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Improved irrigation water management to increase rice productivity in Cambodia

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Contents

1 Acknowledgments

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2 Executive summary

Rice is the staple food in Cambodia and accounts for 70% of the daily calorie intake. Cambodia is lagging behind its Asian neighbours in rice production, yields in Vietnam and Laos being 25 to 50% higher. Poverty is prevalent in Cambodian rice farming communities largely due to low yields (2.4t/ha). However, evidence shows that with improved water management and increased use of inputs, yields could be significantly increased.

This project aimed to enhance the livelihood of rice farmers by improving water productivity and reducing yield penalty due to crop variability. These improvements will inevitably lead to increased water security and hence reduced agronomic investment risk. A number of basin scale studies have determined that overall Cambodian water resources are adequate now and into the future. However, temporal and spatial water availability is variable, the rice crop often suffering from stress related to drought periods during the wet season and poor irrigation management in dry season crops. Rice production in Cambodia can be greatly enhanced by an improved understanding of crop water requirements and how to plan, schedule and manage water and fertiliser at a field scale to maximise production. This project has developed information and practices on water and nitrogen management with the aim of increasing farmer's profitability and thus improving their livelihoods.

Integrated socio-economic and Bio-physical survey of agronomic and water management factors limiting rice production

In the survey area in Takeo province, 70% of household income is generated from rice growing, with the remaining household income derived from off-farm work (11%), livestock (11%), non-rice crops (3%), other income (3%) and fish (2%). Across the province, rice growing was dominated by Dry Season Rice (DSR; 90% of farmers), followed by Early Wet season Rice (EWR; 56%) and Main Wet season Rice (MWR; 49%). There were seasonal differences in yield with DSR yielding 5.5 T/ha compared to 4.0 T/ha for EWR and 3.3 T/ha for MWR. Yield was positively correlated with N fertiliser across all nine villages within the three districts. There was no correlation between yield and P or K application. In EWR and DSR nearly all farmers (98%) applied inorganic fertiliser to their crops whereas in MWR it was slightly lower at 90%. Farmers applied inorganic fertiliser in the form of urea, DAP and NPK (20:20:15) to crops in all seasons. Two main soil types occur in the areas surveyed in the province, Prateah Lang (sandy soil type) and Kbal Po (clay soil type). There were also differences in yield by soil type in different seasons, with lower yields in the lighter Prateah Lang soils in MWR and DSR crops. Most farmers (89%) used some form of levelling (animals, hand tractor and 4-wheel tractor) to prepare fields for sowing. Of the farmers that supplied details about field levelling, the majority used hand-tractors (64%) to level their fields, followed by 4-wheel tractors (16%) and animals (5%). Of the farmers surveyed, 96% used some form of supplementary irrigation (ground or/and surface) to grow their crops. The primary source of supplementary irrigation was surface water (92% growers) followed by ground water (25%). Rice in Takeo were dominated by modern variety IR504 accounting for 73% of crop sown, followed by 21% traditional and 6% CARDI varieties. There is a very strong relationship between the distance to water source and percentage of farmers experiencing water shortages, and in different seasons, distance to water sources was highly negatively correlated with yield.

Crop water use and nitrogen field and modelling studies

A number of field based crop water use and nitrogen fertilizer studies were undertaken in the project. These field studies where then used in two modelling environments – APSIM and CROPWAT to further investigate water and nitrogen interactions on rice yields for dry season rice.

The simulated evapotranspiration over seasonal analysis was very similar across all irrigation treatments and only declined slightly from 705 mm under Continuous Flood to 678 mm at 8 day refill after disappearance of surface water. The key message from these data is that irrigation scheduling has very little effect on water depletion through evapotranspiration (i.e. it does not save real water). APSIM modelling studies indicate that, while delaying irrigation will decrease the amount of irrigation water applied, there will be a yield penalty (greater than 0.20 t ha-1) if the delay is greater than 2 days after the disappearance of floodwater.

Modelling efforts suggest that to obtain yields on the Prateah Lang soil group greater than 4 t ha-1, a nitrogen management strategy of at least 50 kg N ha-1 needs to be applied. To target 6 t ha-1, a nitrogen management strategy of 100 kg N ha-1 is required and a target yield approaching 8 t ha-1, would require a nitrogen management strategy of at least 150 kg N ha-1. These target yields are highly dependent on adequate water being available, good nitrogen management (rate, placement, timing, form) and that the paddy fields are weed, pest and disease free.

