water requirements.

Experiment one 2015-16. – Determination of dry season crop water requirement

At both locations, experiments were run to determine water requirements for dry-season (DS) DS-Maize (Figure 7.3) and DS-peanut growing on a permanent bed furrow systems (Figure 7.4). Initial intentions of the research were to schedule water to the three treatments according to threshold water potentials (Ψ_m) measured at 15 cm depth in the centre of each bed. However, poor lateral movement of water through soil at each site impeded the measurement of Ψ_m by the water mark / gypsum block sensors. Accordingly, the three different levels of water use were achieved using different frequencies of watering (2 or 1 watering per week (W1 and W2 resp.), 1 water per 10 days (W3)). Water was applied to each plot for a given amount of time each time and the amount of water metered and recorded. In Lao, water amount was the only treatment applied where as in Cambodia, a second treatment was applied as a split plot; basal fertilizer dressing at the recommended rate F1 and at 1.5 x recommended rate (F2).

Figure 7.3: Experimental trial at CARDI (Phnom Penh, Cambodia) to evaluate the agronomical response of maize to three irrigation and two fertilisation treatments (left); and tensiometers used in the experiment (right). Note the tensiometers were used to provide secondary measures of soil water tension to validate readings observed by Watermark sensors.

Figure 7.4: Peanut trial conducted at Phone Ngam station, March 2016; note the difference in vegetation wilt between irrigation treatments.

Figure 7.5: Photos showing the poor lateral water movement from furrows into beds in maize at CARDI (left) and peanut Phone Ngam Station (right)

The three water treatments achieved markedly different amounts of water applied as intended (Figure 7.6). At CARDI, total water applied to maize over the crop growing season was 328, 276 and 251 for treatments W1, W2 and W3 respectively. The estimated seasonal crop water requirement for maize was approximately 296 mm which was met by treatment W1 and close in W2, whilst water supplied in W3 was considerably deficient. The total amount of water applied to bed sown peanut at PNG in Lao was 403, 236 and 149 mm for W1, W2, and W3 respectively. Estimated seasonal crop water requirements for peanut was 431 mm and while the water supplied by W1 was almost adequate, water supplied by W2 and W3 were well short of requirements.

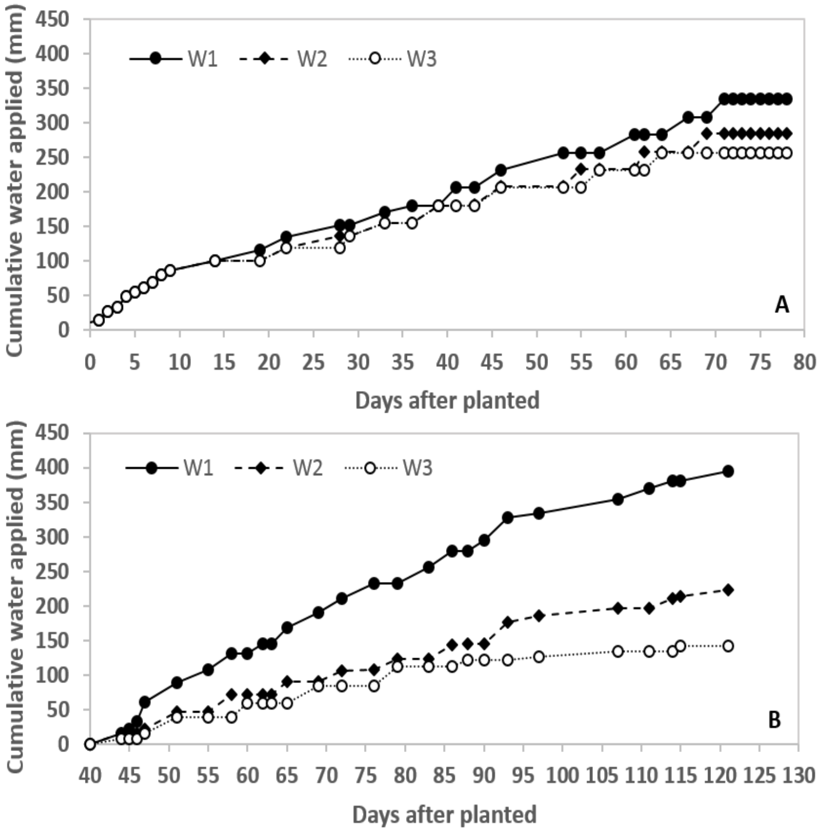

Figure 7.6 Average cumulative total irrigation (mm) applied to each irrigation treatment (W1, W2 and W3) of the DS Maize (A) and DS Peanut (B) studies.

In the DS-Maize trial, the volume of water applied significantly affected above ground biomass production at the vegetative stage and maturity where basically biomass production declined linearly with decreased frequency of irrigation. A similar trend was observed at flowering, but the effect could not be statistically validated. At harvest, mean grain yield ranged from 2.22 t/ha in the more frequently irrigated treatment (W1) to 1.43 t/ha in the least irrigated treatment (W3) but differences here could not be statistically validated. Fertilizer rate at sowing had no effect on biomass production at any time nor on final grain yield. Average values for water productivity for all irrigation treatments and at both fertilizer rates were similar (Table 7.5).

Table 7.5 Effect of water availability on above ground biomass production at three phenological stages and final grain yield by maize

	Above Ground Biomass (t/ha)			Grain Yield (t/ha)	Water Productivity
	Vegetative	Flowering	Maturity		
Irrigation	*	ns	*	ns	ns
W1	1.45a	3.52	2.81a	2.22	0.67
W2	1.10b	3.40	2.27b	1.72	0.60
W3	0.94b	3.13	1.96b	1.43	0.56
Fertilizer	ns	ns	ns	ns	ns
F1	1.07	3.26	2.32	1.69	0.58
F2	1.26	3.44	2.38	1.89	0.63
Irr x fert	ns	ns	ns	ns	ns

In the DS-Peanut trial, mean biomass production was similar amongst irrigation treatments at flowering, pegging and maturity such that at none of the sampling times, could a relationship between the volume of water applied and above ground biomass production be established. At harvest, the mean yield of peanut ranged from 1.75 t/ha in the higher frequency irrigation (W1) to 1.07 t (W3) which featured the least access to applied water. Interestingly, mean peanut yields were lower in W2 than in W3 despite – a direct explanation for this is not apparent but soil matric potential in this treatment was considerable lower than in W1 or W3 indicating that the beds were drier in W2 which may have affected crop yield potential. Apparent water productivity appeared higher in treatment W3 than in treatment W1 and W2 but the effect could not be statistically validated (Table 7.6).

Table 7.6 Effect of water availability and basal fertilizer rate on above ground biomass production at three phenological stages and final grain yield of peanut

	Dry Above Ground Biomass (t/ha)			Grain Yield (t/ha)	Water Productivity
	Flowering	Pegging	Pod development		
Irrigation	ns	ns	ns	*	ns
W1	0.48	1.55	3.30	1.75a	0.43
W2	0.30	1.30	2.60	0.87b	0.38
W3	0.40	1.52	3.04	1.04b	0.70

Experiment 2 – 2016-17. Soil interventions to improve lateral growth of roots and movement of water from furrows in sandy loam soils and DS-crop water requirements and fertilizer requirements.

At both locations, organic matter interventions were investigated for their potential to improve the lateral movement of applied water from furrows into beds, and to ease the lateral passage of roots through soil to aid plants in gaining access to water and nutrients. The organic matter intervention experiments were both designed to assess organic matter options that would be readily available to smallholder farmers in both countries but were tailored to meet particular country interests. In Lao organic interventions particularly involved the use of rice straw residues and cow and goat manures whereas in Cambodia, organic interventions rice straw and biochar-manure composites. Additionally, experiments were run to further assess water and fertilizer requirements for DS-Maize at

CARDI and to assess optimal fertilizer placement for DS-peanut growing on a permanent bed furrow systems in Lao. At CARDI, two experiments were undertaken; experiment one assessed yield implications for reduced access to water; experiment two was a two factorial experiment to assess the impact of organic matter interventions and the effect of two levels of basal fertilizer application at sowing on maize production. In Lao, one, two factorial experiment was conducted to assess the impact of organic matter interventions, and fertilizer placement on above and below ground biomass production and yield of peanut.

Water requirement of DS – Maize (CARDI)

In this experiment, maize was sown (13/01/17) on beds in a bed furrow system (Figure 7.7) both with and without incorporated rice straw and after establishment was irrigated at 100, 75 or 50% of calculated evapotranspiration from flowering to maturity taking into account crop growth factors. Unlike the previous year, substantial rain fell during the crop growing season (125 mm) requiring less applications of water. As consequence, 100-ET_c treatment received 176 mm, 75-ET_c received 156 mm, and 50-ET_c received 136 mm of applied water.

Figure 7.7: Maize grown in a traditional bed/furrow system designed to determine crop water requirement (Experiment 1) at CARDI.

Harvest occurred on April 4 2017. Apparent average fresh stem and cob weights were highest in the 100-ET_c treatment compared to the 75- and 50-ET_c treatments but differences could not be statistically validated for fresh stem weights. Interestingly, fresh cob weights were similar between the 100- and 75-ET_c treatments 2.90 and 3.01 t/h respectively and significantly higher than the 50-ET_c (2.8 t/ha) treatment (Table 7.7). No significant differences were observed with grain yield between water treatments. Average grain yield of maize growing under the 100-ET_c treatment was 2.29 t/ha, which was similar to maize yields (2.20 t/ha) in the frequently irrigated treatment in the previous year. Across this experiment for each sampling, average grain yield for all treatments was 1.78 t/ha which was similar to average grain yield observed at this site across treatments in the previous year (1.79 t/ha). Early on, the inclusion of incorporated rice straw seemed to enhance crop emergence but otherwise had no observable effect on maize biomass or grain production

Table 7.7 Effect of three levels of applied water, with and without incorporated rice straw on fresh weight of stems, cob and final grain yield on DS-maize.

	Stem Fresh weight (t/ha)	Cob Fresh Weight (t/ha)	Grain yield (t/ha)
Irrigation	ns	*	ns
100-ET_c	1.95	2.90	2.29
75-ET_c	1.68	3.01	2.20
50-ET_c	1.44	2.38	1.81
Straw	ns	ns	ns
Straw incorporated	1.46	2.67	2.20
No Straw	1.92	2.85	1.99
Irrigation x Straw	ns	ns	ns

Effect of organic matter interventions and basal fertilizer application DS-Maize CARDI

In this experiment, organic amendments and fertilizer treatments were begun several days before sowing. Organic treatments were: (T1) no organic addition, (T2) 10 t/ha rice straw banded at 10 cm before bed forming, (T3) 10 t/ha rice straw incorporated before bed forming and, (T4) Biochar/manure 10 t/ha banded and buried at bed forming and basal fertilizer treatments were: recommended rate (F1) and at 1.5 x recommended rate (F2). Crop emergence was greater in T1 and T4 than in T2 and T3 due to heavy rain after sowing and inundation of some beds and plots. As a consequence, locations where germination had not occurred were re-sown about 12 days later. Note: in plots where re-sowing had occurred, the development of re—sown maize plants were behind in regards to plant height and biomass production throughout the remainder of the season.

After sowing, crops were hand watered for two weeks after which water was applied by furrow irrigation at the rate matched to 100-ET_c, taking into account crop factors until flowering and then at 75-ET_c until maturity. Soil water content (0-80 cm) was monitored in real time using central bed mounted multi-sensor capacitance probes (Entelechy Pty Ltd, Golden Grove, SA, Australia) with sensors at 10 cm intervals and soil water tension across the beds was monitored using sets of 3 gypsum blocks (Watermark 200SS, Irrometer Company Inc., California, USA) buried at 15cm laterally across the bed from the furrow, to the centre of bed. In this experiment, organic interventions were accessed regarding their influence on lateral water movement from furrows, above and below ground biomass production, soil resistance and plant biomass production and grain yield.

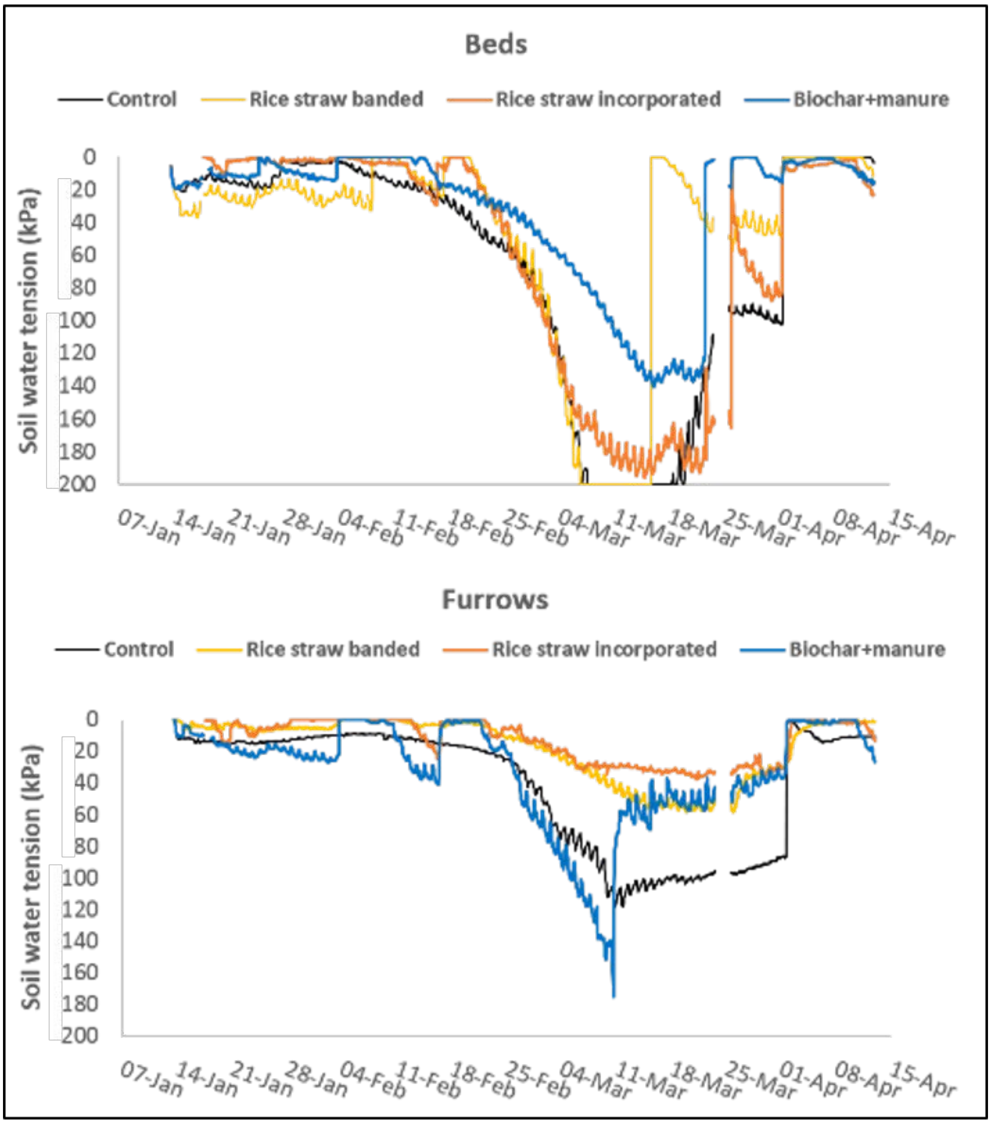

Figure 7.8: Soil water tension recorded in beds and furrows throughout the season in the four amendment treatments assessed.

Soil moisture data showed that as the season progressed, soil water content was lower in the deeper profiles (0-40 cm depth) of treatments T1 and T4 than in T3 and T2 treatments, particularly later in the season. This was most likely because T2 and T3 had the lowest germination rate, and despite re-sowing, differences in plant size between sown and re-sown plants remained throughout the season affecting crop water use (see shoot dry biomass in Table 7.8). As a consequence, toward the end of the season, when plants were irrigated at 75-ET_c, soil water depletion was greater in the T1 and T4 treatments compared to the T3 and T2 treatments, where plants were smaller and water consumption was subsequently lower.

Since soil water tension sensors were limited to one per treatment (furrow, edge and middle of the beds), lateral movement of the water from the furrow to beds could not be statistically established. Comparison between treatments of the soil water tension in beds, however, showed that rice straw incorporated into the soil (T3) and especially biochar mixed with manure (T4) seemed to retain a higher level of soil moisture during the whole growth season compared to T1 and T2 (Figure 17). Sensors showed that soil water tension remained lower in furrows in all the treatments compared to the edge or middle of the bed. Taking this further, in early March the soil water differential between the furrows and beds was least for the treatment with incorporated manure and biochar in contrast to the banded (T2) or incorporated rice stubble (T3) which indicated that treatment T4 may have been more effective in allowing lateral water movement. This indicated that organic (banded rice straw) intervention T2, which was intended to promote the formation of lateral bio-channels in order to improve hydraulic conductivity, was not successful in enhancing lateral water movement.

Total biomass harvest were conducted for each plot on four consecutive dates through the growing season. Across all the treatments and at each sampling date, maize roots were typically shallow, between 15 and 30 cm deep, and made up mainly of primary roots (Figure 7.9). However, some plants produced adventitious roots emanating from the stem. Associated with the primary roots there were some lateral roots radiating out from individual plants of varying lengths up to 25 cm. Root biomass assessment showed that plants from the T4 treatment had the highest root dry mass at harvest (April 10th) although no statistically significant differences were found with respect to the other treatments. No significant differences were obtained in root dry mass either between fertiliser treatments.

Figure 7.9: Maize root structure in a plant sample from the treatment: (A) T1, control; (B) T3, straw banded; (C) T2, straw incorporated into the soil, and; (D) T4, manure/biochar. Note in the straw banded and the manure/biochar treatments (B and D, respectively), the photos show evidence of the residue organic matter interventions.

Except at the final biomass harvest, aboveground biomass was unaffected by organic amendments. At the final harvest, above ground biomass for the two straw treatments (T2 & T3) were considerable less than T4 and statistically less than T1 and followed a similar trend between treatments as established earlier. Two explanations exist which may explain this phenomena. As previously suggested, treatments T2 and T3 had required replanting and a gap in stage of development persisted between these plants and plants in treatments and T1 and T4 over the duration of the experiment which was statistically validated at the final biomass harvest. Alternately, these treatments involved amendment with 10 t/ha high C:N rice straw which is likely to have immobilized inorganic nitrogen, limiting its availability to the maize plants in these treatments.

Soil resistance measurements taken with a penetrometer at three different times during the season showed resistance to be generally higher in the treatment with no amendments (T1) than in treatments with straw or biochar mixed with manure banded or incorporated into the soil (Figure 7.10).

While reduced resistance associated with the organic amended treatments may have eased the movement of individual roots, it seemed to have little influence on overall below ground biomass production (Table 7.8).

At harvest, no significant differences were observed in stem fresh weight among amendment treatments or between fertiliser treatments (Table 7.9). However, cob fresh weight in T1 and T4 was significantly higher than that obtained in the T2 treatment and in the F2 program (135N; 90P2O5; 45K2O) than in the F1 (90N; 60P2O5; 30K2O). Treatments with the highest cob fresh weight had the highest grain yield, that is T1 and T4 among the amendment treatments and the F2 fertiliser program, with significant differences with the remaining treatments. Additionally, no organic amendment had any influence on the ratio of grain wt/stem FW, but greater fertilization at sowing (F2) significantly promoted grain yield in relation to stem FW. These results suggest that, as observed for the aboveground biomass, the larger number of plants had to be re-sown in the T2 and T3 treatments in comparison to the T1 and T4 treatments may have been a contributor to lower grain yields in these treatments. The high C:N amendments associated with these treatments may additionally have caused N tie-up contributing to the lower grain yield associated with these treatments.

Table 7.8 Maize root and shoot production as a function of organic matter treatment and fertilizer rate.

	Dry Root Biomass				Dry Shoot biomass			
	9-Feb	7-Mar	27-Mar	10-Apr	9-Feb	7-Mar	27 Mar	10 Apr
Amendment	ns	ns	ns	ns	ns	ns	ns	*
T1	1.35	9.50	8.67	4.47	5.38	70.50	87.00	108.8b
T2	0.85	10.50	10.17	4.67	3.02	43.17	60.83	47.9a
T3	1.13	11.33	11.00	2.64	2.93	46.83	67.33	46.6a
T4	1.22	10.83	11.83	8.14	3.43	71.33	107.83	79.2ab
Fertilizer	ns	ns	ns	ns	ns	ns	ns	ns
F1	0.84	9.25	12.25	4.78	2.59	49.33	77.92	64.86
F2	1.43	11.83	8.58	5.17	4.79	66.58	83.58	77.90
Amendment x fertilizer	ns	ns	ns	ns	ns	ns	ns	ns

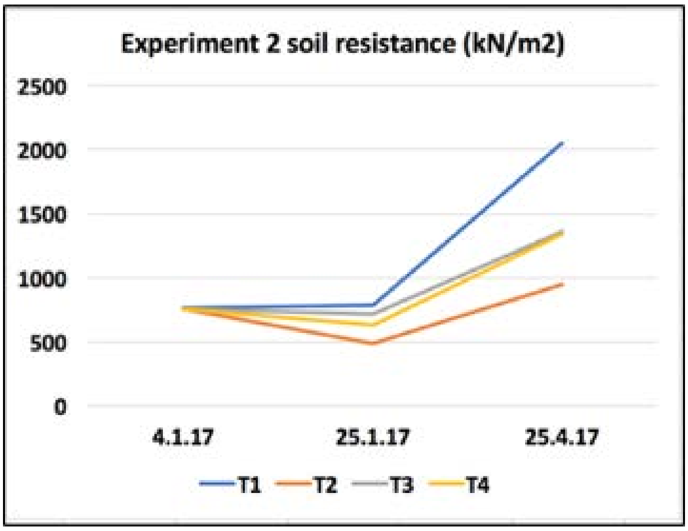

Figure 7.10: Changes in soil resistance (kN/m^2) over the growing season for the amendment treatments applied in Experiment 2. T1: no soil amendment; T2: straw banded; T3: straw incorporated, and; T4: biochar mixed with manure.

Table 7.9 Fresh weight (FW) of stem and cob (t/ha) at harvest, grain yield (t/ha) and harvest index.

	FW cob	FW stem	Grain yield	Grain Yield/FW Stem
Amendment	*	**ns**	*	**ns**
T1	3.90 **b**	2.75	1.94 **a**	0.75
T2	2.23 **a**	2.79	1.40 **b**	0.53
T3	2.93 **ab**	2.47	1.37 **b**	0.56
T4	3.82 **b**	3.24	1.98 **a**	0.62
Fertilizer	*	**ns**	*	*
F1	2.64	2.84	1.45 **a**	0.53
F2	3.80	2.78	1.90 **b**	0.70
Amendment x Fertilizer	**ns**	**ns**	**ns**	**ns**

ns denotes not significant and * significant at $p \leq .05$. Different letters within a column denote significant differences between treatments (Tukey).

Effect of organic matter interventions and fertilizer placement on DS-Peanut (PNG)

In establishing this experiment, site preparation and organic amendments were applied several days before sowing (Figure 7.11). Organic treatments were: (S1) no organic addition, (S2) 5 t/ha rice straw banded at 10 cm as part of bed forming and (S3) 5 t/ha of goat/cow manure surface spread before bed forming. At sowing (8/12/16), fertilizer treatments were commenced at a rate equivalent to 156 kg (15:15:15 NPK)/ ha: (F1) fertilizer banded at 2.5 cm depth in the middle of the bed and, (F2) fertilizer banded along the edge of the bed slightly offset from the seeding row. Poor emergence counts were also observed on 19/12/2016 and so locations where emergence had not occurred were re-sown. After sowing, plots were hand watered until well established after which furrow irrigation commenced, with 13.9 mm applied to each plot twice weekly.

Figure 7.11: Establishment of the trial at PNG during the 2016-17 dry season with detail of bed formation, irrigation system and dataloggers, manure treatment and rice straw treatment.

Mid-bed soil water tension was monitored using gypsum blocks installed at 15 cm depth in the middle of the central bed in each organic matter treatment in each replicate but only in F1. Additionally, three gypsum blocks were buried at 15cm laterally across the bed from the furrow, to the centre of bed in replicate two of the S1 and S2 to gain some appreciation of whether buried straw could enhance lateral water movement. In this experiment, organic interventions were assessed regarding their influence on lateral water movement from furrows, above and below ground biomass production, plant biomass production and grain yield.

Over the growing season, three large, unseasonable, rainfall events occurred; 21-28 January ~ 326 mm; 3-14 February ~340 mm and 16-25 March ~471 mm with the total rainfall over the season being 1171 mm. Including irrigation, the amount of water available to the crop was 1453 mm. Calculated ET over the season was 474 mm. Frequent rainfall events over the early and latter part of the season was attributed to the low average soil water tension recorded from the commencement of the trial to about the 20 January which coincided with the crop vegetative stage, and about the 20-21st of March corresponding to pod formation and maturity (Figure 7.12). The period of flowering , pegging and pod formation occurred during the period from early February until late March, and during this period, soils dried out fairly rapidly with minimal response to irrigation events or early February rainfall when soil water tensions of all treatments reached 240 kPa (Figure 7.12).

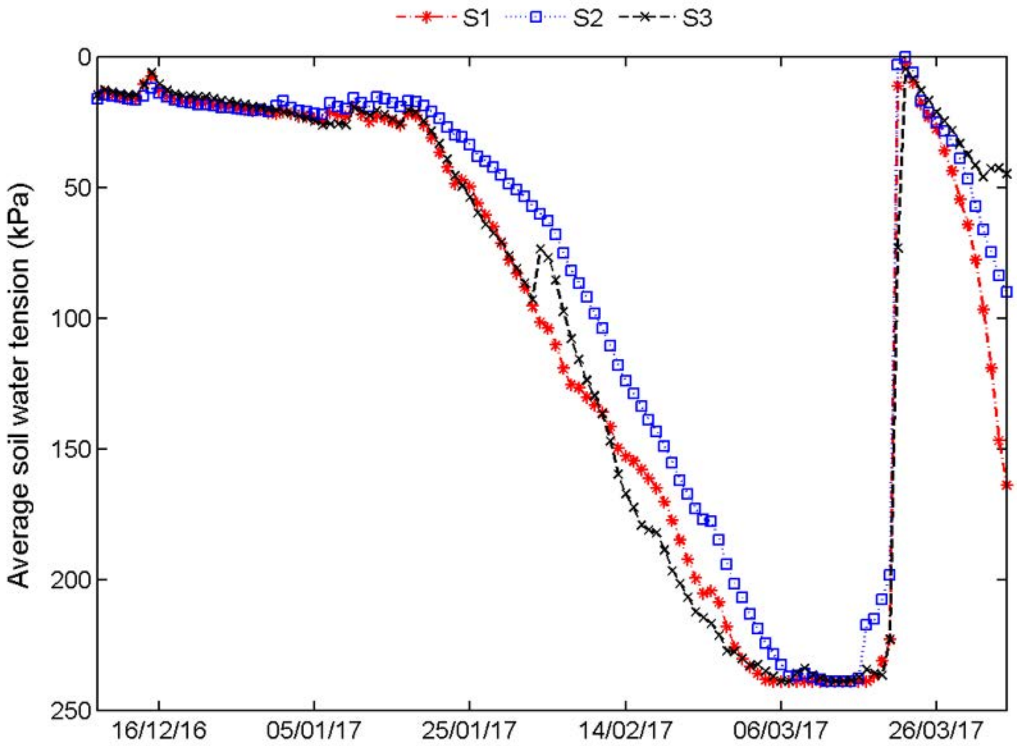

Figure 7.12: Average soil water tension (kPa) for each soil treatment (S1, S2 and S3) recorded at 15 cm depth.

The lack of response to irrigation during this periods highlights the severity of the physical constraint to lateral movement of water and root growth in these physically imperfect soils, as reflected by the fact that the soil/furrows needed to ponded before the soil moisture sensors recovered. However, the soils quickly dried out again, particularly in the control treatment. During the drying phase between early February and late March when the soils dried, while there were no significant differences between treatments regarding mean soil water tension, the treatment where rice straw had been buried (S2) seem to be at a consistent lower soil water tension than in the control (S1) or in treatments where only manure had been surface applied (S3), indicating that the addition of a buried straw layer had intercepted the upward flux of water from the deeper soil, reducing its loss by evaporation.

Analysis showed that there was a significant difference in above ground biomass between soil amendment treatments at 50 % flowering and 50 % full pod development. Manure-amended soils (S3) had significantly greater biomass compared to where rice straw had been banded and where no organic matter had been applied (Table 7.10). However, this difference was not apparent at harvest, and at no stage did fertiliser placement have any effect on above ground biomass. On reflection, this finding is unsurprising as these soils typically have negligible levels of organic matter nor clay and hence minute CEC's. As a result, they are dependent of fertilizers for most nutrients to drive net primary production. As T3, in addition to applied mineral fertilizers had 5 t/h of animal manure applied, the mineralization of this was likely to supplement the peanut crop, supplying particularly the nutrients P and S (less likely N due to their N-fix capacity) which may have bolster T3 plants access to otherwise scarce nutrients.

Table 7.10 Effects of soil amendment and fertiliser placement on aboveground biomass development (t/ha).

ABV (t/ha)	Flowering	Full pod	Harvest
Soil	*****	*****	***ns***
S1	2.75**a**	5.33**a**	7.37
S2	2.51**a**	5.22**a**	7.66
S3	4.42**b**	6.44**b**	7.34
Fertiliser	***ns***	***ns***	***ns***
F1	3.32	5.50	7.41
F2	3.13	5.83	7.51
Soil:Fertiliser	***ns***	***ns***	*****

ns denotes not significant; * significant at $p \leq .05$. Different letters within a column denote significant differences between treatments (Tukey-Kramer).

In addition to destructive above ground harvests at flowering, pod formation and harvest, a plant in each plot was destructively harvested at similar stages to evaluate above and below ground biomass, and reproductive tissue development. On each occasion, roots were carefully excavated to depth to reveal root architecture, maximum rooting depth and extent of lateral root development (harvest 1 and 3) and to recover all roots and reproductive parts.

Figure 7.13: Plant from the manure (left), straw (middle), and control (right) treatments.

Across all treatments, peanut roots were typically shallow, between 15 cm and 35 cm deep with lateral roots radiating out from individual plants up to 60 cm (Figure 7.13). At no sampling date did organic matter addition nor fertilizer placement statistically affect above nor below ground root biomass (Figure 7.14). However, Figure 7.14 indicates that later in the season (22/03/17) coinciding with full pod development, the dry weight of shoots and roots of S3, appeared to be considerably greater than in S2 and S1, similar to the findings from the above ground biomass assay.

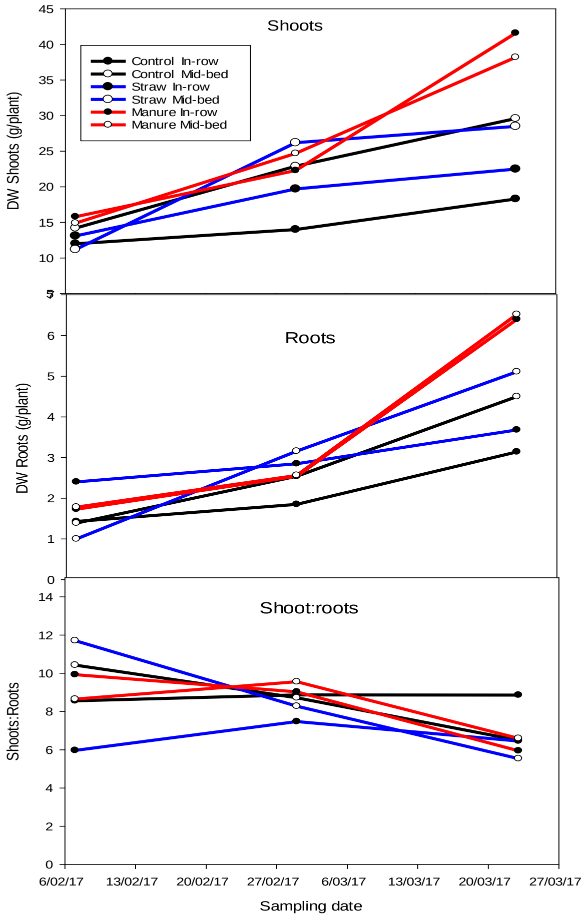

Figure 7.14: Total biomass of peanut shoots, roots and partitioning of biomass between shoots and roots as a function of organic amendment and fertilizer placement during vegetation, mid-reproductive and maturity at PNG during 2017.

The partitioning of carbohydrate between shoots and roots at each sampling remained relatively constant at a ratio of about 8:1 for the three sampling periods. This ratio was not significantly influenced by organic amendment nor fertilizer placement (Figure 7.14), indicating that none of the treatments altered the ratio of biomass partitioning between shoots and roots. However, the length of subsurface lateral roots was statistically greater in the buried rice straw treatment (S2) than in the control (S1) or the manure treated plots (S3) (Figure 7.15). Buried rice straw treatment was included in this study as it was thought that straw residues in this zone might provide a plane of weakness in the bed to encourage development of lateral roots. Observations made at both samplings indicated that roots appeared not to populate the buried straw layer but instead, populated the interface between the straw layer and the soil layer either above or below the buried rice layer. The avoidance of roots to this zone could be due to a lack of mineralizable nutrients in this zone due to microbial decay of the high C:N of rice residues, or the production of decay products that may inhibit peanut root growth in this layer. None the less, the stimulation of lateral roots by this intervention could be a mechanism to enable these plants to grow more roots to provide further access to nutrients and water.

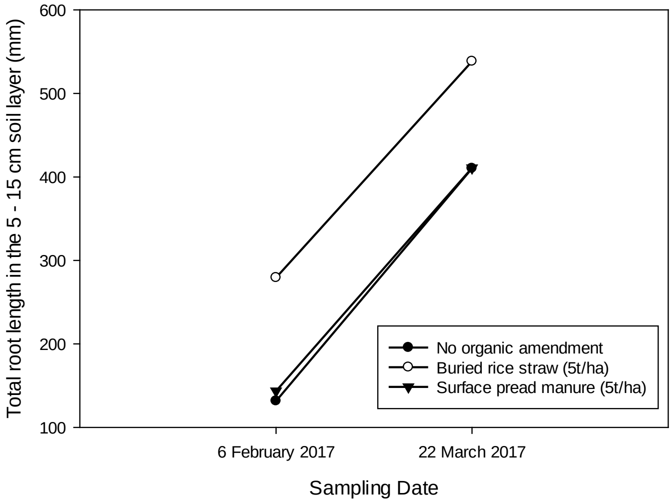

Figure 7.15: Total lateral root growth of peanut plants growing in organic matter amended soils**.**

As a generalisation, the application of manure enhanced both shoot and root biomass in peanut at the final sampling date (full pod stage) (Table 7.10; Figure 7.14), which probably reflects the poor nutrient status of the soil despite the addition of chemical fertiliser at sowing.

Whilst there was no significant difference between soil amendment treatments in above ground biomass development (Table 7.10), of the three organic amendment treatments, there was a significant difference in mean pod and grain yield between the control (S1) and the straw treatment (S2); the mean pod and grain yield of the manure treatment (S3t/ha) did not differ significantly from either of the aforementioned treatments (Table 7.11). Despite no effect on crop biomass at harvest, the reduction in grain yield associated with the buried straw treatment could be due to the induced nutrient deficiency that could occur in soil due to the breakdown of the high C:N rice straw.

Table 7.11 Effects of soil amendment and fertiliser placement on pod and peanut grain yield (t/ha).

Yield (t/ha)	**Pod**	**Grain**
Soil	**	*
S1	2.03**a**	1.07**a**
S2	1.45**b**	0.77**b**
S3	1.68**ab**	0.87**ab**
Fertiliser	***ns***	***ns***
F1	1.71	0.91
F2	1.72	0.89

Soil:Fertiliser	*****	***Ns***

ns denotes not significant; * significant at $p \leq .1$; ** significant at $p \leq .05$. Different letters within a column denote significant differences between treatments (Tukey-Kramer).

Experiment 3 – 2017-18 Alternative irrigation strategies to improve bed wetting and plant access to applied water and organic amendments to improve water movement and lateral growth of roots.

In both countries, following on from previous research that showed poor lateral water movement from furrows, experiments were designed to assess alternative methods of water application to improve plant access to water. Additionally, further investigations were conducted on the effect of organic amendments to improve lateral movement of applied water and lateral passage of roots through soils. At CARDI, a single factorial experiment was conducted featuring three methods of irrigation as the main treatment and three soil organic amendments established as a randomize block experiment with three replications. In Lao, two randomized block experiments with three replicates were conducted; the first investigating the effects of four alternative irrigation methods on peanut biomass production and grain yield and the second, examining the effect of three organic matter interventions on above and below ground biomass production and grain yield.

Effect of irrigation methods and organic amendment on DS-Maize production - CARDI

In this experiment, three irrigation methods were investigated along with three organic amendments (Figure 7.16). Water application methods trialled were standard furrow irrigation, sprinkler irrigation and over bed irrigation, where beds, within a bunded system were flooded for 30 minutes to ensure water could get to the centre of beds but then drained to prevent crop waterlogging. Irrigation methods were tested in combination with either rice straw, manure and biochar, or where no organic amendment was applied. Prior to bed formation, the site was levelled and organic treatments applied followed by fertilizer application and sowing on the 24 January 2017. As in previous years, soil water tension were determined continuously in all subplots at a depth of 15 cm and soil water content was determined to a depth of 55cm in plots associated with two of the three replicates in the control and rice straw amended plots. During the season, soil penetrometer resistance were measured. Date of flowering, above and below ground biomass development was assessed over the period of flowering – maturity on up to five occasions. At harvest, plant height as well as fresh cob weight and grain yield were determined.

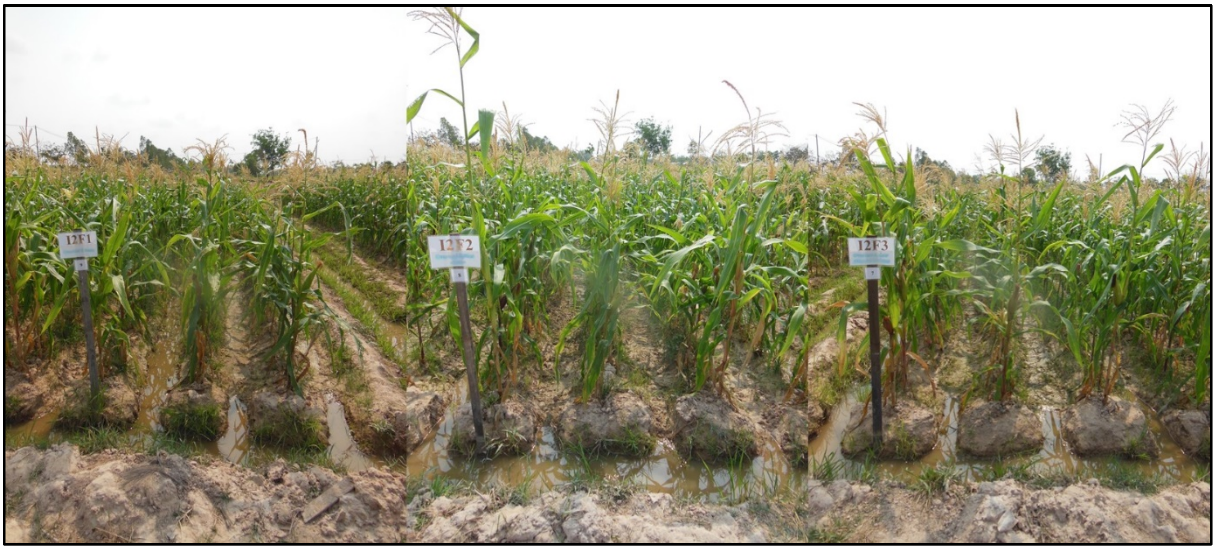

Figure 7.16: Maize crop growing at CARDI with the overbank method of irrigation and with three organic amendments. Left no organic addition; centre buried rice straw; right buried biochar/manure.

The 2018 growing year was markedly drier than the previous year. Total ETo and rainfall values recorded during this period were 544 mm and 39 mm. Average cumulative water applied to the furrow-irrigated and sprinkler-irrigated treatments were 236 ± 20 mm and 209 ± 16 mm respectively (Figure 7.17).