A field experiment was carried out on Prateah Lang soil at the CARDI Research Station to determine the effect of nitrogen (N) rates and water regime on rice growth and yield, and to determine the interaction effect of irrigation water regimes and N rates on rice growth and yield. It was conducted in the dry season from February to June, 2014 (sown on 21st February, transplanted on 21st March and harvested on 6th June), using Sen Pidao (aromatic) early rice variety. This experiment was laid out in split plot design with 3 replications and 2 factors (1) three water irrigation regimes as main plot and (2) two N rates as subplot. The plot size 5m x 5m (total 18 plots).

Water treatments were as follows: W1-Continuous Flooding, W2-Alternate flooding and Non-flooding of 15 days interval, and W3-Non-flooding (Wet Soil). Nitrogen treatments were F1- as of Recommendation Rate (N=100; P_2O_5 -P=40; K_2O -K=80) (kg/ha) and F2- as of 1.5 times Recommendation Rate (N=150; P_2O_5-P=40; K_2O -K=80), in kg/ha.

Results of the experiment indicated that the number of tillers was 271-358 tillers/m^2 and panicle number was 224-291 panicles/m^2, and the average plant height was 48-57 cm. Even though applying N at 150% of recommended rate (150 kg/ha) rice grain yield did not increase if P and K rates were not also increased. However, the irrigation regimes strongly affected rice growth and yield. Continuous flooding which required 6760 m^3/ha of irrigated water produced the highest grain yield with average yield of 3.58 t/ha, followed by flooding and non-flooding conditions (15 days flooding, 15 days non-flooding) which required 3970 m^3/ha of irrigation water produced an average yield of 2.9 t/ha, and non-flooding which required 2740 m^3/ha of irrigated water produced grain yield about 2 t/ha. The continuous flooding had low water use efficiency (WUE) produced only 0.53 kg of rice grain/m^3 of water, where alternative flooding and non-flooding, and non-flooding (wet soil) produced 0.73 to 0.76 kg of rice grain/m^3 of water.

Establishment of Laser Land Levelling

Demonstration trials of laser land levelling in Kandal Stung, Kandal province and upper Slaku, Takeo province where undertaken in 2012. Demonstration trials of laser land levelling were also conducted at 2 locations in Takeo (6ha) and Kampong Thom (10ha), in 2013. Re-survey of land levelling in 2012 and yield changes (rice cultivation after laser land levelling) were recorded on laser land levelling. Further demonstration trials of laser land levelling have been conducted in Pursat (~ 10 ha) in 2014 and re-survey of land levelling in undertaken in 2012, 2013 and yield data after laser land levelling were collated. A final 15 ha of demonstration trials of laser land levelling at Kampong Thom Province were undertaken in 2015 and re-survey of land levelling form 2012, 2013 and 2014 was undertaken.

The trials have shown that after laser land levelling, dry season rice yields were increased and farming inputs were reduced because of the change of transplanting to direct seeding, improved weed control and easier water management on the laser levelled fields.

Topographic survey of laser levelled land from the first year (2012) to third year (2014) indicated that the land level did not change significantly due to standard farmer practise of ploughing and harrowing. This would indicate that the beneficial effects of laser land levelling under standard practice would be at a minimum 3 years and most likely greater than 5 years.

On farm field trials on laser land levelling compared lasered to non lasered paddy's under the same management were conducted at three location with four crops showed that land levelness reduced weed biomass by up to 50%. Water savings of up to 300 m^3/ha were achieved and rice grain yield increased by 573 kg/ha. A further study conducted to identify the effects of cutting soil to fill the low part of rice paddy was investigated. The results showed that the rice grain yield was increased on all the land areas involved from second to fourth crops. There was no significant yield penalty observed through soil cuts and fills provided appropriate fertiliser recommendations were followed. Five farmer field days were organized during the project implementation with over 200 participants.

The project also worked to develop a private sector contracting industry to provide laser levelling services to farmers in Cambodia. Three private sector contractors took part using a model to help contractors demonstrate laser levelling with support from project partners and collaborators and then offer laser levelling services to farmers. This model has been replicated in a new ADB funded project which will see an additional 15 service providers supported using this model across Cambodia.