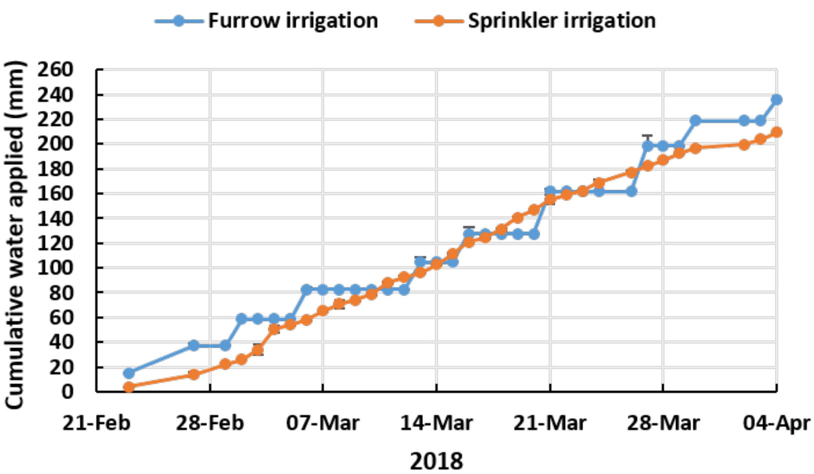

Figure 7.17: Average cumulative water applied to the furrow and sprinkler irrigation treatments during the maize growing season at CARDI. Vertical bars indicate the standard deviation (n = 3).

Bulk density at 0-20 cm was significantly affected by both irrigation and organic amendments. Treatments, in which water was applied over the bed (sprinkler and over-bed irrigation) had statistically higher bulk densities at the 0-20 cm soil profile (1.42 and 1.38 Mgm^{-3} respectively) compared to furrow irrigated plots (1.21 Mgm^{-3}). Rice straw amended plots had the lowest bulk density (1.26 Mgm^{-3}) which was statistically different to the non-amended plots (1.39 Mgm^{-3}).

Soil water tension in the over-bed and sprinkler-irrigated treatments was higher than in the furrow-irrigated plots, indicating that there was less soil moisture in the former treatments in spite of plots being watered regularly (Figure 7.18).The application of rice straw and biochar/manure amendments prior to sowing enhanced in-general soil moisture retention (Figure 7.18). This effect was more marked in the treatment with rice straw banded and buried at 10 t/ha for all the replicates within the furrow-irrigated treatment, which had the lowest soil water tension values over the season.

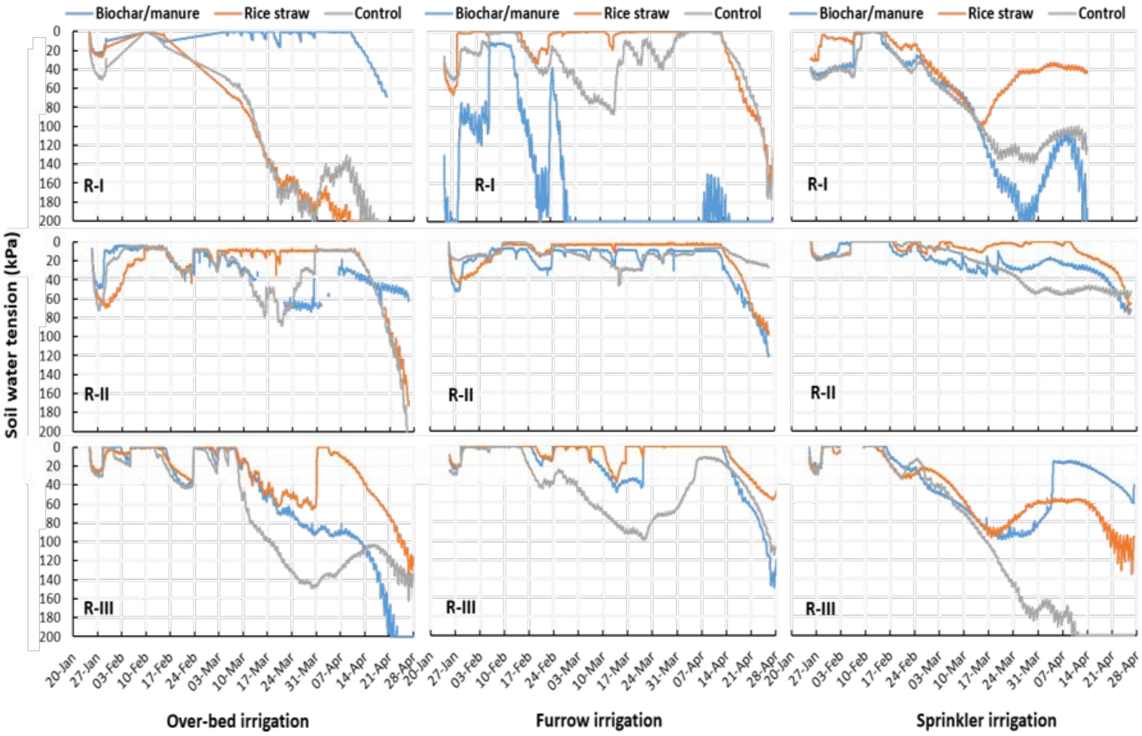

Figure 7.18: Soil water tension recorded during the growing seasons in all subplots within each irrigation treatment.

Soil penetration resistance in the top 20 cm of the soil profile ranged between 1000 and 2500 KN m^{-2} (Figure 7.19). As in the previous season, treatments featuring rice straw banded and buried in beds tended to show the lowest soil strengths which was statistically validated on 19 February and 1 March 2018. All the treatments showed similar values at 20-40 cm depth. We speculate that the reduction in soil strength was due to the presence of organic residues preventing the soil from forming a thick cemented layer.

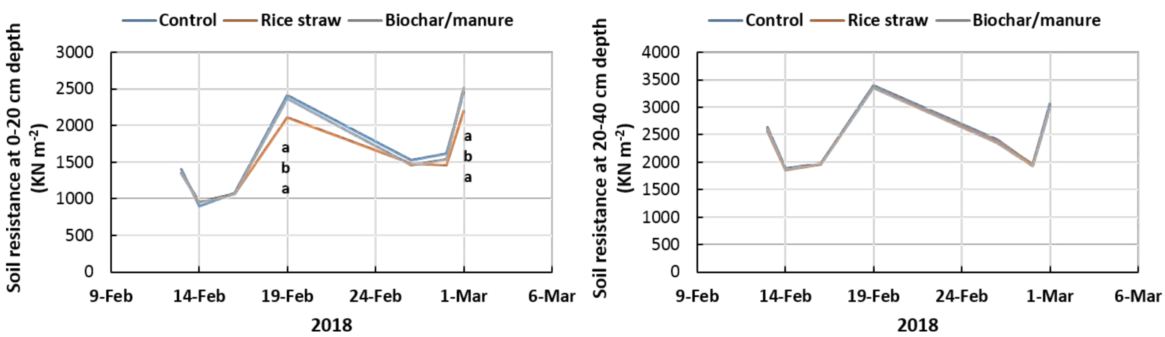

Figure 7.19: Average soil penetration resistance for the amendment treatments over the growing season. Different letters within a date indicate statistically significant differences ($p < 0.05$). Top, middle and bottom letters correspond to the control, rice straw and biochar/manure treatments, respectively.

Flowering was delayed by two days in the over-bed irrigation treatment compared with the furrow and sprinkler irrigation treatments. While full bloom in the furrow and sprinkler-irrigated plots was reached on 12 March 2018, it was not until 14 March when the same was observed for the over-bed irrigation treatment. Assessment of root and shoot biomass within the furrow-irrigated treatment from flowering to harvest did not show any significant difference in root or shoot dry weight, shoot to root ratio, root depth nor roots system width as a function of soil organic amendments (Table 7.12)

Table 7.12 Above (SW) and below (RW) ground biomass production (g plant^{-1}), shoot/root ratios (S:R), maximum depth (cm) and width (cm) in each of the furrow-irrigated treatments.

	Flowering (5/3/18)					Cob formation (29/3/18)					Maturity (19/4/18)				
	RW	SW	S:R	Depth	Wide	RW	SW	S:R	Depth	Wide	RW	SW	S:R	Depth	Wide
Control	13	37	3.1	31	26	21	112	7.7	36	46	8.7	142	18.2	26	38
Rice Straw	8.3	29	3.6	29	27	18	123	7.7	33	40	9.7	85	9.7	21	28
Manure and Biochar	11	34	3.0	33	27	15	115	7.7	31	33	10.3	131	12.7	28	32

In contrasting irrigation treatments, aboveground biomass and plant height at harvest in plants from the over-bed treatment were significantly lower than in the furrow and sprinkler irrigation treatments (Figure 7.20 and Table 7.13). On the later sampling date, maize plants from the treatment amended with a mix of biochar and manure had the highest aboveground biomass with statistically significant differences recorded between this and the treatment amended with rice straw.

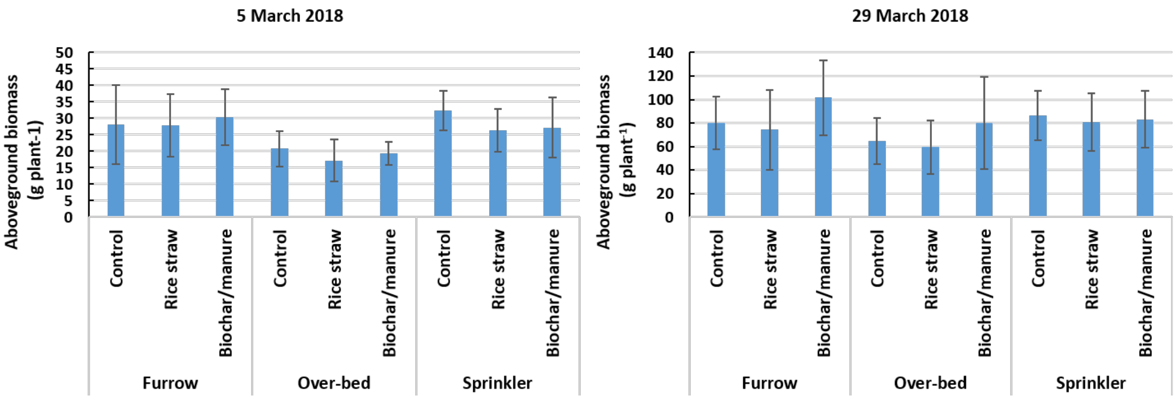

Figure 7.20: Aboveground biomass for the amendment and irrigation treatments on 5 March 2018 (flowering) and on 29 March 2018. Vertical bars indicate the standard deviation (n = 12).

Table 7.13 Impact of irrigation and organic soil amendments on the height (cm), grain yield (t/ha) and water use efficiency (WUE, kg ha^{-1} mm^{-1}) of maize plants at harvest.

	Plant height	Grain yield	WUE
Irrigation	*	Ns	*
Furrow	167.56**a**	2.07	8.76
Over-bed	140.83**b**	1.81	-
Sprinkler	162.50**a**	2.23	10.62
Amendment	ns	Ns	ns
Control	157.22	2.00	9.67
Rice straw	161.56	1.87	9.05
Biochar/manure	152.11	2.11	10.35
Irrigation x Amendment	ns	ns	ns

Apparent grain yield appeared lower in the over-bed treatment compared to other treatments but the difference could not be statistically validated. The lower apparent yield in the over-bed treatment could have been exacerbated by lower aboveground biomass. Similar results were obtained for the amendment treatments. The application of biochar and manure produced the highest grain yield (2.11 t/ha), which on average was respectively 5% and 11% higher than in the control and rice-straw amendment treatments, and had the greatest apparent WUE although with no statistically significant differences between treatments (Table 7.11). Comparison of the WUE between the sprinkler and furrow irrigation treatments, where the amount of water applied was monitored for each plot individually, showed that with 10.62 kg ha^{-1} mm^{-1}, WUE was significantly higher in the sprinkler-irrigated plots (Table 7.11).

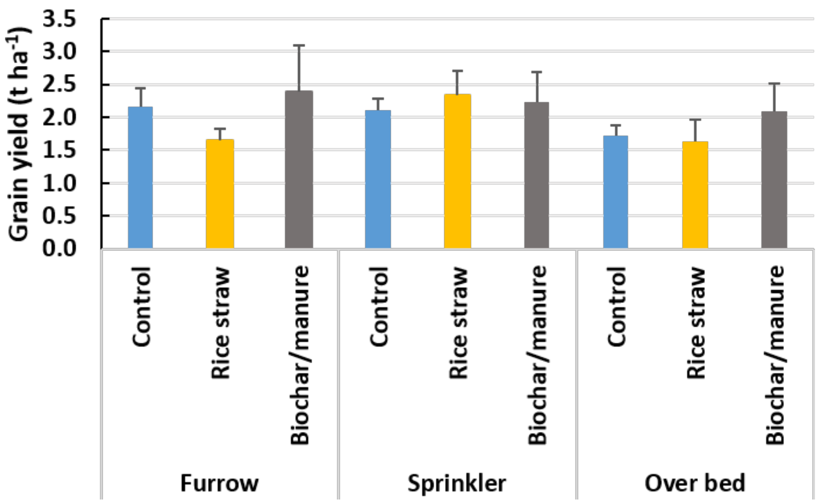

Figure 7.21: Average grain yield for the amendment treatments within each irrigation system assessed. Vertical bars indicate the standard deviation (n = 3).

Effect of irrigation methods and organic amendment on DS-Peanut production

Two experiments were established at PNG over the 2017-18 dry season. Experiment one evaluated four different bed configurations and water application methods to improve access of peanut to applied water: Experiment 2 featured an organic amendment trial to improve lateral water movement and root development.

Experiment 1 was a single factor, randomised block design with three replicates investigating the following treatments: (I1) a conventional bed/furrow system with furrow irrigation; (I2) flat bed with sprinkler irrigation; (I3) – conventional bed/furrow system with sprinkler irrigation; and (I4) narrow beds (ridge/furrow) with furrow irrigation (Figure 7.22). Experiment 2 was a single factor, randomised block design with three replicates, with the following treatments: (S1) no organic amendment (control); (S2) – incorporated manure (20 t/ha) and buried straw (5 t/ha); (S3) – Incorporated manure (20 t/ha) (Figure 7.23).

Prior to establishment of both experiments, the field was ploughed to incorporate any remaining crop residue and levelled, lime (100 g m^{-2}) was incorporated using a tractor powered rotary hoe following which the treatments were established and beds formed. Following site establishment, peanut variety L23 were sown on 7 December 2017 and fertilizer (15:15:15 NPK) banded in a row along the centre of each bed at the rate of 156 kg ha^{-1}. Poor emergence following sowing necessitated resowing of the site on the 25 December 2017 using a more vigorous local peanut variety. Following sowing the site was hand watered for 2 weeks after which the appropriate method of irrigation was established on 10 January 2018, three times per week.

Phenological stages of development were recorded, above ground biomass production and % canopy cover were monitored regularly (experiments 1 & 2) whilst root biomass and root length were measured on three occasions: 06 & 07 February 2018 (~ 43 DAS); 01 & 02 March (~ 65 DAS); and 28 & 29 March (~93 DAS). At final harvest (30 March 2018) the above ground biomass yield components fresh weights were recorded.

Only one significant rainfall event (21.6 mm) occurred over the crop growth season, over the period 13-16 March. The modest daily maximum VPD of under 4 kPa indicate that evaporative demand during the season was not particularly high, consistent with the average daily value calculated to be 3.9 mm as in 2017 (Annual Report SMCN 2012/071).

Experiment 1: Effect of layout and Irrigation method on access to soil water by DS-peanut.

Both furrow irrigated treatments I4 and I1 received significantly greater amounts of applied water (422.7 and 405.2 mm resp.) than did sprinkler irrigated treatments I2 & I3 (308.4 and 315.1 mm resp.). These differences were an artefact of the irrigation design, bed layout and irrigation method, with sprinklers delivering less water over the same time period as the furrow irrigation system. Soil water tension was monitored regularly over the season in each plot using Watermark sensors installed at a depth of 15 cm. Average soil water tension for each treatment showed three apparent groupings (Figure 7.24). The sprinkler irrigated treatments (I2 and I3) maintained a drier soil for the entire season with average tensions over 200 kPa occurring from pegging until harvest. This higher average soil water tension was ascribed to less water applied to these treatments. The two furrow irrigated treatments maintained more moist soil conditions throughout the majority of the season with the top 15 cm of soil in the narrow bed treatment (I4) maintaining a lower soil water tension in the same zone than in the conventional bed treatment (I1). The lower soil water tension in I4 was ascribed to slightly greater amount of water applied and difference in bed geometry between I1 and I4. In I4 treatment, twice the number of furrows along with narrow beds meant that water could laterally transverse the narrower bed from two directions to get to the seeding row in contrast to the conventional beds treatment (I1). As a consequence, the sensor (and plants) growing in the narrow bed received more water than the sensors mounted in seeding row of the conventional bed.

Figure 7.22: The effect of water application method on peanut production at Phone Ngam Station: Peanut grown on conventional beds, furrow irrigated (left); peanuts growing on narrow beds, furrow irrigated (centre); peanut grown on flat (no beds) sprinkler irrigated (right). Note: in centre of both narrow bed and in the flat (no bed) system, peanut growth suppression due to water ponding on each plot.

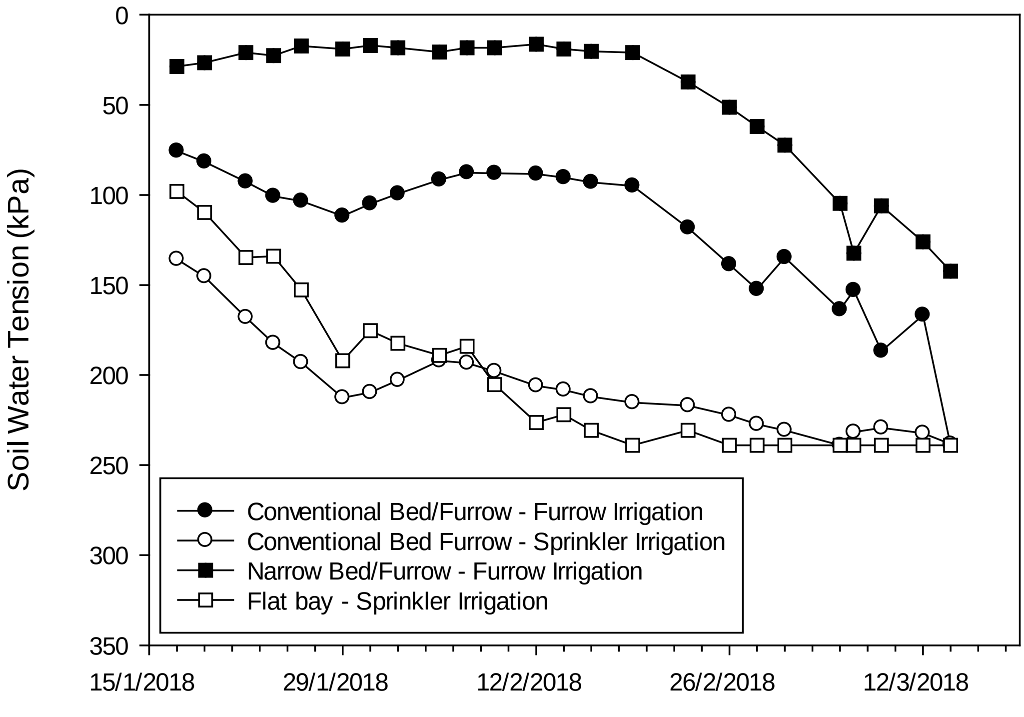

Figure 7.24: Average soil water tension (kPa) for each soil treatment (I1 Conventional Bed/Furrow – Furrow irrigation, I2: Flat bay – Sprinkler Irrigation, I3: Conventional Bed/Furrow – Sprinkler Irrigation and I4: Narrow Bed/Furrow – Furrow Irrigation) recorded at 15 cm depth.

Evapotranspiration for each plot was calculated using rainfall and the amount of water applied in irrigation, assuming no water leaked through the underlying compacted layer. Significantly more water was evapotranspired by the furrow irrigated treatments (I4, 11) compared to the sprinkler treatments (I2 and I3) (Figure 7.25a)

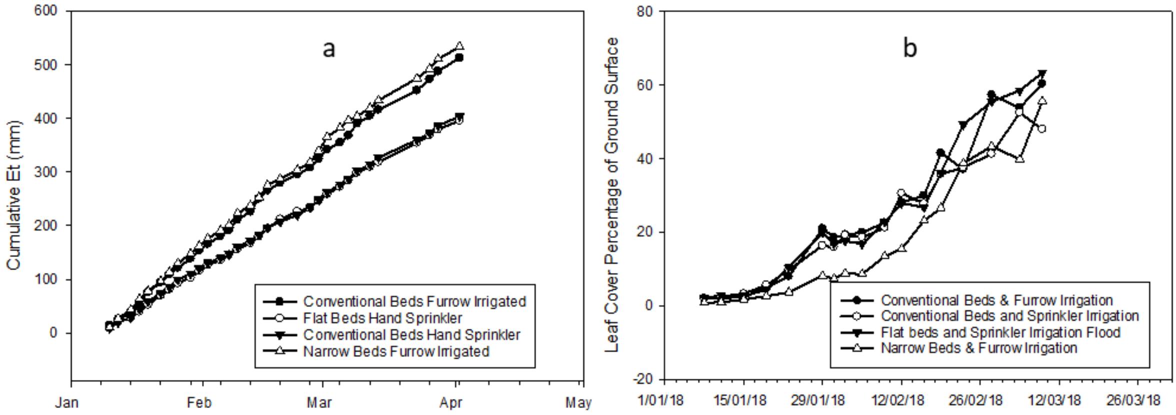

Figure 7.25: Cumulative evaporation (a) and canopy cover (b) by peanut as affected by bed architecture and irrigation method.

The development of canopy cover as a function of the bed architecture and irrigation method is presented in Figure 7.25b. On almost all occasions, canopy development by peanut grown on narrow beds/furrow irrigated was significantly retarded in contrast to the other three treatments. This was particularly prominent during the flowering - early pegging period (mid-January – mid February). However, closer to maturity, the canopy of I4 peanuts developed further and was similar to that of the other three treatments.

Unlike leaf area, aboveground biomass did not vary significantly between particular treatments over the four sampling intervals (Table 7.14), but similar to canopy cover, above ground development of peanut grown on the narrow beds appeared to be considerably behind compared to the other three treatments at first two sampling intervals. Peanut, like other pulse crops is sensitive to anoxic soil conditions associated with waterlogged soils. The fact that for the first thirteen weeks, the water potential of the surface soil in the I4 treatment was maintained close to or above field capacity, this condition is likely to have limited oxygen availability to the plant roots and had a detrimental influence on the early development of these plants.

Table 7.14: The effect of bed architecture and irrigation method on the development of above ground biomass by peanut at Phone Ngam Station 2017-18.

	Above ground biomass (t/ha)			
	Vegetative	Flowering	Pod Development	Maturity
Treatments	ns	ns	ns	ns
I1	0.57	1.47	3.73	4.76
I2	0.55	1.44	2.28	3.68
I3	0.48	1.25	3.72	3.18
I4	0.30	0.97	4.45	4.56
Mean	0.47	1.28	3.54	4.04

Neither layout nor irrigation method had any substantiative effect on either pod fresh weight, grain fresh weight or grain dry weight (Table 7.15). While pod and grain weight appeared considerably higher in the flat bed – sprinkler irrigated treatment (I2) compared to other treatments, this effect could not be statistically validated. Interestingly, apparent water productivity of the two sprinkler treatments were considerably higher than that of the furrow irrigated treatments (Table 7.15). Higher apparent water productivity of I2 and I3 could be due to improved efficiencies as a product of less vertical leakage associated with sprinkler applications of water. As about 25% more water was applied to the furrow-irrigated treatments (I1 and I4) than to the I2 and I3 with no effect on yield, this result indicates that higher water losses occur in furrow irrigation systems in these soils. The original estimate of ~ 400 mm of water applied to the I1 and I4 treatments then included water losses and cannot be considered as water used by the crop. As drier soils were observed in the sprinkler than in the furrow-irrigated treatments (Figure 7.25), it is possible that the higher level of osmotic stress imposed by the I2 and I3 treatments due to the lower availability of water, may have led to greater amount of carbohydrate being channelled into reproductive development and grain production.

Table 7.15: The effect of bed architecture and irrigation method on the yield components of and water productivity peanut grown at Phone Ngam Station 2017-18.

Treatments	Pod Fresh Weight ($t.ha^{-1}$)	Grain Fresh Weight ($t.ha^{-1}$)	Grain Dry Weight ($t.ha^{-1}$)	Water Productivity ($kg.\ mm^{-1}$)
	ns	ns	ns	ns
I1	4.67	1.19	0.80	1.56
I2	6.05	2.24	1.12	2.83
I3	4.75	1.72	0.90	2.24
I4	5.23	1.57	0.75	1.42

Experiment 2 Effect of organic amendments on water access and biomass production of DS-peanut

The average cumulative amount of irrigation water applied to each treatment over the growing season were not significantly different between treatments nor blocks. The total amounts applied over the season were 395.3 mm, 394.3 mm and 409.3 mm for the control (S1), incorporated manure and buried straw (S2) and the incorporated manure only (S3) plots respectively. Soil water tension was not assessed in experiment 2.

Figure 7.23: The effect of organic amendment on peanut growing on a bed/furrow system: Left, no amendment; Centre, buried rice straw and manure and; Right manure incorporate manure.

Calculated cumulative evapotranspiration were 500.4; 499.1 and 517.0 mm for the control (S1); incorporated manure and buried straw (S2); and, incorporated manure only (S3) treatments, respectively (Figure 7.18a). Average daily evapotranspiration for the three treatments 6.39, 6.32 and 6.65 mm day^{-1} for S1, S2 and S3, respectively.

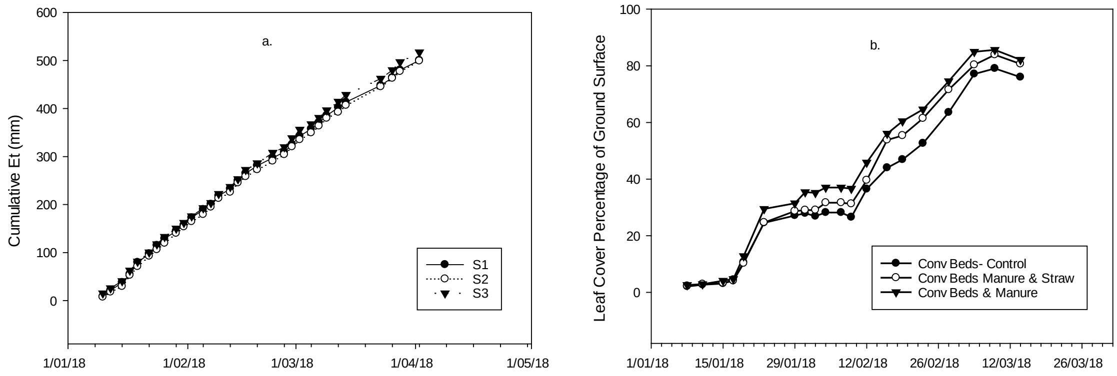

Figure 7.26: Cumulative evapotranspiration (a) and canopy cover (b) over the peanut growing season for the three soil amendment treatments.

In Figure 7.26a, the cumulative ET of S2 appeared to lag marginally behind cumulative ET for S1 & S3 at all intervals. This is similar to the 2016-17 season where the buried straw treatment consistently had lower soil water tension through the season. We speculate that consistent with the previous year, buried straw seems to constrain the evaporative loss of soil water by impeding vertical upward movement of soil water from the deeper soil layer.

The crop canopy of the two treatments where animal manure had been used (S2 & S3) were significantly larger than in the unamended control (S1) despite all treatments having substantial starter NPK fertilizer (156 kg ha^{-1}) (Figure 7.26b). This suggested that incorporated manure may provide additional nutrients to the crop that were not supplied in the starter fertilizer nor were available in soil. However, despite the inclusion of manure appearing to favour above ground biomass for the first three harvests, this advantage was not apparent at the final harvest and statistical analysis from all four harvests indicated that the inclusion of manure did not significantly promote above ground biomass production (Table 7.16).

Each plot in experiment 2 was sampled three times to assess above and below ground biomass development as affected by organic soil amendments. The dry weight of above ground, reproductive tissue and below ground tissue of peanuts growing in organic amended soils at three harvest dates is shown in Table 7.17.

Table 7.16: The effect of soil amendment on the development of above ground biomass by peanut at Phone Ngam Station 2017-18.

	Above ground biomass (t/ha)			
	Vegetative (30/1/18)	Flowering (12/2/18)	Pod Development (21/3/18)	Maturity (4/4/18)
Treatments	ns	ns	ns	ns
S1	0.53	1.17	4.72	6.52
S2	0.73	1.77	5.94	5.91
S3	0.62	1.59	5.53	6.32
Mean	0.63	1.51	5.4	6.25

Table 7.17: The effect of organic amendment on above ground biomass by DS- Peanut.

		Above and below ground biomass (g $plant^{-1}$)		
		Veg-flowering	Pegging/Pod Development	Maturity
Plant part	Treatments	ns	ns	ns
Dry Shoot tissue				
	S1	7.6	24.1	44.3
	S2	8.7	27.0	89.5
	S3	8.1	29.2	61.3
Dry Reproductive tissue				
	S1	0.32	4.7	27.0
	S2	0.08	6.1	34.4
	S3	0.06	4.6	27.3
Dry Root tissue				
	S1	0.73	2.2	4.2
	S2	0.82	2.3	5.0
	S3	0.96	1.9	3.4
Shoot:Root				
	S1	10.4	11.0	10.7
	S2	10.5	11.6	17.9
	S3	8.4	13.4	18.3

As the season progressed, the biomass for each component increased. However, at no sampling period did either of the organic amendments significantly affect above ground, reproductive tissue nor below ground biomass vary. Similarly, organic amendments had no significantly influence the ratio of shoot to root dry weights indicating that carbohydrate partitioning was unaffected by soil organic matter treatment. Interestingly, at the first two samplings, the ratio of above and below ground biomass maintained similar value to the value determined in the 2016-17 trial. However, about maturity, in contrast to the control (S1) the shoot-root ratio in the organic amended treatments (S2 & S3) had increased to 15.55 and 15.37 respectively, likely due to the continued greater rate of expansion of the above ground parts of peanut grown in the presence of incorporated manure relative to the development of their root systems. This provide further evidence that the inclusion of animal manures probably contributed nutrients to these treatments that was lacking in S1 despite applications of basal fertilizer at sowing.

Roots in the 5 -15 cm layer were individually separated and total combined root length for all roots recovered from this layer recorded. There was only a slight increase in total root length of this layer over the three sampling intervals. In contrast to findings in the previous season, there was no statistically significant difference in total root length in this depth horizon between amendment treatments in any of the three sampling periods (Table 7.18).

Crop yield and water productivity

At maturity, neither pod fresh weight, grain fresh weight, nor grain dry weight of peanut was statistically affected by the organic amendments (Table 7.19). Water productivity appeared considerably lower (~35%) in the treatments featuring incorporated manure (S2 & S3); there was practically no difference between these two treatments despite the fact that S2 had also been amended with 5 t/ha of straw buried about 50 mm beneath the surface layer. The fact that these two treatments had had statistically greater leaf canopy (Figure 7.26b) for the majority of the season indicated that they were under less biotic stress than S1 and that as a result S1 may have devoted more photosynthates to reproductive development in contrast to S2 & S3. Additionally, the harvested crop had been replanted on the 25 December 2017, more than two weeks after the original crop was sown; at the time of harvest the crop was less than 100 DAS. As crops in previous years had been harvested 120 – 130 days after sowing, the harvest of the crop in the present study may have been premature, which may have had particularly detrimental consequences for the less stressed treatments S2 and S3.

Table 7.18: Total root length of peanut growing in the 5 – 15 cm layer of organic amended soil.

	Total root length in the 5-15 cm soil layer (cm plant^{-1})		
	Flowering (6/02/18)	Pegging (5/03/18)	Maturity (2/04/18)
Treatments	ns	ns	ns
S1	207.3	197.8	293.2
S2	272.5	184.7	296.7
S3	213.0	190.3	253.0

Table 7.19 The effect of organic amendment on the yield components and water productivity peanut grown at Phone Ngam Station 2017-18.

	Pod Fresh Weight (t/ha)	Grain Fresh Weight (kg ha^{-1})	Grain Dry Weight (kg ha^{-1})	Water Productivity (kg mm^{-1})
Treatments	ns	ns	ns	ns
S1	5.30	1.69	0.72	1.45
S2	5.20	1.23	0.47	0.94
S3	5.14	1.29	0.50	0.97

Conclusions:

The findings from the present study highlight a series of known and previously unreported important edaphic factors that constrain the performance of non-rice dry-season crops on the Mekong alluvial sandy loam soils. Several factors were observed in the present study that have previously been reported by others. These include high bulk density, acidic soils, generalized deficiency in essential plant nutrients, low CEC and negligible levels of organic matter. However, the present study also identified several previously unacknowledged or little acknowledged major constraints to dry season crop production including: the lack in lateral movement of applied water from furrows into beds, and the attainment of high soil strength associated with non-clay soils as a result of drying and the associated limitation on plant root growth. The main conclusions obtained were:

- *Poor lateral soil water movement and apparent poor lateral root growth are major constraints that negatively affect agricultural production of field and horticultural crops in* *these soils*. The poor lateral movement of water is of particular importance for crops grown on a 'conventional' bed and furrow irrigation system, which is the common practice for dry-season crops in both Cambodia and Laos. The project showed that in this system of bed and furrow irrigation, improvement of plant access to water can be achieved by modifying bed architecture. Narrowing beds increased soil moisture availability for peanuts. However, this intervention resulted in the soil about the peanut root getting too wet, particularly during the vegetative, flowering and early pegging stage, which may have reduced both vegetative and reproductive development of peanut plants. This result, however, may not be problematic to other non-pulse crops but peanut, and particularly its below ground fruit bearing habit, is likely to be extremely sensitive to the wetness of soil resulting from this form of irrigation. Results from the study conducted during the 2017-18 dry season, indicate that peanut, indeed, would probably benefit from more frequent but lower volumes of irrigation per event as in the case of sprinkler irrigation to prevent the soil from achieving and maintaining near saturation, which in turn may lead to a boost water productivity.

- *Incorporation of rice straw into beds could enhance soil moisture retention and root development although it may prevent the crop to have access to nutrients*. Results obtained during the 2016-17 and 2017-18 dry seasons in both countries indicated that the inclusion of below ground layer of straw into beds could enhance soil moisture retention and, in the case of peanut enhance root development in this layer, allowing the plant to develop a larger root system and access more water. This effect is commonly observed where the roots of the current crop exploit stable bio-pores remaining from a previous crop. Analysis of root imagery taken from harvested peanut plants grown in the 2016-17 dry season, indicated that the presence of rice straw in the layer about 50 mm beneath the bed surface promoted the length of lateral roots emanating from the main root at this depth band. Results from studies conducted in both seasons, however, also showed that although a below ground layer of straw had in general a positive effect of on soil moisture retention, the consequence of burying high C:N ratio rice residues is likely to cause tie up of N & P that may prevent the crop to have access to these nutrients. Incorporating animal manure to the treatment with rice straw, which could negate any risk of nutrient tie up, was posed as a practice that could overcome this possible issue. However, attempts to prove this during the 2017-18 dry season failed when root length in the affected zone was unaffected by any treatment and crop yield by peanut growing in soil amended with animal manure appeared to be less than that of plants growing in unamended soil. Further research is needed to verify if amendments of readily available organic or inorganic sources can benefit subsequent crop performance by beneficially influencing crop root growth and enhancing crop access to water and nutrients.

- *There is a gap between actual and potential peanut yield simulated using AquaCrop that indicates that factors other than water could be detrimentally affecting peanut production*. Further in-sights of the effect of edaphic factors on peanut yield have been made by the project through comparing early model simulations with data emerging from project field trials and have led to a revision in our thinking. Simulations using AquaCrop showed average peanut yields across Champassak province to be 3.76 t/ha, and for the three provinces in southern Cambodia, to be 2.69 t/ha. The maximum yield of peanuts attained by research trials undertaken by the project (Champassak province) were 1.87 t/ha, indicating that our recommended strategies were only producing peanut crops capable of achieving yields 50% of potential. Trials conducted in 2015-16, clearly established crop water requirement and irrigation frequency for peanut crops when growing on these soils. The gap between actual and potential yields indicates that factors other than water to be detrimentally affecting actual crop yields. While basal fertilizer application at sowing clearly met crop needs for N, P and K, it is likely that other essential nutrients may have been lacking. We had assumed that heavy applications of animal manures may help crops overcome deficiencies in other essential nutrients. However, the inability of animal manures to make up for other nutrients deficiencies indicates either a lack of appropriate nutrients in this material, or a lack of adequate soil microbial activity able to mineralize and release the required nutrients in a plant available form at a rate required by peanuts. Further research is needed to verify if amendments of readily available organic sources can overcome inheritant soil nutrient deficiencies and bridge the identified gap between potential and actual peanut yields.

- *Addition of organic amendments such as biochars and manure may enhance maize production*. Deliberations of our findings of maize production on these soils have identified new opportunities to substantially improve maize yields. Early simulations of grain production by maize growing in these soils showed yields to range from 2.13 – 1.99 t/ha with an average grain yield of 2.10 t/ha. In many cases, research trials conducted by the project produced commensurate yields, reflecting on the robustness of the model and model parameterisation by the modellers. However, in the final year of the project, several treatments examined produced crops whose grain yields were well in excess of average simulated yield. Treatments leading to actual crop yields exceeding model predictions included those featuring biochars and manure, under traditional furrow irrigation, and of rice straw combined with sprinkler irrigation. These findings have caused the project team to revise our thinking regarding opportunities to enhance maize production on lowland soils across Cambodia and Lao. It seems likely that the addition of stable organic amendments such as rice hull biochar may provide yield enhancement through improved storage of water as well as enhanced retention of mobile nutrients. Heavy applications of animal manures may contribute to maize production through the increased availability of plant essential nutrients. Further research is needed to verify the mechanism and extent by which amendments of readily available organic sources can augment further maize yields on the extensive areas of these soil types across Cambodia and Lao.

Farmer research/demonstration trials

While the project's initial approach was to conduct on-farm research with key-smallholder farmers, in-country trials conducted in 2014-15 revealed insuperable difficulties in undertaking intensive research on-farm; particularly in relation to the adoption and maintenance of research protocols and in recognition of the financial impact that research trials can have on smallholder production expectations and profits. A review of research undertaken in the 2014-15 season at the 2015 annual project meeting recommended an alternative approach to work with key farmers including establishing research questions and trialling possible research solutions using on-farm demonstration trials commencing in the 2015-16 dry season.

As a consequence, and taking into account DS-cropping practices in each country, particular country themes were established. As many farmers across Takeo and Kampot province had already adopted DS-crop production, the approach in Cambodia focussed on irrigation method and improved methods of fertilization to improve crop performance. In Champassak, remote from the Mekong River, DS crop production is rare, and research with southern Lao farmers focussed on establishment, improving crop access to soil water and the use of organic amendment to improve crop water use and crop nutrition. In both countries, an array of different crops were trialled that suited farmer circumstances and preference; these included maize, peanut, long bean, cucumber and radish.

Cambodia

2014-15

Given the newness of the project in relation to its commencement in December 2014, the project conducted a limited number of trials to compare farmer practice to best bet CARDI recommended fertilizer methods and to investigate irrigation methods to determine crop water use. Focus areas were Takeo with sandy soils and Kampot, near Chamlang Chery village, with heavy clay soils.

A mungbean trial was established at Steung village, Takeo. The site was prepared as a bed/furrow system and split into two plots where hand sprinkler irrigation (1.5 m, 5 rows) and furrow irrigation (1.0 m, 3 rows) methods were compared. Lime had already been applied at the site in that season at the rate of 140 kg/ha and hence no more lime was added to the soil for the trial. Despite the crop establishing well, unseasonal heavy rainfall that occurred several weeks after sowing caused the site to become inundated with flood water due to its low lying nature and caused total crop failure.

The effect of lime addition on Chinese kale was assessed near the village of Chamlang Chrey on heavy clay soil. The crop established well and responding favourably to lime addition. Prior to sowing, a basal application of NPK fertilizer was applied and the crop was top-dressed with about 470 kg/ha of urea. The yield of the Chinese kale was 12% greater in the limed (10 t equivalent per ha) treatments compared to the un-limed treatment (8.8 t/ha). Applications of fertilizer were necessary as the inherent P-deficiency is a major limiting factor in these soils.

Figure 7.27: Cambodian farmer demonstration trials 2014-15. Left Mungbean trial after inundation by heavy rainfall. Right, Chinese kale crop growing on heavy clay soils in Kampot.

2015-16

Following best bet trials the previous season, trials in the current season looked to contrast fertilizer strategies to reduce input cost while improving crop yield and farm income. Trials were established at Chamlang Chrey, Steung village and Snao village on farms growing maize/sweetcorn, mungbean and radish, respectively, which were identified as the farmers' preferred crops. In the present year, trials at Chamlang Chrey switched from Chinese celery to irrigated maize due to the high labour requirement for growing Chinese celery. At all sites, crops were sown on a bed-furrow system; particular details for the trials on maize and mungbean crops are given in Table 7.20.

Table 7.20 Summary of on-farm trials conducted in southern Cambodia during the 2015-16 dry season.