Preliminary Groundwater Assessments

In Cambodia, shallow groundwater resources are prevalent in the rainfed lowland ecosystem where rice is the main growing crop. The utilization of groundwater tube wells to extract water for irrigation or supplementary irrigation in the lowlands is commonly practiced in some of the main rice-growing provinces (Seng et al, 2007). However, only a limited number of studies have been conducted to observe the groundwater quality and quantity in Cambodia (Robertson, 1998, JICA, 2002, IDE 2009) and there is no comprehensive assessment of the groundwater resource (Johnston et al., 2013). This study was conducted to obtain an up to date status of groundwater use and quality issues in relation to improving rice productivity in Cambodia. The Angkor Borei district of Takeo province was selected for this study as groundwater is used quite commonly in this area. A baseline analysis was conducted in 2012 to understand the overall situation of the groundwater quality by analysing water samples and soils in rice fields and water from tube wells for elements such as pH, EC, TDS, Ca, NO_3, NH_4, as, and turbidity. The result of this testing indicated that water quality was overall good and the impacts of > 10 years of groundwater irrigation on soils did not present serious causes for concern. Groundwater salinity was somewhat elevated (up to 2 dS/m) but still within the normal range for irrigation water (FAO, 1985). Anecdotally, some farmers consider that the use of groundwater, which has not been blended with river water or rain water tends to negatively affect the establishment and growth of rice crops. In 2013-15, two long term tube well sites were selected for water table and water quality monitoring. Groundwater levels changed over time corresponding to river level hydrographs. At times the depths to groundwater surface extended deeper than 6 m below the ground surface. Previously this has been considered the maximum depth at which water remains accessible using hand pumps which are used to obtain domestic water IDE, 2009). From the observation of farmers, the use of unshandied groundwater on the dry season crops without any supplementation of rain water or surface water may impact plant production, particularly at establishment. Therefore, consideration on how farmers may be able to blend river water with groundwater through on farm dams or channels may be worthwhile to ensure long term sustainable use of groundwater for crop production and soils.

Establishment of an Agricultural Weather Station (AWS) Network in Cambodia

The project has established an agricultural weather station network across the three initial CAVAC provinces in Cambodia and at the CARDI research station. This network has been further expanded during the life of the project to include an additional 5 weather station networks spread across the country that have been funded by outside donors that wish to make their AWS data available.

The project has also collated previous historical weather station data from a number of sites spread across Cambodia from different agencies and made these available on-line as a single database download. This is the 1st time such resources have been made available in Cambodia.

In summary the project has made significant advances in improving irrigation water management in Cambodia. The project has increased in country partner knowledge in a number of key areas related to irrigation water management (laser levelling, water balance studies, groundwater assessment and AWS) which have been taken and adopted by end users such as farmers who have changed management practices (i.e. laser levelling and direct seeding). The private sector have also gained knowledge, training and assistance in the development of a private sector laser levelling industry.

3 Background

Rice is consumed by approximately 3 billion people across the globe and is the most common staple food (Maclean et al, 2002). Globally, population growth, rising incomes and urbanization are increasing the demand for water from the household and industrial sectors (Hoanh et al, 2003). Increased demand for water from these sectors and concerns about food security has increased the need for water in rice production systems to be reduced and water productivity increased. These factors have led to a growing interest in intensification through irrigation as a way to increase food production (Wokker et al, 2011). A further threat to food production is the uncertainty of climate change (Bank, 2006; Mainuddin and Kirby, 2009a).

As in other countries, drivers of water demand (population growth, rising incomes and urbanisation) are present in Cambodia (Wokker et al, 2011). The Cambodian population is expected to increase from the current 14.8 million (CRDI, 2012) to between 20.4 and 27.4 million by 2050 (ADB, 2010). Although Cambodia is one of the poorest countries in the world, it simultaneously experienced a strong record of economic growth that averaged 8.4% between 1994 and 2008 (CRDI, 2012).The projection for economic growth is approximately 7% annually for the next 3 years. Increases in per capita income and urbanisation are to increase demand for food between 109% and 206% from the year 2000 levels (Hoanh et al, 2003). With economic growth and consumers becoming more affluent, meat and fish consumption are likely to increase while it is predicted rice consumption will decrease (Delgado et al, 2007). Nevertheless, total food production still needs to increase to feed a growing population and reduce poverty. Since this increase will be required to be satisfied by domestic production, under increasing competition for water, then greater pressure will be placed on agricultural water and land resources.