Year and Location	Crop	Soil & water application	Treatment	Yield t/ha
2015-16; Chamlang Village. Mr Tob Yorn	Maize	Kampong Siem (Heavy clay self-mulching), bed with furrow irrigation	Farmer Practice basal NPK fertilizer (200 kg/ha) and 4 topdressing NPK & trace elements	10.1 t fresh cobs/ha
			CARDI recommended practice of lime, basal NPK fertilizer and 2 topdressings of NPK and trace elements	5.2 t fresh cobs /ha
2015-16, Stueng village, Ms Nub Moul	Mung bean	Prateah Lang (hard setting course sandy loam)	Farmer Practice basal fertilizer on beds	0.8 t grain /ha
			CARDI recommended practice of basal fertilizer and 1 top dress with urea	1.0 t grain/ha

Note: The radish trial evolved into a longitudinal study investigating continuous radish growing at a single site over four years, featuring an assessment of the ongoing effects of a single lime application, and fertilizer strategy on both crop production and financial impact of continuous radish production over time. This particular trial is dealt with in a separate section and in a later table (Table 7.23)

Poor yields of maize observed at the Chamlang Chrey village trial in association with the CARDI recommended fertilizer strategy compared to the farmer practice was likely attributed to a lack of supplied N in CARDI strategy as indicated by observed N crop deficiency at flowering. Conversely, mungbean slightly increased yield under the CARDI fertilizer strategy, which was attributed to a higher N economy associated with the CARDI recommended treatment (Table 7.20).

2016-17

Chamlang Chrey Commune, Kampot: Maize

The site where maize demonstration trials had previously been conducted and were planned for 2016/17 was inundated due to unseasonal heavy rainfalls recorded for the area after establishment of the trial. As a consequence the crop was lost and no data was available for this site in the present year.

2017-18

Trials planned for the Chamlang Chrey field site were shifted to Trapeang Chrey village Chhuk commune, Kampot as our collaborative farmer was no longer able to participate in field trials with the project.

Two demonstration trials were conducted at Trapeang Chrey village. Both trials consisted of maize crops grown on beds comparing farmer fertiliser practice to CARDI's fertiliser recommendations rates (CRR). Fertiliser rates used for each treatment at each site (site 1 and site 2) are shown in Table 7.24.

Both sites consisted of two plots of 15 m x 3.25 m where maize was grown in beds at a row and plant spacing of 0.65 m x 0.3 m. Both crops were sprayed once to control the insect pressure. Yield was estimated by sampling cobs at harvest in a harvesting area of ~22 m^2. At site 1, similar yields were obtained in both treatments. At site 2, however, yield estimates at harvest showed that the farmer's strategy led to a reduction in fresh cob production of 0.90 t/ha when compared to the CARDI's fertiliser recommendation rate (7.0 t/ha) (Table 7.21). Considering that the cob price at the market this season was 0.3$ kg^{-1}, the income reduction in the farmer practice with respect to the CRR treatment was of $270 USD ha^{-1}.

Table 7.21 Summary of on-farm trials conducted in southern Cambodia during the 2017-18 dry season.

Location	Crop	Soil & water application	Treatment	Yield t/ha	Financial return (USD/ha)
Trapeang Chrey village: site 1	Maize	Beds with furrow irrigation	Farmer Practice basal NPK&TE fertilizer (308 kg/ha) at sowing and 1 topdressing NPK & TE (205 kg/ha) , 28 DAS	9.3 t fresh cobs/ha	2790
			CARDI recommended basal DAP fertilizer (95 kg/ha) plus Urea, KCl and NPKS at sowing and 1 topdressing of all but DAP and NPKS, 28 DAS	9.5 t fresh cobs /ha	2850
Trapeang Chrey village: site 2	Maize	Beds with furrow irrigation	Farmer Practice basal NPK&TE fertilizer (205 kg/ha) at sowing and 1 topdressing NPK & TE (205 kg/ha) , 28 DAS	6.1 t fresh cobs/ha	1830
			CARDI recommended basal DAP fertilizer (95 kg/ha) plus Urea, KCl and NPKS at sowing and 1 topdressing of all but DAP & NPKS, 28 DAS	7.0 t fresh cobs /ha	2100

2018-19

Trials during the 2018-19 dry season were conducted on three farms in Chhuk district, Kampot, on maize. At each site, crops were grown on a bed/furrow system comparing two irrigation schedules (irrigation every 7 (I1) or 9 days (I2)), and comparing farmers' fertiliser practices to CARDI's fertiliser recommendations rates (CRR) with and without the addition of 5 t/ha rice hull biochar (see Table 7.22). Although there were no replicates within each farm, the same treatments were tested on the three farms and therefore data (fertiliser cost, yields and economic returns) from all were assessed together (Table 7.22).

Figure 7.28: Maize trials in Kampot investigating irrigation frequency, improved fertilizer management and ensuring benefits from biochar.

A field day was conducted in March 2019 at the maize trials which demonstrated the beneficial effect of biochar and CARDI's recommended fertilizer strategy on maize production. The field day attracted 45 regional officials and 41 farmers.

Figure 7.29: Farmers inspecting the maize demonstration plot (right) and government officials and farmers hearing the results from maize trials in March 2019.

Table 7.22 Summary of on-farm maize trials conducted in southern Cambodia during the 2018-19 dry season.

Irrigation treatment		Fertilizer strategy	Fertilizer Cost USD/ha	Fresh cob yield (t/ha)	Yield increase due to biochar (t/ha)	Farm income $USD/ha
One irrigation /7days (I1)	Farmer practice	Basal application of N(180 kg/ha) P_2O_5 (109 kg/ha) & K_2O (55kg/ha)	314	8.2		3357
	Farmer practice & 5 t/ha Rice Hull Biochar	Basal application of N(180 kg/ha) P_2O_5 (109 kg/ha) & K_2O (55 kg/ha)	314	8.4	0.2	3488
	CARDI recommended practice	Basal application of N(135 kg/ha) P_2O_5 (90 kg/ha) & K_2O (45 kg/ha)	263	8.9		3753
	CARDI recommended practice & 5 t/ha Rice Hull Biochar	Basal application of N(135 kg/ha) P_2O_5 (90 kg/ha) & K_2O (45 kg/ha)	263	9.4	0.5	3986
One irrigation /9days (I2)	Farmer practice	Basal application of N(180 kg/ha) P_2O_5 (109 kg/ha) & K_2O (55 kg/ha)	314	8.1		3339
	Farmer practice & 5 t/ha Rice Hull Biochar	Basal application of N(180 kg/ha) P_2O_5 (109 kg/ha) & K_2O (55 kg/ha)	314	9.3	1.2	3858
	CARDI recommended practice	Basal application of N(135 kg/ha) P_2O_5 (90 kg/ha) & K_2O (45 kg/ha)	263	8.0		3320

Irrigation treatment		Fertilizer strategy	Fertilizer Cost USD/ha	Fresh cob yield (t/ha)	Yield increase due to biochar (t/ha)	Farm income $USD/ha
	CARDI recommended practice & 5 t/ha Rice Hull Biochar	Basal application of N(135 kg/ha) P_2O_5 (90 kg/ha) & K_2O (45 kg/ha)	263	10.2	2.2	4315

Two major outcomes emerged from the 2018-19 on-farm maize trials. CARDI's recommended fertilizer strategy resulted in a slight increase in crop yield, particularly in the treatment featuring more frequent irrigation (I1) and due to its lower cost compared to the farmer practice alternative, generated greater income when more frequently irrigated ($396 USD/ha). However, the addition of biochar in all instances increased markedly fresh cob yield, most particularly in treatments I2 featuring less applied water (Table 7.25). The range of increased yields as a result of the addition of biochar ranged between 0.2 – 2.2 t/ha. The larger increases in yield in response to biochar additions occurred in treatments where irrigation water was more sparingly applied (I2). As the source of the biochar were rice hulls, a substrate which is notoriously nutrient deficient, it seems unlikely that the biochar improved the amount of available nutrients. But biochar could add to the fraction of stable organic matter in these soils and effectively increase the soil's water retention capacity. This treatment may prolong plant access to water in the more water scarce treatment resulting an increase in yield. Interestingly, in the absence of biochar, reducing the frequency of irrigation had only a slightly negative effect on maize cob yield.

Radish on-farm trials

This trial evolved as a continuous longer-term trial over time featuring two successive radish crops each year and investigating compounding effects of prior fertilizer practice on crops and on economic returns (Table 7.23). In this trial, the farmer's practice of applying manure and basal fertilizer plus a single urea top dress in each crop was compared to CARDI's strategy to incorporate lime prior to sowing the first crop and then basal fertilizer at sowing plus four top dressings with urea over the 45-day crop growth period. For details of the trial see Table 7.23.

Table 7.23 Summary of continuous radish production conducted in on-farm trials in southern Cambodia during the period 2015-19. (Figure in red shows the net financial margin for each year by adopting the CARDI fertilization strategy).

	Year & Crop #	Treatment	Watering method	Radish yield t/ha	Fertilizer cost USD/ha	Financial return (USD/ha)
Mr Topau	2015/16-1	Farmer method Manure and 200 kg NPK plus urea/NPK/TE top-dress	Sprinkler	36.4	327	4221
	2015/16-1	CARDI Recommended Lime at bed preparation, manure NPK starter fertilizer plus urea top dress (4 times)	Sprinkler	38.4	668	4127
	2015/16-2	Farmer method Manure and 200 kg NPK plus urea/NPK/TE top-dress	Sprinkler	26.5	321	2738
	2015/16-2	CARDI Recommended Lime at bed preparation, manure NPK starter fertilizer plus urea top dress (4 times)	Sprinkler	27.9	296	3189 (+16)
	2016/17-1	Farmer method Manure and 200 kg NPK plus urea/NPK/TE top-dress	Sprinkler	40	324	4680
	2016/17-1	CARDI Recommended Lime at bed preparation, manure NPK starter fertilizer plus urea top dress (4 times)	Sprinkler	48.8	316	5697
	2016/17-2	Farmer method Manure and 200 kg NPK plus urea/NPK/TE top-dress	Sprinkler	27.9	321	3163
	2016/17-2	CARDI Recommended Lime at bed preparation, manure NPK starter fertilizer plus urea top dress (4 times)	Sprinkler	34.1	296	3970 (+1824)
	2017/18-1	Farmer method Manure and 200 kg NPK plus urea/NPK/TE top-dress	Sprinkler	25.3	345	2815
	2017/18-1	CARDI Recommended Lime at bed preparation, manure NPK starter fertilizer plus urea top dress (4 times)	Sprinkler	29.4	341	3330
	2017/18-2	Farmer method Manure and 200 kg NPK plus urea/NPK/TE top-dress	Sprinkler	38.7	441	4395
	2017/18-2	CARDI Recommended Lime at bed preparation,	Sprinkler	38	296	4458

	Year & Crop #	Treatment	Watering method	Radish yield t/ha	Fertilizer cost USD/ha	Financial return (USD/ha)
		manure NPK starter fertilizer plus urea top dress (4 times)				(+578)
	2018/19-1	Farmer method Manure and 200 kg NPK plus two top-dress applications of urea plus a foliar fertilizer as well. *Note modification in farmer method was as a result of findings over the previous two years CARDI treatments*	Sprinkler	25.5	441	2750
	2018/19-1	CARDI Recommended Lime at bed preparation, manure NPK starter fertilizer plus urea top dress (4 times)	Sprinkler	23.8	341	2628

In 2015-16, CARDI recommended fertilizer strategy increased crop yields in both the first and second crop, but had a lower economic return in the first crop due to the cost of lime. The additional economic return from the second crop using the CARDI strategy ($451US/ha) more than covered the initial cost of lime. Over all, taking into account the two radish crops in the 2015-16 season, the higher yield associated with the CARDI recommended fertilizer strategy, resulted in a minor net gain of $16 USD. In 2016-17, the harvest of the radish crops grown using the CARDI strategy exceeded the farmers' preferred strategy 8.8 and 6.2 t/ha in the first and second crop, respectively. The combined additional yield, from the two crops under the CARDI fertilizer strategy in this season yielded the farm a gain of $1824 USD/ha. In the third season (2017-18), the production gain in radish grown using the CARDI recommended fertilizer strategy was not as pronounced as in the previous season, yielding only a production gain of 3.4 t/ha and an additional financial return of $578 USD/ha. In the fourth and final year of the trial, the plots featuring the CARDI recommended strategy yielded less in the first crop than when following the farmers preferred strategy which had changed from previous years practices and included two separate applications of urea plus a foliar fertilizer.

The improvement in yield of radish from adopting the CARDI recommendations is likely to be due to the beneficial effect of liming soils prior to the first crop. However, the benefit from lime lessens over a number of seasons to the point where it needs to be reapplied.

A field day organised at Snoaw village in 29 March 2017 attracted local and regional government officials and 60 radish farmers many of which were female and who were keen to learn new strategies to improve productivity and reduce costs.

Figure 7.30: Radish farm demonstration plot (left) and government officials and farmers attending radish farm field day in March 2017.

Lao PDR

Farmer trials established soon after the commencement of the project in 2014-15 were intended to determine crop water requirement and assess the impact of liming on crop establishment and production across four farms from three key villages. Crops selected were of interest both to the farmer and to the project team. Trial details and crop outputs are shown in Table 7.24. Treatments were not replicated on farm but farms were intended to replicate a common experiment.

Table 7.24: Summary of on-farm trials conducted in southern Lao during the 2014-15 dry season.

	Location	Crop	Soil treatment	Water schedule	Area (m^2)	Water used (m^3)	Yield (kg per plot)
Mr Keep	None Yang	Cucumber/Long bean	+lime not incorporated	1d/2d/3d or wilting	600	134	40 & 70 resp
			-				
Mr Sum	None Yang	Cucumber/Long bean	+lime not incorporated/-lime	1d/2d/3d or wilting	756	190	-lime 6.74 &504 resp +lime 4.32 & 273 resp
Mr Heow	Park Xang	Cucumber/Long bean	+lime not incorporated	1d/2d/3d or wilting	800	34	No yield data available
Mr Vipot	Beoung Keo	Water melon	+lime/-lime	3d,5d,7d,10d	600	Not metered	793, 367, 624, 916.8 resp

The performance of the trials during the 2014-15 dry season revealed several important issues that were taken as a lesson and were used to modify how the trials were approached in future seasons for the benefit of the project. Among the collaborative farmers in Sukumar district, only one had prior experience in DS-crop production, and expert advice to aid the other farms in establishing and managing these trials was lacking. Farmers selected were very good wet season rice growers but their skills in rice production did not transfer to DS-crop production. Farmer tended to use their own intuition in spite of trial protocols and hence, weeds were abundant and luxuriant, lime applied had not been incorporated into the soil and the size of plots land were much larger than the available labour could manage.

In general, water use between the two None Yang farmers were similar with applied water ranging from 223 – 251 mm at the two farms. At Park Xang, metered water applications indicated that only 42.5 mm of water had been applied which could explain why no crop yield was recorded. Weed competition at all sites was substantial and farm labour at each site was insufficient to be able to suppress their detrimental impact on the growth and yield of target crops. Pest damage was extensive on all cucumbers plots. All cucumber plants were infected by cucumber mosaic virus and in most instances, leaves and vines were severely deformed and fruit were produced severely undersized.

Figure 7.31: Farmer cucumber and long bean trials in Ban ParkXang in 2014-15. The trials were particular weed infested and cucumber in top left particular chlorotic and suffering cucumber mosaic virus.

2015-16

Experience from 2014-15 lead to a change in the way the project engaged with collaborative farmers with farmer trials being used to test and disseminate new technologies developed by the project team to improve the production of DS-crops. In the 2015-16 season, the number of participating farmers were reduced compared to the previous season (Table 7.25). Two trials were conducted in Ban NoneYang and a single trial in Ban Beoung Keo. In NoneYang, trials compared the farmer practices of adding manure at sowing with the NAFRI method of applying NPK fertilizer at sowing. Additionally, two water schedules were applied at each site but yield impacts were not recorded. At Ban Beoung Keo, the main treatment was watering method.

Table 7.25 Summary of on-farm trials conducted in southern Lao during the 2015-16 dry season.

	Location	Crop	Soil treatment	Water schedule	Area (m^2)	Water used (m^3)	Yield (kg per plot)
Mr Keep	None Yang	Long bean	Organic + NPK one spoon per plant	2d or 3d	10*30	48.1 & 32.6 kL	35 & 58 resp
			NAFRI fertilizer recommendation (600 kg NPK / ha)	2d or 3d	12*30		
Mr Som	None Yang	Long bean	Organic + NPK one spoon per plant versus	2d & 3d	2*13.6	27.3 *& 36.4 kL 208kL	44 kg
			NAFRI fertilizer recommendation (600 kg NPK / ha	2d & 3d	2*13.6	18.5 & 25.7 kL 193 kL	67 kg
Mr Vipot	Beoung Keo	Cucumber	NPK fertilizer	Every 2or 3d	170	7.62 or 4.86 kL	157.9 & 83 kg fruit per ha

Water use data for Mr Sum's trial indicated that more water was applied on the experimental plots than required to meet crop water requirements, implying a huge drainage coefficient. Site inspections at the time, showed the furrows to be full of water. Conversely, estimated water use at the trial in Ban Beoung Keo seemed to underestimate crop water requirements with only 89 and 45 mm of water applied recorded for the 2-day and 3-day watering scheduled treatments over the entire season indicating incomplete record taking or misinterpretation of farm records; the more frequent watering resulted in an apparent yield increase. However, common across all sites, weeds were a major issue due to farmer's early inaction in removing weed seedlings and a lack of available labour to remove larger weeds. In both NoneYang trials, amendment with NPK fertilizer at sowing promoted yield markedly compared to when only manure or manure supplemented with a nominal amount of NPK was applied at sowing. At Beoung Keo, more frequent watering resulted in substantial yield increase. At Beoung Keo, cucumber fruit were small and plants had suffered damage from cucumber mosaic virus affecting ultimate plot yields.

2016-17

In the 2016-17 season, farmer trials were reduced to two farms at Ban NoneYang, where animal manure applied at 10 t/ha incorporated at sowing was compared to NAFRI recommended basal chemical fertilizer NPK application (300 kg/ha) at sowing for three crops: maize and long bean (Table 7.26). Crops at Ms Wat's farm were irrigated via furrows while at Mr Som's crops were irrigate with fixed sprinklers.

Table 7.26 Summary of on-farm trials conducted in southern Lao during the 2016-17 dry season.

	Location	Crop	Basal fertilizer treatment	Water schedule	Area (m^2)	Fresh yield of maize cob and long bean pods (kg per ha)
Ms Wat	None Yang	Long bean	10 t/ha Organic vs NPK fertilizer (300 /ha)	Furrow	75.6	1851 (M) 1322.8 (IF)
Ms Wat	None Yang	Maize	10 t/ha Organic vs NPK fertilizer (300 /ha)	Furrow	100.8	9920.6 (M) 7936.5 (IF)
Mr Som	None Yang	Long bean	10 t/ha Organic vs NPK fertilizer (300 kg/ha)	Sprinkler	100.8	3968.3 (M) 2480.2 (IF)
Mr Som	None Yang	Maize	10 t/ha Organic vs NPK fertilizer (300 kg/ha)	Sprinkler	82.4	7281.6 (M) 4247.6 (IF)

Trials suffered from poor levelling and drainage and waterlogging was common in several plots. Poor land forming and layout led to anoxic soil conditions prevailing for extended periods in parts of each plot which probably induced poor crop nutrition in affected areas. In all cases, manure treated crops out yielded inorganic fertilized crops by between 25 – 71% of yield. Interesting, long bean yields were considerable greater on sprinkler irrigated than furrow irrigated plots. However, the reverse was true with maize, indicating that the strategy of irrigating maize with sprinklers may not enabled crop water requirements to be met. We interpreted higher yields by crops associated with heavy applications of manure prior to sowing to be due to manure providing the essential nutrients required by crops, similar to inorganic fertilizers, but to also supplement some other nutrients not provided by the inorganic fertilizer which may have led to a yield loss in the treatment with a basal chemical fertilizer. Additionally, manure may have compensated for losses of fertilizer applied nitrogen, lost through denitrification in water-logged plots. Like in previous years, weed competition was high with farmer complaining of not enough labour to manage weeds.

DS-crop practices over the past several seasons indicated that farmers still lack basic technical capacity to grow good, high yielding dry season crops. The project arranged for participating farmers to visit PhonTong Village on two occasions to observe well grown crops and to discuss with Phontong farmers practices used which enable them to grow successful DS-crops (see figures 7.32-7.34).

Figure 7.32: Farmers Training Farmers: Ban Phontong farmer showing Ban NongYang farmers correct bed furrow preparation techniques (Left) and, on constructed beds the appropriate technique to sow pre-germinated seed in the furrow off the edge of the bed so as to best capture applied water.