Cambodia is bordered by Thailand, Laos and Vietnam and is situated in the Lower Mekong Basin (Figure 3-1).There is wide spread poverty in the basin, with the people of Cambodia and Laos among the poorest in the world. Cambodia's economy is largely based on the agricultural sector which contributes 27% of GDP and in which 65% of the labour force are engaged (CRDI, 2012). Within this the agricultural labour force is the poorest sector of the population earning less than US$1/day, constituting up to 34% of the national population (ADB 2010). Rice production is central to this sector and central to the policies laid out to eradicate extreme poverty.

Physical rice productivity in Cambodia lags behind surrounding countries (particularly Vietnam and Laos). The productivity of rice varies with the highest yields in the Delta region of Vietnam (maximum of 4.86 t/ha), moderate in Laos (maximum of 3.28 t/ha) and the lowest in Cambodia (maximum of 2.16 t/ha) between 1993 and 2004 (Mainuddin and Kirby 2009a). Agricultural diversity is also relatively low. For example, the majority of vegetables are imported from Vietnam.

Irrigated agriculture in Cambodia is responsible for approximately 90% of total water abstractions, although the estimate varies from between 80% (Nesbitt et al, 2004; Nesbitt, 2005) and 95% (MOWRAM, 2009). In 2010, approximately 2,795,892 ha were under rice cultivation. Even though yields per ha are higher in dry season rice crops, these systems constitute only about 20 percent of the total area. Average rice yield in 2010 was 2.76 tonnes per ha in the wet season and 4.2 tonnes per ha in the dry season (MAFF 2011). With rice farming traditionally being dependent on rainfall, the majority of lowland farmers grow just one crop a year.

Rice cultivation, i.e. cultivated land, harvested area and production, has increased annually since 1980 (MAFF 2011) despite the series of floods in 1984, 1996, 2000 and 2012 and droughts in 1983, 1991, 1994, 1997, 1998 and 2004 that destroyed hundreds of thousands of hectares of paddy fields (ADR, 2012). Lack of water during dry season rice farming is a significant constraint and has occasionally caused conflict among farmers (CRDI, 2012).

Inadequate irrigation water allocation that coincides with drought has been a severe constraint to intensifying rice productivity. In addition, climate change impacts, for example, lower rainfall, may result in water shortages for farming which could push farmers to adopt seed varieties that consume less water.

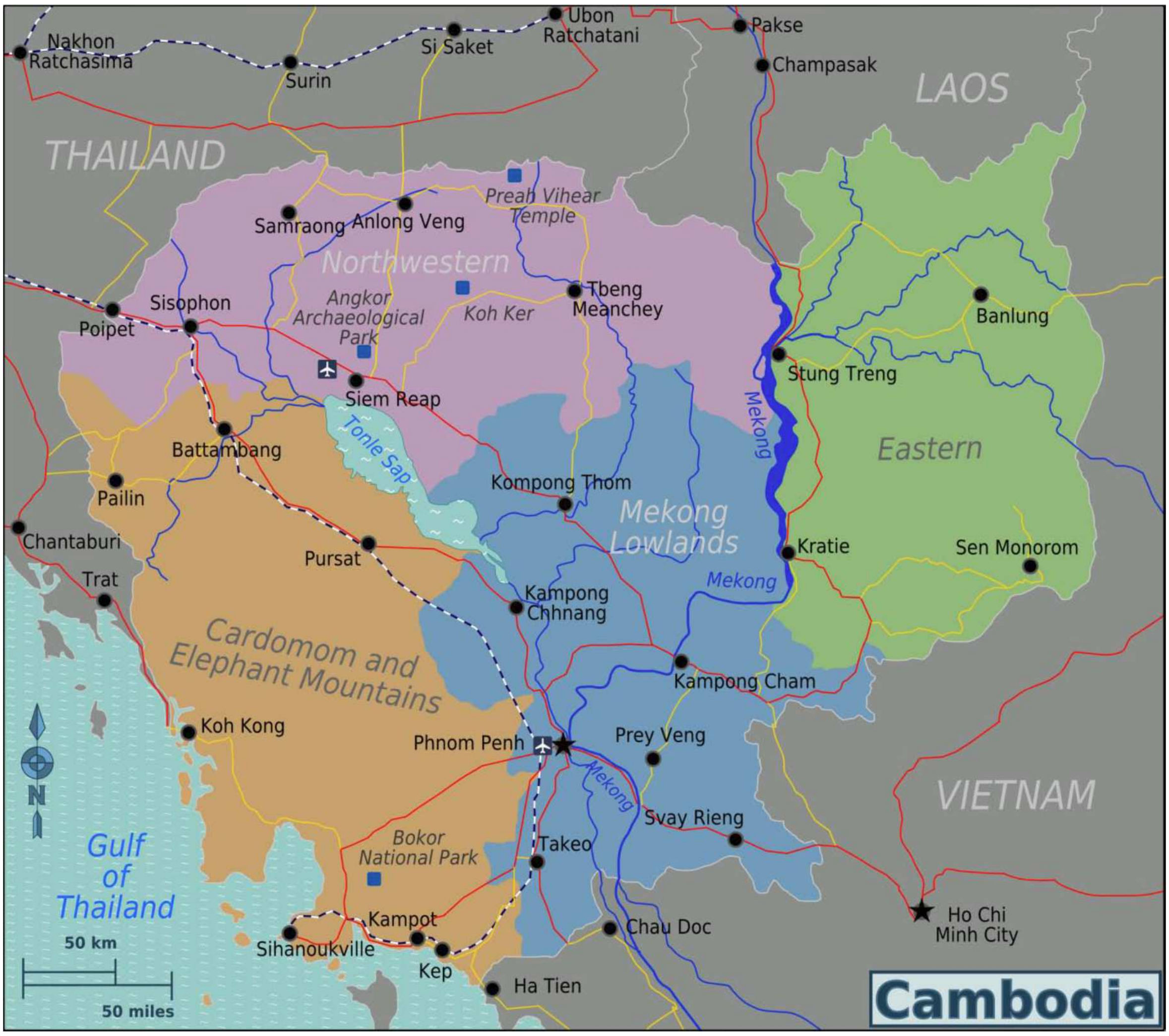


Figure 3-1 Map of Cambodia and surrounding countries

With rice being the most important food staple in Cambodia, accounting for 68% of the daily calorie supply (FAOSTAT 2014) improvements in productivity can have significant effect on both health and income. Agriculture dominates the Cambodian economy contributing 35.6% GDP in 2012 (World Development Indicators 2014). Like many countries around the world, the agriculture sector is facing a labour crisis with the number of people working in agriculture dropping rapidly in the last ten years, creating a significant challenge for both existing and future farming systems. Access to agricultural land, lack of technical farming skills / knowledge and lack of water (no irrigation) are rated by Cambodian farmers as the three key factors constraining increasing agricultural production overall (ADB, 2014).

Farming in Cambodia has historically been dependent on rainfall and this remains the case. While current water demand in the lower Mekong basin is estimated to be less than 4% of annual flow a number of modelling and climate change studies suggest that changes in extraction (dams and increased irrigation usage) and rainfall patterns may lead to decreased rice yields in Cambodia under future climate conditions (Nesbitt et al. 2004; Mainuddin et al. 2013). In addition, high levels of temporal and spatial variability in water availability also mean rice crops regularly suffer from stress related to drought periods during the wet season in some parts of the landscape as well as poor irrigation management e.g. timeliness and uneven water application. These factors combined with increasing population pressure create an imperative to improve water and crop productivity from their current low levels. In addition, with 85% or 1.9 million households across the country engaging in growing crops in agricultural holdings (NIS MAFF 2013) improvement in crop and water productivity can have a significant impact on poverty alleviation across the country.

Improving water and crop productivity can be an important pathway for improving average household income and general standards of living. Mainuddin and Kirby (2009) found Cambodia had lower than average water productivity for lowland rice, with lower production being attributed to one or a combination of factors including low annual rainfall, longer than average dry season, poorer soil nutrition, cultivation of low yield local varieties, lower fertiliser applications and inadequate management practices (White et al. 1997; Linquist and Sengxua 2001). To meet the region's future food requirements, large increases in agricultural water availability and/or significant increases in water productivity must occur in both rainfed and irrigated cropping systems (Johnston et al. 2010; Kirby et al. 2010).