Figure 7.33: Farmers training farmers; Ban NoneYang farmers and the project team learning techniques to prepare manure for dry season crop production.

Figure 7.34: Farmers training farmers. Farmers and project team sharing a meal after training and discussing experiences regarding growing dry season crops.

2017-18

Research conducted during the past two seasons at Phone Ngam Station and CARDI identified poor lateral subbing of water associated with sandy alluvial soils endemic across the floodplains of the lower Mekong, and the need for methods to improve access to water and to reduce water loss. Also lower trial yields in contrast to simulated yields, highlighted the lower availability of nutrients not supplied with basal fertilizers. Hence, farmer trials were used in investigate the use of animal manures and surface spread rice straws to improve the availability of nutrients for crops and reduce evaporative water loss respectively (Table 7.27).

Table 7.27: Summary of on-farm trials conducted in southern Lao during the 2017-18 dry season.

		Crop	Soil treatment	Water schedule	Fresh cob and pod yield (kg per ha)
Mr Som	None Yang	Maize	NPK starter fertilizer plus urea top-dress: 20t/ha animal manure no rice (Tech 1) versus and animal manure plus rice straw on beds (Tech 2)	Sprinkler	10119 (Tech 1) 10714 (Tech 2)
Mr Som	None Yang	Long bean	NPK starter fertilizer plus urea top-dress: 20t/ha animal manure no rice (Tech 1) versus and animal manure plus rice straw on beds (Tech 2)	Sprinkler	9524 (Tech 1) 14286 (Tech 2)
Mr Lonthu	None Yang	Maize	NPK starter fertilizer plus urea top-dress: 20t/ha animal manure no rice (Tech 1) versus and animal manure plus rice straw on beds (Tech 2)	Furrow	12083 (Tech 1) 12643 (Tech 2)
Mr Lonthu	None Yang	Long Bean	NPK starter fertilizer plus urea top-dress: 20t/ha animal manure no rice (Tech 1) versus and animal manure plus rice straw on beds (Tech 2)	Furrow	11905 (Tech 1) 21429 (Tech 2)

		Crop	Soil treatment	Water schedule	Fresh cob and pod yield (kg per ha)
Mr Khamchane	None Yang	Maize	NPK starter fertilizer plus urea top-dress: 20t/ha animal manure no rice (Tech 1) versus and animal manure plus rice straw on beds (Tech 2)	Furrow	11262 (Tech 1) 11905 (Tech 2)
Mr Khamchane	None Yang	Long Bean	NPK starter fertilizer plus urea top-dress: 20t/ha animal manure no rice (Tech 1) versus and animal manure plus rice straw on beds (Tech 2)	Furrow	7143 (Tech 1) 8929 (Tech 2)

Trials at Ban NoneYang were expanded to three farms; all participating farmers had attended visits to Phontong farms to learn the fundamentals of dry season crop production including preparation and incorporation of animal manures as part of site preparation, land preparation and layouts, strategies at sowing to improve crop access to water and wed control. In this season, two methods were compared: no organic addition, compared to 20 t/ha animal manure and rice straw spread across beds. All plots were treated with NPK fertilizer at sowing and seed were sown on the side of the furrow to assist plants in gaining access to applied water.

Yields in 2017/18 trials at all sites were greater than yields in trials conducted in 2016-17, due to better layouts which improved application of water and improved crop establishment and management (see figure 7.35). Offset sowing of seeds on the sides of furrow improved plant access to water and concomitant yield at all sites. In the non-mulched plots, regular hand weeding reduced week competition and particularly in comparison with the previous greatly improved crop yield compared to the previous year where hand weeding was avoided. Using each farm as a replicate, paired T analysis showed the addition of rice straw residues significantly improve yields only for maize. The data analysis could not resolve a similar statistically valid response in long bean yield to applications of manure; this is likely due to the high variance associated with the response in long bean yield to manure between the three sites – not the lack of effect of addition of straw mulch.

Figure 7.35: Project team visiting Mr Som's maize fields in Ban NoneYang, Soukoumma district. Left to right. Dr Thavone Inthavong (NAFRI), Mr Vorachiths (PAFO-NAFRI); Mr Som, (Chief Ban NoneYang); Dr Pheng Sengxua (DaLM-NAFRI) and Mr Kesone (DAFO-Sukuma).

Anecdotal evidence indicated that the addition of rice straw mulch on beds, enhanced the size of the crop canopy which increased shading and light exclusion at the bed surface compared to crops growing without rice straw amendment. This increase in the size of the canopy was thought to be due to reduced evaporative loss of water in the presence of rice residues and the increased exclusion of light at the bed surface coincided with a noticeable reduction in weed population – both of which will have resulted in an improved efficiency in the use of water. Additionally, given the poor chemical fertility of Ban NoneYang district soils, the addition of animal manure to all plots is likely to have assisted crops in accessing nutrients from the mineralization of the added goat and cattle manure that may otherwise have been deficient.

2018-19

Trials at Ban NoneYang continued with the three project key farmers replicating in time a similar trial as conducted in the previous season but with each farm only growing one type of crop and consideration being given to financial returns.

Consistent with the previous year, the main treatments had similar observed impact on crop yields; for the three crops investigated, paired T analysis indicated that crop yields responded positively to application of animal manure and rice straw. Yield improvements ranged between 40 – 67%. These improvements in crop yield also improved the economic return to each of the farmers with the greatest return being experienced with maize-sweetcorn production (Table 7.28).

Table 7.28 Summary of on-farm trials conducted in southern Lao during the 2018-19 dry season. (Figure in red shows the net financial margin per ha by adopting the NAFRI recommendation of using animal manure with rice straw on beds).

Farmer	Crop	Soil treatment	Water method	Area (m^2)	Yield kg/plot	Fruit Yield t/ha	Financial return ($US/ha)
Mr Som	Maize	NPK starter fertilizer plus urea top-dress: no manure (Tech 1)	Furrow	149.85	85	5.7	3705
Mr Som	Maize	NPK starter fertilizer plus urea top dress: 20t/ha animal manure and rice straw on beds (Tech 2)	Furrow	149.85	137	9.14	6123.8 (2418.8)
Mr Lonthu	Peanut	NPK starter fertilizer plus urea top dress: no manure (FP)	Furrow	72.6	15	2.06	1277.2
Mr Lonthu	Peanut	NPK starter fertilizer plus urea top dress: 20t/ha animal manure and rice straw on beds (Tech 2)	Furrow	72.60	25	3.44	2132.8 (855.6)

Farmer	Crop	Soil treatment	Water method	Area (m^2)	Yield kg/plot	Fruit Yield t/ha	Financial return ($US/ha)
Mr Khamchane	Longbean	NPK starter fertilizer plus urea top dress: no manure (FP)	Furrow	87	38	4.37	2731.25
Mr Khamchane	Longbean	NPK starter fertilizer plus urea top dress: 20t/ha animal manure and rice straw on beds (Tech 2)	Furrow	87	53	6.09	3806.25 (1075)

Figure 7.36: Details of dry season crops grown at the farm demonstration trials conducted in Ban NoneYang during the 2018-19 dry season. Maize (top left); long bean (bottom left); peanut with rice straw on beds (right).

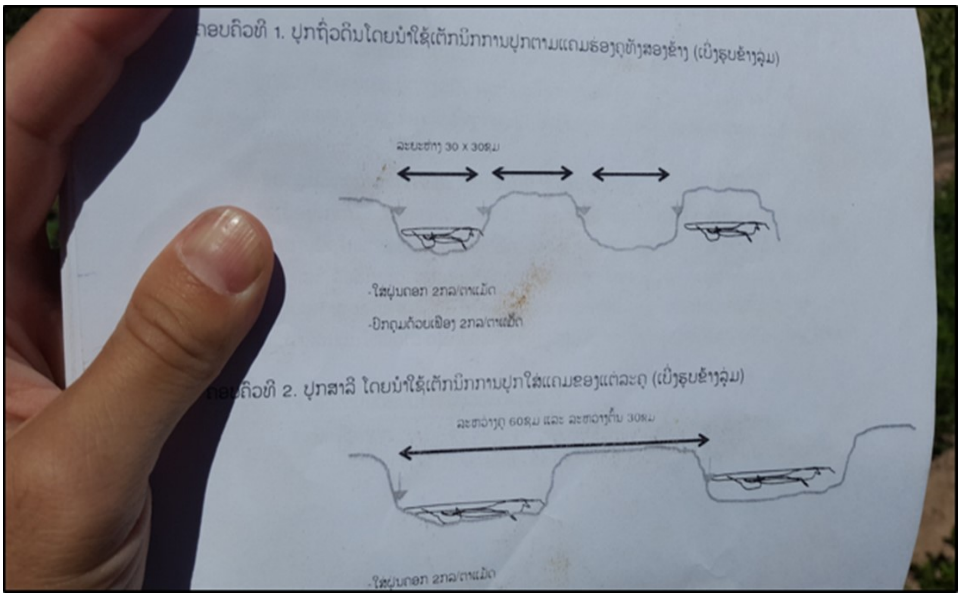

Figure 7.37: Information sheets provided to farmers at the 2018-19 field day advising to grow plants closer to the water source (furrows) rather than in the middle of beds. Top scenario – peanut and longbean; Bottom scenario – maize.

Average yields for maize and long bean were lower in the present year by about 4 t and 7 t per hectare respectively, than in the previous season. At this stage, there is no tangible reason as to the overall reduction in yield of the two crops between the two seasons. Along with improved yield, organic amendments improved financial returns of crops growing in treated plots. Without amendment, yields returned between \$0.13- \$0.38 m^{-2} but with straw and manure, returns ranged from \$0.37 - \$0.57 m^{-2}. But as each of these trials were conducted on comparatively small plots, the amount of manure used per plot was comparatively small, an amount easily found by farmers. If however, areas of production were to expand, a situation which is likely to occur into the near future, then sourcing 20 t/ha of animal manure may become more difficult and more expensive, a cost which could reduce the economic margins as presented here.

Figure 7.38: Matt Champness (Crawford fund volunteer) illustrating in a demonstrative manner the benefits of manure and NPK fertilizer with urea top dressing (right) compared to manure alone (left) on maize height and biomass production in Ban NoneYang in February 2020.

Conclusion from on-farm trials

The on-farm component of the project were a mechanism for the broader project community to observe issues which challenged dry season crop farmers from the region. On-farm trials were used to formulate issues into a research question, which were investigated at an allied research station, to test possible solutions in conjunction with key farmers, and to use these latter trials to demonstrate new methods to overcome challenges affecting the regional farming community.

Key outcomes learned from on-farm trials:

- *Farmers learning from farmers*. Difficulties were experienced by dry season farmers in Ban NoneYang in the early stage of the project. Taking these farmers to another village to learn from other farmers was a particular successful way to engender the required methods needed for these farmers to succeed in dry season crop production.

- *Shift plants close to the water source.* Research in the project identified that soil common across the region set hard on drying and have poor capacity to laterally move (sub) water from irrigation furrows into beds. This project undertook research into interventions to lessen these soil properties with only minor effect. The solution tested on–farm to sow plants closer to the irrigation furrow improved crop productivity.

- *Need for lime to correct acidic soils.* Application of lime has been well acknowledged globally to correct acidification and to grow crops on acidic soils. In the first dry season in Lao, while the object of the work was to investigate the influence of lime on dry season crops, no clear impact was shown. However, on-farm trials in Cambodia showed an apparent beneficial effect from the addition of lime coupled with more frequent topdressing with urea on radish production. A decline in yield in radish grown several years after application of lime is consistent with how lime would be expected to behave on these soils of sandy texture in a monsoonal environment and therefore more regular applications are likely to be required – perhaps every three years in these environments.

- *Nutrient fertilizer strategy:* In general, farmer practice were to apply basal fertilizer either at or soon after sowing with only limited top dressing of fertilizers. Emphasis on reducing the dosage of starter fertilizer and strategic nutrient supplementation using topdressing may have achieved several unintended benefits. Soils across the region have limited nutrient retention capacity. Applying nutrients in lesser amounts but more frequently through the season and in different forms provides plant access to particular nutrients at times when required and reduces the risk of loss of nutrients applied in a single dose at sowing by leaching.

- *Role of organics in the farming system.* The beneficial effect of application of organic materials, including animal manure, rice straw and biochar were clearly demonstrated in all trials in both countries in several ways. Given the poor nutrient status of these soils across the region and their inability to retain nutrients, the use of animal manures provides a non-leachable source of nutrients to supply plants as well as a mechanism to provide some nutrient retention. Given the lack of retention sites for sulfur in these soils – higher crop yield where soils were treated with heavy applications of animal manure may have provided a source of sulfur. A detrimental impact reported by participating farmers regarding animal manures is the introduction of weeds associated with their use. However, aging the manure in the sun under a plastic cover for several months provides a mechanism to sterilize viable seed contained with manure. Experience with Lao farmers regarding the use of rice straw laid on beds resulted in crops with larger canopy (more shading) and higher yields. The improvement in yield was attributed to reduce water loss via evaporation and greater water productivity of applied water as well as reduced weed growth and therefore less competition by weeds for nutrients and applied water. Biochar derived from reduced rice hulls also resulted in enhanced yields - particularly with maize growing where water was less frequently applied. This enhancement of yield water attribute maize having greater access to stored soil water as we speculate that some applied water was stored in the biochar residues in soils, retained against vertical drainage.

8 Impacts

8.1 Scientific impacts – now and in 5 years

- An appraisal of, and appreciation for challenges associated with efficiently irrigating dry-season crops on soils of the lowlands has been made. Research undertaken consistently demonstrated a lack of lateral water movement from furrows into adjacent beds in lowland alluvial soils of both countries - fundamentally limiting crop access to applied water. Evidence of poor lateral water movement was demonstrated clearly in 2015-16 where soil tensiometric data from both sites (Annual report SMCN 2012/071 2015/16; Figs 14 & 26) showed immediately after the cessation of applied water from sprinklers, a major increase in soil water potential occurred within a matter of days, in spite of regular applications of water applied to adjacent furrows. Interventions investigated to overcome this phenomena included burying of rice straw during bed construction to provide conduits to enhance lateral water movement and promote the growth of roots to sources of water had only slight impact but did reduce soil strength in the affected layer facilitating root growth in one season. The on-farm solution to this constraint, examined in on-farm trials were to sow the crop on the side of the bed closer to the water source. This enabled crops to meet more easily meet their water requirements. However, the fundamental issue of poor lateral water movement has not been completely solved in this project but if resolved would appreciably remove one of major factors constraining dry season crop yield across vast areas in both countries. It is a major issue identified in this project and requires further research.

- An Improved understanding of the processes and driving factors behind yields of irrigated dry season non-rice crops through both modelling and field based research approaches in the lowlands has been developed. Experiments and modeling have shown the importance of irrigation and irrigation application methods/scheduling for successfully growing dry season non-rice crops (see Ballester et al. 2019). Shorter irrigation intervals had positive effects on yields, due largely to the poor lateral water movement indicated above with more frequent applications of less water, tending to 'pulse' applied water into the root zone. This poor lateral movement of water may also affect fertiliser placement and efforts should be made to place fertilisers to consider poor lateral water movement effects on nutrient availability to the rootzone.

- An appreciation for the poor chemical fertility of lowlands soils and their constraints to dry season crop performance has progressed further. Soil testing identified the poor chemical fertility of lowland soils across both countries: lacking adequate amounts of plant essential nutrients, negligible organic matter and associated poor nutrient cycling, negligible nutrient retention (CEC) (e.g. Table 7.2 and 7.3) and poor water holding capacity. Due to the sandy nature of the soil, leaching of applied nutrients will be a common mechanism of loss of applied fertilizer nutrients. Evidence to support this assertion comes from Cambodian radish trials where progressive applications of nitrogen fertilizer (basal plus four topdress applications of urea) led to considerably higher crop yield compared to normal practice of basal fertilizer at sowing plus one topdress application.

- Research into the contributory benefits of fresh organic manures in almost all trials highlighted their importance in assisting to address inheritant soil infertility through contributing to the retention of nutrients as well as a source of other nutrients. The addition of fresh manures which improved yield in almost all trials, we assert occurred through the supply of deficient nutrients; sulfur being a likely contender. Subsequent research trials should aim at unravelling the role of fresh organic manure as a source to supply mobile nutrients, and the role of biochar in contributing stable organic complexes to retard cations against leaching and absorb and retain water. We anticipate these inclusions will vastly improve the fertility of these impoverished soils and improve dry season crop yields in the near future.

- Regional GIS mapping combined with crop modeling highlighted the extensive potential contribution that each province could make to national food security and national GDP. Project research combined with on farm trials consistently showed peanut yields to be typically between 40-50% less than simulated potential yields. Research and on-farm trials showed that maize yield were in most cases closer to simulated potential yield. In fact, research trials at CARDI (2017-18) showed maize grain yield in two treatments (furrow irrigation plus Biochar/manure and sprinkler irrigation with rice straw and biochar) (Figure 7.21) to exceed simulated yield potential indicating that method of application of water and organic amendment can positively impact maize. This indicates also that higher maize yields, beyond modelling predictions are readily attainable through the additions of organic material however, the mechanism by which this occurs is as yet unclear and requires further research.

- Population growth in the region will challenge regional food security and subsequent research needs to find solutions to constraints to peanut and maize production. For all crops, poor water movement reducing plant accessibility to water will be a major limiting yield constraint, while a further and perhaps more fundamental limitation is associated with the poor chemical fertility and high nutrient leaching potential. Trials in the present study have shown the amendment of soil with animal manure and biochar to have a large beneficial effect on crop growth and identifying the fundamental means by which this occurs will improve yield and allow for a reappraisal of these soils from a modelling perspective.

Scientific outputs:

The articles, monographs, manual, theses, and posters that have been published within the frame of the project or are in preparation for publication are listed in Section 10.2.

8.2 Capacity impacts – now and in 5 years

Skills development

A significant advance has been made in developing skills and capacity in the Cambodian and Lao partner organisations. Due to all partners having early career researchers/professionals this has been a very positive experience and the capacity of these partner organisations has greatly benefited. In both countries, undergraduate students have visited or been shown demonstrations exhibiting principles developed by the project, such as methods to apply water and options to supply nutrients to dry season crops. These exhibitions which in Lao coincided with NAFRI's 20th Anniversary were viewed by many university students and were displayed in a number of provinces (Attapeu, Saravan, Savannakhet, Vientiane and Sayabouly) in a roadshow sponsored by World Food Program.

Four engineering students from ITC in Cambodia and two CSU B Agr. Sci. (Hons) have undertaken their final year thesis on topics related to the project and have been involved in activities such as the collection of field data using scientific instrumentation and modelling the results collected by the project. The project has provided scientific training and real world opportunities for the students to undertake research which has given the students highly relevant skills.

Capacity building impacts have occurred across both Cambodian and Lao partners in accessing scientific literature, designing, testing, conducting and analysing experimental data. Multi-disciplinary understanding of many of the constraints to crop establishment in Cambodia and Lao, including direct seeding, irrigation regimes, weed management and agronomy, design and implementation of more complicated research trials, development of training and extension/advisory materials has also been improved.

A significant advance has been made in developing the skills of farmers from Ban NoneYang in southern Lao to successfully produce dry season non-rice crops. Two consecutive visits to the farms of successful dry season crop farmers at Ban PhonTong were arranged to show key NoneYang farmers successful, well-grown, dry season crops; the second visit provided an opportunity for NoneYang farmers to learn the principles of growing dry season crops from other farmers including treating manure in preparation for sowing, land preparation sowing methods to optimize crop access to water, crop fertilization strategies, irrigation management and weed management - farmer training farmer principle. NoneYang farmers now successfully grow dry season and new farmers from the region are able to attend field days, and view and learn new farming methods from key farmers of their region.

The Australian partners have continued to up skill all in-country partners on the use of scientific measuring equipment for undertaking water use studies and irrigation cropping trials. This has included training in a wide range of scientific instrumentation for monitoring and management of irrigated crops (Figure 8.1). These skills are now being utilised by partners in new projects to develop crop water use measurements and benchmarks and identify soil limitations in new projects.

Figure 8.1 Dr James Brinkoff demonstrating to CARDI staff and ITC students, the procedure to install soil moisture sensors and the operation of Io T dataloggers.

A drone training workshop was undertaken with CARDI researchers to implement this emerging technology into current projects. Costs and technical knowledge have now reached a point that it is viable technology to be used in country by project partners. The training was undertaken at CARDI for the SW research group and covered training on physically flying a DJI Phantom 4 drone for collecting high resolution images of field trials and farmers' fields. Participants were given training on manually flying the drone using a controller and the DJI platform. The training also covered the use of drone automation software (DroneDeploy) for automating drone flights and image capture with the drone.

Figure 8.2: CARDI Soil water & Irrigation team undertaking drone training for collecting high resolution aerial images (left) and high-resolution stitched drone images showing irrigation performance across field trials during the irrigation season (right).

The training also covered the use of the DroneDeploy software for stitching image captures from the drone camera together to create maps of areas of interest and using individual spectral data in the Red, Green and Blue bandwidths for creating vegetation indices. Since the training the CARDI SW team have successfully completed hundred individual drone flights and captured images of the research plots over the 2016-2018 irrigation period. This has included image captures not just for this project but also for other research projects such as SMCN/2012/075, SMCN/2014/088 and the technique is becoming a valuable tool for looking at variability in plots and fields.

Figure 8.3: High resolution drone images were used to observe vegetable growth at farmer fields ACIAR SMCN 2014/088 (left) and forage experiments in farmer field at Takeo province, ACIAR project SMCN 2012/075 (right).

Images have been used to identify poor germination, variability across plots, irrigation performance and soil variation. It offers potential for identifying issues and limitations in farmers' fields as well and this aspect will be investigated further during the project.

Local workshops have recently provided training to agricultural advisors to develop their capabilities in advising farmers in the agronomy, methods of water application and irrigation scheduling, and nutrition and nutrient management needs of dry season crops. These skills are now being used to guide inexperienced farmers in preparation, optimal sowing methods and applying nutrients, applying water and managing weed management to achieve optimal performance in their dry season, crop production program.

Geographic Information Systems (GIS) and Crop Modelling

Geographic Information Systems combined with crop modelling have allowed for a regional assessment of agricultural productivity to be performed. This work, originally led by Dr Thavone Inthavong and Dr Camilla Vote, resulted in Mr Khanthavy and several other NAFRI staff attaining great expertise in GIS modelling, using ARC-SWAT and crop simulation modelling using AquaCrop (FAO). With these skills, agro-hydrological maps and simulated crop production potentials for Champassak province in Lao and Kampot, Takeo and Kampong Speu in Cambodia have been successfully produced. Senior managers at NAFRI have recognized the development in modelling skills by Khanthavy and have indicated him as now being ready for higher degree training.

Staff associated with the project have developed a great appreciation in the use of crop models as a precursor tool in agricultural research. The project has extensively use the FAO crop model *AquaCrop* and has sponsored several workshops related to crop modelling. In April 2016, a three day Aquacrop training workshop organised by Dr Camilla Vote was conducted at ITC. The workshop was led by Dr Sue Walker, Professor Emeritus for Agricultural Meteorology at the University of the Free State, Bloemfontein, South Africa. During the workshop, a brief introduction to the model was followed by the presentation of theories and methods to calibrate the model to local environmental conditions and the process of model validation and provided an opportunity for project staff to manipulate the model under expert instruction. Alternate sources of meteorological and soil data beyond that of CLIMWAT were also presented to the group, highlighting numerous input data alternatives that can be used in the absence of field data. Australian staff as well as researchers from NAFRI, ITC and CARDI attended the workshop. These skills have also being utilised by partners in other projects to develop indices for crop water use measures and identify soil limitations. A further workshop, led by Camilla Vote (CSU), was held at ITC, Phnom Penh, Cambodia on 02 – 05 May 2017 for students and researchers who working with the project. The workshop was specifically designed to finalize calibration and validation of the model for maize so that AquaCrop could confidently be used to simulate and predict biomass and yield production in the lowland context in Cambodia. The student workshop also presented an opportunity to assist ITC students with the interpretation of model output, based on specific objectives of each individual and preparation of their theses for examination.

Personnel development

The experience of establishing experimental sites at CARDI and PNG and in farmer fields, has provided junior scientists and technical staff important insights into experimental research design, implementation of new technologies, importance of carefully managed field trials, accurate data collection and subsequent analysis. Soil water monitoring sensors (Gypsum block and EnviroPro) and data loggers (Watermark, MEA Bug and Retriever, MEA, Australia) have been installed in some field demonstration trials and at the experimental sites at CARDI and PNG research stations. Furthermore, information and communications technologies (ICT) were introduced to monitor the trials, improving data collection and enabling cloud storage and online access to project data. For example, the Canopeo application, which provides a rapid assessment of green canopy cover, was used to regularly monitor and record crop growth. It is freely available for both iOS and Android operating systems and enables the user to store original and classified images to the cloud as well additional metadata records including location, planting dates, repetition/treatment identification, vegetation type, vegetation height and any adjustments made to the image during the classification. Additional ICT's were established at CARDI and allowed project staff to remotely access soil tension and temperature data through Google Docs via a 3G/4G Wi-Fi logger/sensor prototype designed by project staff. The introduction of relatively inexpensive or freely available ICT's will improve the delivery of accurate, up-to-date information required to make management decisions; this will serve to familiarise national, provincial and district staff with the range and use of ICT's in agriculture and contribute to better irrigation management and optimisation of water resources during the dry season.

An appreciation of the international nature of agricultural production was gained by Australian students visiting and working on project field sites. Several Australian 4th year Agricultural Science students/Australian Government New Colombo Plan (NCP) Mobility Program interns worked with in country partners on project research over the period 2016-2018 (Table 8.1; Figure 8.4).

Table 8.1 Students that worked with in country partners on project research over the period 2016-2018.

Year	Site of main activity	CSU students involved	Activities
2016	CARDI	Alistair Dart Cheyenne Gibbs	Installation and trialling of soil water application and measurement instrumentation
2016	Phone Ngam Station	Harriet Brickhill Jillian Lyall	Participation in trial management, irrigation. Determination and quantification of below ground constraints soil water
2017	Phone Ngam Station	Grace Rogers	Participation in trial management, and progressive crop biomass harvests
2018	Phone Ngam Station	Tom Jeffreys	Participation in trial management, installation and use of instrumentation, crop biomass harvests

Figure 8.4: New Colombo Plan Mobility program Internees Jillian Lyall (left) and Harriet Brickhill (middle) with Dr Camilla Vote tending peanut research trials located at Phone Ngam station February 2016.

While in-country, student interns worked with project researchers for a period of four weeks contributing in the delivery of project activities as well as assisting local staff in managing and monitoring data-intensive research trials using tools, instrumentation and equipment including tensiometers, flow meters and ICT's previously untested at these sites. These collaborations enabled increased capacity for both local and international participants in the overseeing of day-to-day field trial operations and data collection which resulted in relatively robust, complete datasets of agronomic parameters which have been used to inform future experimental and modelling project activities whilst promoting cross-cultural exchange between young Australian and Cambodian and Lao researchers.

Following their previous placements through the NCP Mobility Program and Australian Government Volunteer program for International Development, Ms Anika Molesworth and two interns (J Lyall & G Rogers) embarked on post graduate studies to partly fulfil and/or add value to the project in areas previously unidentified in the proposal document; this not only enhanced project outputs, but helped to develop capacity amongst Australian early career researchers wishing to pursue a career in international development. One of these interns has recently returned to Lao as a Crawford Fellowship volunteer (J Lyall).

Further capacity has been built through the successful completion and defence of four theses written by ITC students, Soknith Chreok, Sengkong Khov, Borin Heang and Raksmey Na, to meet requirements for the Bachelor of Engineering degree. All studies were based on the use of AquaCrop model and field observations of 2015/16 & 2016-17 groundnut trials at PNG and 2015/16 and 2016/17 maize trials conducted at CARDI.

To get a better understanding of the model and the soil, water and crop processes upon which it is based, these engineering students were also responsible for agronomic data collection in Experiment 1 conducted at CARDI (2016-17), expanding their knowledge base beyond typical engineering studies.

The greatest indicators of success in capacity building for the project partners have been:

- In research, demonstration and education activities, an increasing quality of trials implemented by the project team have been achieved. Research and farmer demonstration trials have been improved over the life of the project. Specifically in Lao, capacity has been significantly improved, particularly in relation to working with key farmers and using demonstration trials and other aids to extend knowledge to aid adoption by new farmers. Farmer with no dry season crop experience have indicated by way of survey the high value placed on field days as valuable tools in developing networks and in learning new ways in their transition into growing new crops.

- More than 130 farmers attended field days/events run by the project in both countries. These events, where farmer talked with farmers, helped farmers to gaining skills in land preparation and crop establishment, water and nutrient management for a range of dry season crops. Partners have observed changes in crop productivity, and in water and nutrient management based on farmers' interaction with project activities in the target provinces. Recommended change in farm practices have not only improved productivity, but have increasing farm income and improving farm profits through increasing yield and reducing input costs.

- Provincial Departments and District Offices of Agriculture staff have been exposed to the project and actively involved in implementing the project trials, participated at field days, attended project sponsored specialist workshops and have improved their capacity to support adoption among farmers

- This project has helped to improve the undergraduate curriculum and learning experiences for undergraduate irrigation hydrology curriculum at the Institute of Technology Cambodia

- This project has introduced and consolidated new capacity with country partners in terms of crop modelling and resource evaluation using GIS. Partners are now either using or able to use these tools in other projects to assess landscapes capable of supporting new industries, in simulating potential crop productivity given particular levels of inputs and prior to conducting field trials to predict the impact of particularly interventions on crop system output.

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

Regional modelling undertaken by the present project highlights the potential for substantial gains to be made in food production and economic returns in relevant zones across each country through the adoption of non-rice crop production during the dry season. GIS mapping and modelling established baseline dry-season crop production potential for relevant zones across each country. Based on arable land within provinces of interest for Lao and Cambodia, potential production of maize and peanut for Cambodia were 1,450,123 and 1,939,386 tonnes, and for Lao, were 906784 and 531353 tonnes respectively. Assuming a current price received of about $0.65/kg for these commodities, maize and peanut production in Takeo, Kampot and Kampong Speu represent regional income of $942.6 and $1260 million, and in Champassak province, of $589.4 and $345.4 million respectively. While these amounts could not be realized in their entirety due to assumptions made in the modelling process, trial data conducted within the project supports the contention that adoption of dry season crop production will provide a significant economic benefit to farm incomes and across the region.

Participating farmers have improved their incomes from dry season crop production and following project recommendations. Analysis of farmer participant trials in both countries demonstrate the income benefits from dry season crop production and the improved impact on farm profits. Maize demonstration trials in Chhouk district of Kampot Province Cambodia show that by using fertiliser recommendation rates with soil amendment material (Biochar) farmers can improve maize production and gain additional profit from 600-1000 $/ha. Similarly, in Prey Kabas district of Takeo province, using improved soil management technology, radish farmers can gain additional profit 500-1000 $/ha. Trials in

Ban NoneYang in southern Lao illustrated the benefits of using project endorsed crop establishment techniques combined with organic amendments (manure and rice straw), and showed the productivity of a range of dry season crops i.e. maize to be substantially increased, increasing from farm incomes from 3705 to 6124 $/ha. Benefits were also showed with peanut and long bean production which could generate farm incomes of 2133 and 3807 $/ha respectively.

The economic benefit from the adoption of these technologies differs between the two countries, particularly given that dry season crop production is at present more widely adopted in Cambodia than in Lao. In Cambodia, the impact is largely driven by farmers accepting new technologies; in Lao, benefits accrue both from the adoption of system intensification through the growing of crops in the dry season as well as from adopting best soil and agronomic management technologies. Using these assumptions and farm production figures demonstrated in this project, assuming over time, that 20% of the regions farmers adopt improved crop management technologies, and produce dry season crops on 20% of their land, using maize as an example, the regional impact for Cambodia could be as high as an additional 57,808 t of maize being produced generating a further $26.8 million regionally. In Lao, the regional impact could be even greater with 91,253 t of maize being produced in Champassak province generating up to $59.3 million across the region. This would have a major economic impact regionally and nationally.

It is clear from the experimental data and modelling results that dry season cropping on the lowlands does have significant economic potential. However, it is a challenging environment for growers and further research needs to be undertaken to continue to support these moves. Already project farmers which have previously never grown dry season irrigated crop in the lowlands have been able to achieve commercially viable yields. For example, Ban NoneYang farmers who grew peanut in 2017-18 achieved 2.14 t/ha using improved fertilizer management strategy. But regional modelling associated with this project shows that peanut yield for Ban NoneYang under ideal conditions should be 3.52 t/ha, indicating that even with our current recommended management strategies, significant constraints still exist regarding dry season crop production. It is clearly apparent that further research is required to assist in solving these constraints so that production in these environments is maximized and that economic potential achieved.

8.3.2 Social impacts

An improvement in the productivity and profitability of small landholder agriculture will have numerous positive discernible societal impacts including improvement in the incomes of small landholders, improved access to a wider range of higher quality food stuffs as well as the creation of further opportunities for rural employment.

The appeal of dry season crop production in Cambodia and Lao has been advancing, and improved practices as demonstrated in this project which improve farm incomes by reducing input costs and increasing productivity is adding to the growth in appeal. Prior to the commencement of this project, commercial scale dry season crop production in Ban NoneYang was negligible. However, observations by the project leader of the adoption of dry season crop production by non-project farmers grew from 0 in 2016-17 to 3 in 2017-18 (see Annual Report Social Impacts 2017-18) to 6 in 2018-19. A project survey conducted in at a field day in Ban NoneYang in February 2019 showed further growth in interest by new farmers and a willingness to trial for themselves dry season cropping activities using project recommended strategies. Action learning from farmers and attending field days were acknowledged as valuable information sources and indicated the need for further information regarding diversification of crops and connections to markets as important to galvanizing the social influence of small holder farm intensification.

There is evidence of better coordination among government extension agencies, NGOs, private sectors and local service providers for the judicious use of scarce research and extension resources. Project field days are now regularly attended by local and region government advisers, and project advisor workshops are well attended by regional extension agencies who require further knowledge regarding the management of dry season crops. Comments from the Head of the District Agriculture and Forestry Organisation (Sukumar District, Champassak Province, Lao) at a project field day in February 2019 at Ban NoneYang reinforced the importance of this project and the position of dry season crops regarding the Lao governments view as being: 'The Governments position is that it approves dry season crop production and intends to declare None Yang village an Agriculture Village where farmers will be able to come and learn new skills and techniques.

Project partners have formed strong links with each other and the community, this is particularly evident by the excellent turnout at project field days and the ready engagement of young career researchers of the partner organisations in their interactions with community.

8.3.3 Environmental impacts

The project recognises the potential for two immediate environmental impacts associated with water use and fertilizer use.

The project advocates the irrigation of crops using either on-farm stored water (ponds) or groundwater. As channel water is rare and that ponds are expensive, and that many farmers have access to groundwater via small shallow ground bores, that increased uptake of these practices are likely to lead to greater use of ground water which may at times lead to a reduction in the height of groundwater. We recommend that relevant government authorities undertake investigations to quantify the sustainability of the groundwater resource in the appropriate districts and as necessary, initiate means to assess resource use and regulate its use. Improving water management has flow-on environmental impacts in improving efficiencies and potentially reducing the amount of water required for crop production. Improving efficiency increases sustainability of production systems and may reduce the extraction of water from river systems if correct policies are in place.

Unused fertilizers can detrimentally impact the environment. Recommendations for applications of fertilizer have been made so that the correct amount of nutrients are supplied to progressively meet crop needs at critical times, reducing the risk of leakage and unintended negative environmental impacts, associated with their overuse**.**

At this stage, no negative environmental impacts have been identified from activities or recommended practices which have been undertaken in the project, however with the general move to mechanisation and more intensive farming practices such as dry season cropping, there are potential issues particularly in relation to pesticide use and groundwater extraction. These are two issues that do warrant further investigation or policies in place to ensure any environmental impacts are minimised.

8.4 Communication and dissemination activities

The project has undertaken a broad range of communication and engagement activities applicable to a wide audience. These have ranged from individual farmers (i.e. field days and demonstrations) to policy makers from for example, the Lao PDR Ministry of Agriculture and Forestry who have recommended that the MAF Department of Agriculture and FAO SAMIS project extend project technical advice to extension services and rice farmers to improve productivity and profitability of non-rice crops in the central and southern provinces. Traditional scientific communication methods i.e. journal papers and conference have been produced in the project and are listed in section 8.1. These have covered a board range of conferences focusing on both policy makers and the scientific community

Additional communication and dissemination activities not captured in section 8.1 have included:

Farm/village field days:

Technology generated by the project has been extended to in excess of 145 farmers attending field days along with 60 government advisory staff and regional and government officials.

- Snoaw Village, Takeo province. – March 2016: Purpose of the field day was to introduce to delegates the longitudinal benefits of improving soil fertility through the use of lime and strategic and timed application of nutrients.

- Snoaw Village, Takeo province. –August 2017: Purpose of the field day was discuss with farmers the use of lime and strategic and timed application of nutrients to improve the efficiency of nutrient use, improving production and reducing production costs. The field day coincided with the Mid Term Review of SMCN2012/071.

- Ban NoneYang, Champassak province. - February 2018: Field day demonstrating improved productivity and yield enhancement of maize and long bean through off-furrow sowing to improve plant access to water and the inclusion of rice straw mulch on beds to reduce evaporation.

- Ban NoneYang, Champassak province. - February 2019; Field day demonstrating: 1) the effect on productivity, yield enhancement and impact on farm finances of the inclusion of animal manure and rice straw on maize, peanut and long bean production and 2:) the use of crop calendars to guide farmers in the critical steps and appropriate timing of operations to grow dry season maize, peanut and long-bean (see appendix 1). Farmers attending surveyed regarding their activity or interest in dry season crop production. Many were interested to learn from the projects work - about half had not grown a dry season crop and were intending to try cropping the following season and found project information and resources very useful. Particularly, favourable comments were made about the Crop Calendars (Section 8.1; Appendix 1).

- Preysbov Village, Kampot Province. - March 2019: Field day demonstrated the productivity and yield gains through the more timely and strategic use of fertilizers and the incorporation of biochar in maize farming systems.

- Ban NoneYang, Champassak province. - February 2020; Field day at Mr Som's farm, demonstrating the comparison between manure only fertilization versus inorganic fertilizers with urea topdressing on maize peanut and longbean production.

- *Farmer Training workshops*:

    - February 2017 *Farmers training farmers*: Ban NoneYang farmers visit Phontong district to observe high yield maize production. Farmers discussed land preparation and crop protection and crop management.
    - December 2017 *Farmer training farmers:* Sequel visit for Ban NoneYang farmers to observe Ban PhonTong farmers land preparation, sowing and crop establishment methods.

- *Farm advisor (PAFO and DAFO) training workshop February 2020:* One day advisor training workshop to guide advisors on the techniques researched and adopted by the project to improve crop productivity:
    - crop seasonal water requirement and scheduling irrigation to maximise productivity.
    - key growth stages and the agronomy of groundnut/peanut and sweetcorn
    - dry season crop nutrient requirements and the role of organic residues and fertilizers in dry season crop production.
    - Use of GIS and modelling to determine crop production potentials across southern Lao and Cambodia

  Travelling Roadshow: The idea for a lighthearted show for school children to demonstrate the benefits of diversification amongst smallholders in order to improve livelihoods and income streams was conceived and organised by the project Research Fellow, Dr Camilla Vote. The show which used clowns to convey themes, played to school children whose families were uninvolved in research or extension networks and were otherwise unlikely to hear project messages. A poster of the presentation was presented at the Innovation fair as part of an EU funded CDAIS project (Agrinatura, FAO and the GoL) (Appendix 2)

Conference attendance

- Layheang Song attended and presented a paper at the 18th Australian Agronomy conference Ballarat Australia (September 2018)
- Camilla Vote attended and presented a paper at 22nd International Congress on Modelling and Simulation (MODSIM2017) Hobart Australia (December 2017)
- Annika Molesworth attended and presented an oral poster at the Irrigation Australia International Conference Sydney Australia, June 2018

9 Conclusions and recommendations

9.1 Conclusions

Key messages:

The determination of areas suitable for, and simulated production potentials of several dry season crops as generated by the project identify maize production on low fertility soils across the region to be frequently close to simulated yield potential, but peanut production on the same soils as being typically well below production potential.

A previously unreported phenomenon of poor lateral water movement in soils which predominate the Mekong alluvial lowlands, identified early in this project, is a major constraint to dry season crop production on the lowlands soils of both countries and across the region. This edaphic feature vastly reduces the efficiency of irrigation on traditional bed/furrow systems, restricting crop access to water, curtailing dry season crop production. The inclusion of organic residues showed promise through improved yields with maize, but limited access to applied water still undermined crop yields - maintaining yields well beneath their climatic threshold.

Alleviation of chronic nutrient deficiencies as typically afflict lowland soils was optimally achieved in farm trials through progressive applications of nutrients through the season rather than when applied all at sowing, improving productivity, reducing input costs, and resulting in less movement of nutrients into the environment. Despite the resultant improved efficiency in crop nutrition, peanut yield remained considerably beneath simulated potential yields indicating further scope for management to readily improve productivity.

The inclusion of rice hull biochar to maize crops in several trials illustrate benefits of improving soil fertility in improving crop (maize) yields, considerably beyond modelled predictions (15-20%) and identifies that the scope to further improve yields exists through the removal of soil nutritional and hydrologic constraints to crop production. While evidence of improved dry season crop yield following biochar amendments is compelling, the mechanism is as yet unclear, and research aimed at revealing the means by which this occur would uncover management strategies, adoptable on-farm which would immediately boost on farm crop yields and yield potentials.

A major increase in the capacity of young scientists has occurred during the project in research methodologies and research training in relation to dry season non-rice cropping, and in the evaluation of natural resources across landscapes using GIS technologies and in the use of crop modelling and simulations. The project has been able to provide research training for six undergraduate students to complete their thesis associated with Bachelor degrees or honours thesis on project research topics related to water and nutrient management or other themes relevant to this project. Additionally, knowledge generated in the project is now being used in the teaching curriculum across both Cambodia and Lao, and in Australia.

Research scientists in partner countries have been introduced to new technologies and approaches and now have the ability to undertake dry season irrigation trial studies across a range of cropping systems using a variety of techniques. Previously, little focus on non-rice based crops had been undertaken by researchers in the area. Additionally, a number of early career Australian scientists associated the project now have significant knowledge of the agricultural landscape and major issues in land and water management within Cambodia and Lao. This also includes knowledge of major stakeholders, impact pathways and in-country operational issues. This knowledge will allow faster on-ground impacts and efficiencies of operation on any future projects that many arise.

During the project, *farmers learning from farmers* was an approach successfully used to enhance knowledge transfer through experiential training of early farmers which had positive outcomes and saw immediate practice change by participants. This model worked well and had positive response from farmers who participated. This is a model of extension which should be further utilised to expand uptake of dry-season cropping moving forward.

9.2 Recommendations

Recommendations

The fundamental issue of poor lateral water movement from furrows into beds was identified clearly in this project as a major limiting constraint in both countries, which has not previously been well documented nor understood. This is a major limitation, which significantly limits crop yields for non-rice crops in both countries. Further efforts should be undertake to investigate options and solutions to overcome this constraint. While strategies such as plant placement in furrow and side of beds have been developed and used in this project these approaches increase waterlogging risk. If the lateral water movement constraints could be overcome then this has significant potential for major impact across large areas to increase dry season non-rice crop yields. Touch Veasna, an early career researcher with CARDI has a John Alwright Fellowship and will pursue a PhD which intends to focus on this constraint.

Crop modelling associated with the project identified two anomalies:

1) Despite most maize trials achieving potential yields commensurate with simulated potential yield, the addition of biochar elevated yields considerably beyond modelled yield potential (by 15-20%). While biochar may enhance the production of dry-season crops, the mechanism remains obscure. This farm scale intervention represents a major opportunity by which dry season crop yields can be substantially increased but to use biochar to achieve sustained yield increases, the mechanism by how it works and nuance's regarding its use need to be revealed to allow yield enhancing production strategies to be addressed.
2) Typical on-farm peanut production remained well below modelled production potential. An appreciation for crop water requirement were clearly established early on in the life of the project as was an insight into the crop's fertilization strategy. But in all trials, yields were typically well beneath modelled expectations, indicating deficiencies in other non-researched nutrients exist or constraints associated with growing DS-crops under these conditions are not immediately obvious – perhaps incidental to occasional waterlogging. The production of dry season crops are desirable from farmers' perspective and substantial markets for dry season crops exists, but for farmers to benefit from growing these crop, there is a considerable need to learn how in a cost effective manner, to manage other less well understood constraints so that yields of a diverse range of crops growing on these soils come closer to matching their edaphic and genetic potential.

On-farm water management research skills, by Cambodian and Lao scientists need further support for addressing the countries future needs in irrigated agriculture, particularly focused on water management in non-rice crops. Irrigation water management under these conditions is quite different to traditional knowledge gained from irrigating rice and requires different approaches to overcome constraints. In-country researchers had limited knowledge before this project on non-rice crop water management in irrigation situations and this knowledge needs to continue to build in future projects and activities. This support should include future training linking agronomic and on-farm irrigation methods and infrastructure to reduce risks with irrigation cropping to allow diversification. For example, techniques such as laser levelling in Cambodia should continue to be promoted and introduced into Lao to assist with water management on non-rice irrigated dry season crops.

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10.2 List of publications produced by project

Peer Reviewed Journal papers, Monographs and Conference Articles:

Ballester, C., Vote, C., Hornbuckle, J., Inthavong, T., Lim, V., Oeurng, C., Quayle, W., Seng, V., Sengxua, P., Sihathep, V., Touch, V., & Eberbach, P. (2019). Effects of frequency of irrigation on dry-season furrow-irrigated maize and peanut production in

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Non-refereed publications, industry reports and farmer notes

Na, R., Vote, C., Oeurng, C., Song, L., & Lim, V. (2017). *Predicting maize yield response to climate change: Case Study in Cambodia*. Poster session presented at 2nd International Symposium on Conservation and Management of Tropical Lakes, Siem Reap, Cambodia.

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NAFRI (2019b). Advisory for Maize Planting in 2020 Growing Season for Soukoumma District, Champasack Province, Lao PDR

NAFRI (2019c). Advisory for Peanut Planting in 2020 Growing Season for Soukoumma District, Champasack Province, Lao PDR

CARDI (2019a) Nutrient Management for maize production in Lowland of Cambodia. CARFI farmer

note).

CARDI (2019b) Crop Calendar for dry season maize production in the Lowlands of Takeo, Kampot and Kampong Speu Cambodia.

Theses emanating from the project:

Molesworth A (2020) *Optimising poultry litter as an organic amendment in cropping systems. Doctor of Philosophy, Deakin University, Griffith Campus, Griffith, NSW, Australia (in examination)*

Rogers G (2018) *Peanut (Arachis hypogaea) production in Lao PDR: Digital canopy measurements as a predictive indicator of above and below ground biomass development and grain yield*. Bachelor of Agricultural Science (Hons), Charles Sturt University, Wagga Wagga, NSW, Australia

Lyall, J (2017) *A comparative study of dry season, non-rice crop production and management practices in the rice-based farming systems of southern Laos.* Bachelor of Agricultural Science (Hons), Charles Sturt University, Wagga Wagga, NSW, Australia

Heang, B. (2017). *Improvement of Aquacrop performance on the development of maize.* Bachelor of Engineering Engineer Thesis Report, Institute of Technology of Cambodia, Phnom Penh, Cambodia.

Khov, S. (2017). *Modelling Growth and Yield of Peanut in Response to Irrigation Treatments in the Lao Lowlands.* Bachelor of Engineering Engineer Thesis Report, Institute of Technology of Cambodia, Phnom Penh, Cambodia.

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Chreok, S. (2016). *Effect of irrigation water regime on the development and yield of maize.* Bachelor of Engineering Engineer Thesis Report, Institute of Technology of Cambodia, Phnom Penh, Cambodia.

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K. Souliyavongsa, Inthavong, T, Vote C, Hornbuckle J, McCormick J, Sarith H, Lim V, Veasna T, Oeurng C and Eberbach P (2020) Agro hydrological mapping to determine dry season market-oriented smallholder production potential in the rice-growing lowlands of Lower Mekong Basin using ArcSWAT: in Champasak Province, southern Laos and three provinces in southern Cambodia. Agricultural Water Management *(in preparation).*

Ballester, C., Vote, C., Hornbuckle, J., Inthavong, T., Lim, V., Oeurng, C., Quayle, W., Seng, V., Sengxua, P., Sihathep, V., Touch, V., & Eberbach, P.(2020) Evaluating strategies to improve water availability and lateral root growth of furrow-irrigated peanut and maize grown in the rice-growing lowlands of the Lower Mekong Basin. Agronomy *(in preparation)*.

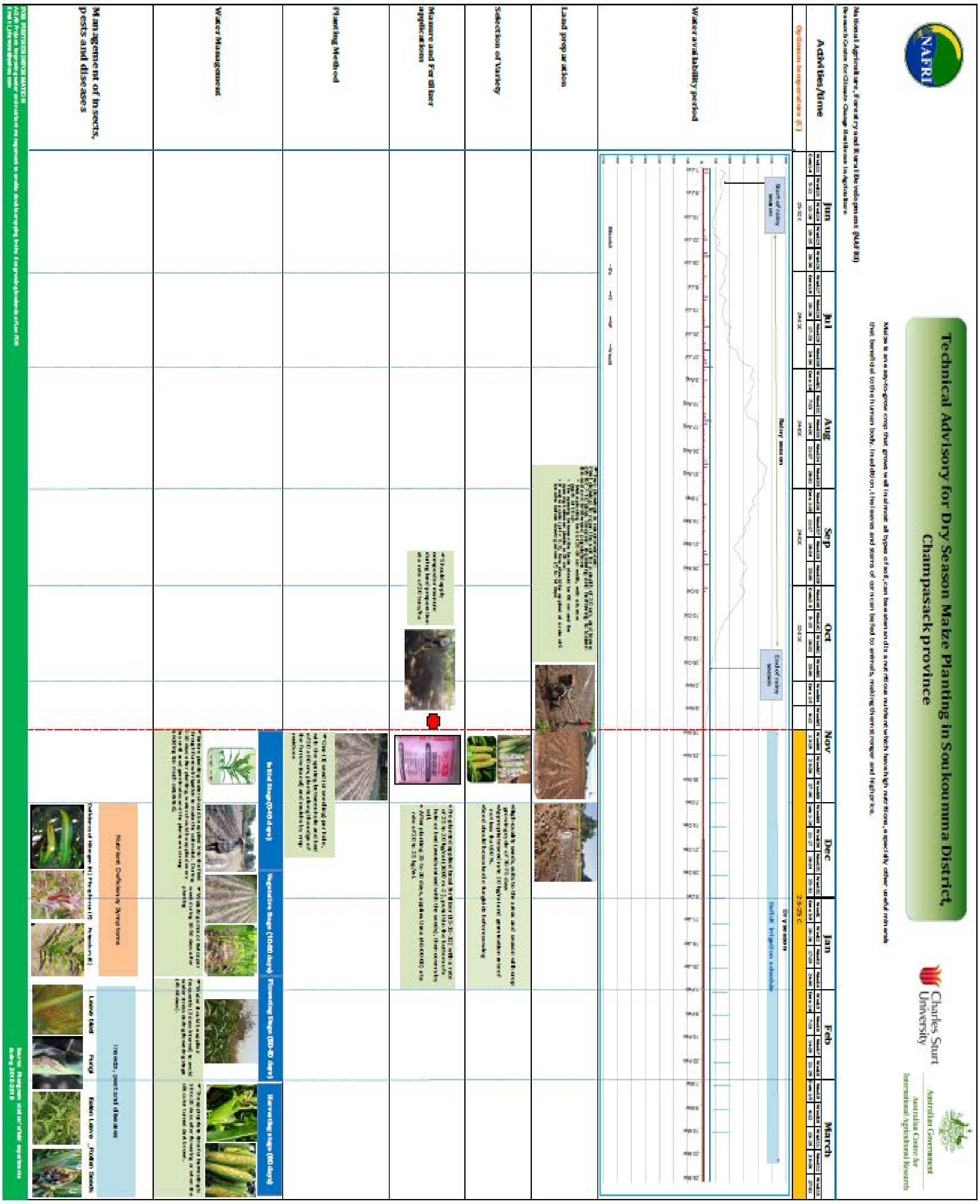
Vote C, Khov S, Hornbuckle J, Inthavong T, McCormick J, Oeurng C, Sengxua P, Sihathep V, Eberbach P (2020) Performance assessment of AquaCrop for smallholder peanut (*Arachis hypogaea*) production under varying irrigation and soil management strategies in the rice-growing lowlands of southern Laos. Experimental Agriculture (submitted).

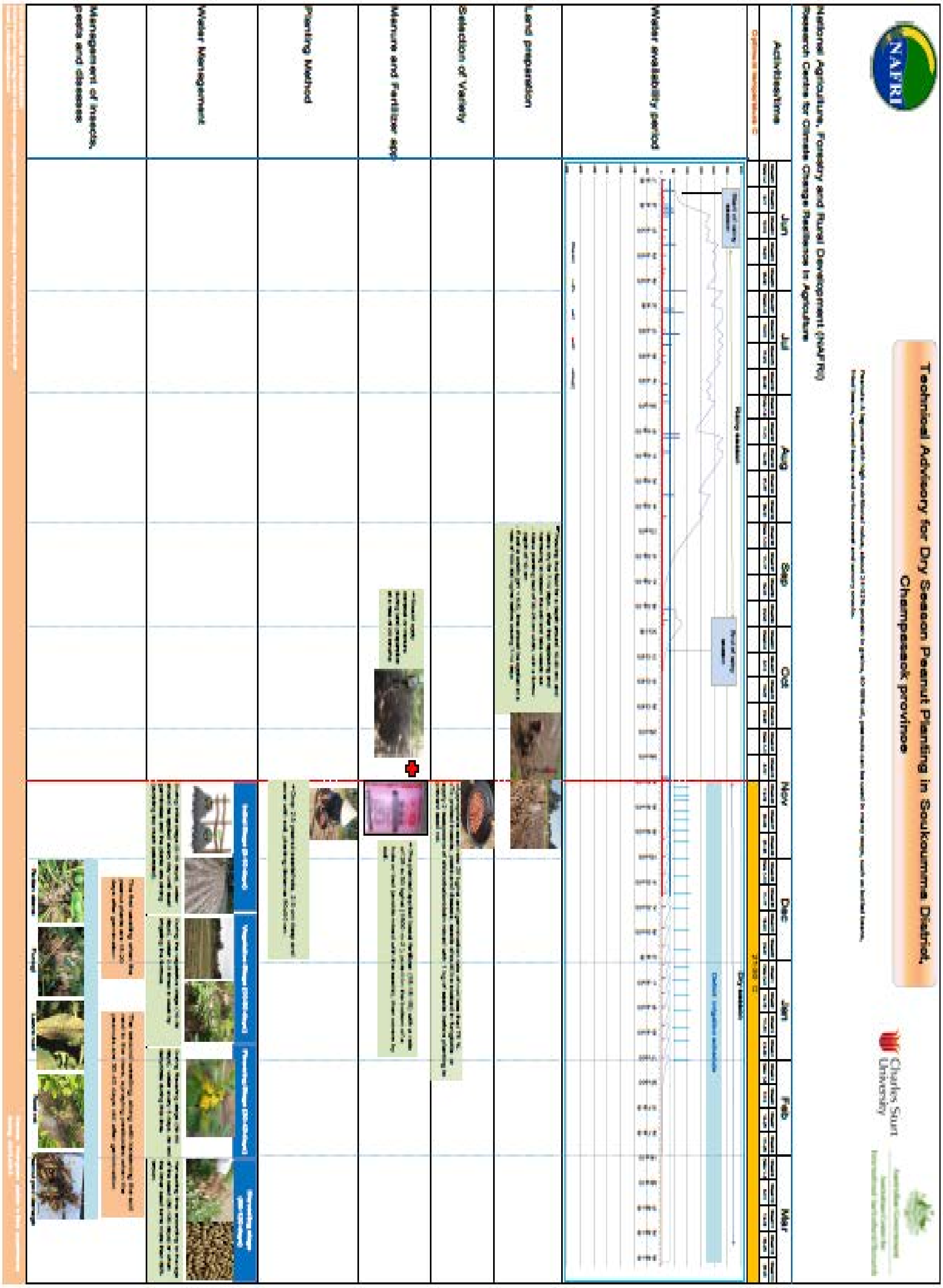
Sarith H, Veasna T, Lim V, Martin R, Ballester-Lurbe C, McCormick J, Hornbuckle J and Eberbach P (2020) Manual for Maize Production in the Lowland of Cambodia *(in preparation)*.

11 Appendixes

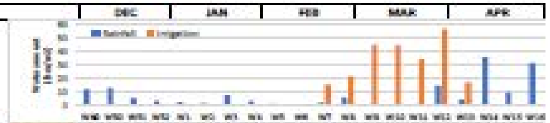
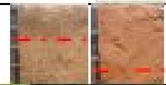
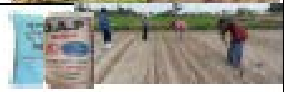
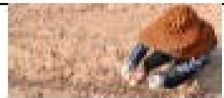
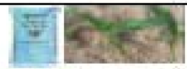
11.1 Appendix 1:

Crop calendars Lao (maize and peanut) and Cambodia (maize) developed by the project and distributed at farmer field days to illustrate the main tasks and timing of critical events in the dry season crop growing cycle




Technical Advisory for Dry Season Peanut Planting in Soukhoumma District, Champassak province
National Agriculture, Forestry and Rural Development (NAFRI)
Research Centre for Climate Change Resilience in Agriculture
Charles Sturt University
Activities/time
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Water availability period
Land preparation
Selection of Variety
Manure and Fertilizer app
Planting Method
Water Management
Management of insects, pests and disease

CROP CALENDAR FOR DRY SEASON MAIZE PRODUCTION IN LOWLAND

ACTIVITY	DESCRIPTION	
Weekly Rainfall characteristic (mm)	Source: CARDI data, 2009 to 2018	
Soil group identification: There were two major soil groups in rainfed lowland occupied about 50% of the main rice growing area.	Prateah Lang (PL): -0-15cm=Sandy, 15-50cm=Loamy or Clayey Prey Khmer (PK): -0-50cm=Sandy	
Land preparation (Plough-harrow) and beds raising.	Twice (1st plough, 2nd plough and harrow). Raising bed as soon as harrowing done.	
Basal Fertilizer application and Sowing	Fert. rate(kg/ha): N=60, P_2O_5=46, K_2O=30 Type (g/m^2): DAP=10, Urea=5, and KCl=5 How to apply: put in furrow and buried in band Amendement: CM=5t/ha put in furrow and buried in band, and Biochar=5t/ha apply on suface and cooperate with soil. Lime 1-2 t/ha if soil pH is below 5.5	
	Planting in row: Plant spacing: 30cm Row spacing: 65cm Sowing depth: 2-4 cm Sowing method: place soaking seed into hole on the top of bed, cover it with soft soil.	
Method weed control	Two weedings are recommended in Cambodia. The first weeding should be done two weeks after germination and the second should be done two weeks later. Weeding is normally done by hand hoe and corner weeder on the bed and in furrow, although herbicides can also be used. Commonly used herbicides include applied pre-emergence, and applied postemergence.	
1st Topdressing Fertilizer	Fert. rate(kg/ha): N=60, and K_2O=30 Type (g/m^2): Urea=8 and KCl=5 will be applied 2 weeks after seeding. How to apply: place them in the hole between plants then cover with soft soil.	
Irrigation	Method: furrow irrigation Irrigation frequency (15-17 litres/m^2): 4-6 days intervals depend on soil water condition and ground water level.	
Pest and disease	The most important maize diseases in Cambodia are Southern leaf bright (1), downy mildew (2), corn rust, sheath blight (3), and stem rots (4). The best control for these diseases is varieties that are resistant or tolerant to them. The most important field pests of maize are Asian maize borer (stalk borers)(5) and armyworms (6). The most common borers are the spotted stalk borer (Chilo partellus) and the pink stalk borer (Sesamia calamistis). These are controlled by applying a pinch of dust or granules of an insecticide such as Endosulphan 4% dust, at 5 kg/ha, Cymbush dust 1% at 2.5 kg/ha, or Sumicombi 1.8% at 5 kg/ha. Once the damage is assessed to be economic, insecticide should be applied to all plants in the field. Armyworm (Spodoptera exempta) occurs in major outbreaks. These pests are controlled at the national level through aerial spraying of insecticide. Hand sprayers and ultra low volume applicators (ULVA) may also be used for local control. Chemicals such as Fenvalerate 75C at 2 L/ha, Malathion 50EC at 1.25 L/ha, and Cypermethrin 25EC at 0.5 L/ha may be used.	
2nd Topdressing Fertilizer	Fert. rate(kg/ha): N=60 Type (g/m^2): Urea=8 will be applied 2 weeks after 1st top-dressing. How to apply: place them in the hole between plants then cover with soft soil.	
Harvesting	Method: manualy Duration: 80 days (green), 85 Days (rippening) for Cambodia Maize1 (CM1) : 65 days (green), 90 days (rippening) for hybrid variety (V8).