Cultivated rice areas have increased by about 14% from 2000 to 2005. Total irrigated rice areas including supplementary irrigated area increased by about 67% from 2001 to 2005. Water availability is the key factor to increase crop yield and production in the irrigated and rainfed lowland rice-based cropping systems.

Cambodia is lagging behind its Asian neighbours in rice production with yields in Vietnam and Laos being 25 to 50% higher. There are many reasons for this including: use of local rather than improved varieties, low seed rates, poor fertility due to low fertiliser inputs and pest pressure. This 'traditional' low risk management is in large part a response to poor water availability and management. The approach of low inputs of seed, fertiliser, pesticides and labour is justifiable risk management due to variability in rain which can lead to periods of water stress and crop failure. In many areas there is a 100% inter-annual variability in rice yields. Improved water management is critical and underpins the application of other agronomic components to be confidently applied so that yields are reliably increased. Where water resources are certain and delivery infrastructure and management effective, yields are double the national average due to confidence in increased inputs and improved farming practices. This improvement in irrigation infrastructure is being undertaken by the Royal Cambodian Government (RGC) which has ambitious plans for extension of irrigation supply. However, there is also consideration that overall, agricultural productivity is low (Thuon, 2007, ADB 2011a; ADB, 2012, De Silva et al, 2014). At present the FAO 1999 AQUASTAT Cambodia reports that there are around 841 full/partial control irrigation schemes, covering a total area of 269,461 ha. But only 176 of these schemes were reported to be fully operational, while 115 schemes covering 27,638 ha were equipped but not operating. The cropped area in these full/partial control irrigation schemes is estimated at 172,727 ha during the wet season and 103,656 ha in the dry season (FAO1999). However, it appears that double cropping is practised only on a restricted area and triple cropping is unknown. These 'schemes' are not designed and operated in the sense of irrigated schemes in developed nations nor even SE Asia. It appears that the local farmers are largely left to their own devices to try to get whatever functionality out of the schemes they can. The RGC undertakes limited maintenance of the head works, of some of the schemes. This is due to the legacy of poorly designed schemes, interference of schemes with existing 'natural' irrigation and other schemes and an ad hoc disjointed approach to irrigation in any particular area. This is in the context of a complex landscape that is subject to huge inflows in the wet season and rapid drying out during the dry. To demonstrate this complexity we have divided the types of irrigation into five main categories (adapted from FAO1999):

1) River lake or stream diversion by gravity. These systems are used for wet season supplementary irrigation as there are no storage facilities. Off takes are generally uncontrolled, although in some cases, water level control is provided by diversion weirs.

2) Water pumping from rivers or canals. These systems can provide water for both the wet and dry seasons and recession rice. Pumping can be by Government pump stations, farmers or private service providers

3) Reservoirs/lakes/ponds storing local rainfall runoff for wet season supplementary irrigation and recession rice. Water is abstracted from the reservoir by gravity or mobile pumps provided by farmers.

4) Reservoirs/lakes storing flood waters from the Tonle Sap, Bassac and Mekong rivers. Water released by gravity to canal systems that maybe either above or below ground. These areas also benefit from natural flooding for land preparation, usually a floating rice crop is grown in the flooded area and then the second crop (recession rice) is planted as the floodwater recedes and irrigated during the growing season with the water stored in lakes and reservoirs. This system takes advantage of the large range of water levels in the river systems to fill the reservoirs during the flood to a level sufficient to give gravity command of the paddy fields, at least initially and not in all areas. The recession areas use the remains of the natural flooding at the beginning of the season for land preparation and the filling of the reservoirs.

5) Groundwater. Groundwater is used as a supplementary irrigation source in the wet season to provide water during periods of low rainfall, especially the "short dry season" of about two weeks and at the end of the wet season rice crop if the rains end before crop maturity. Groundwater is also used to finish the recession rice crop if the local sources of surface water are exhausted (this is a spatial as well as temporal problem). Groundwater may also be used on a small scale for vegetable production during the dry season. Groundwater abstraction is from shallow tube wells. Groundwater availability is highly variable and depends upon local aquifer properties, monsoon recharge and connectivity to rivers.

However, the use of groundwater for irrigation in Cambodia remains somewhat ambiguous as it has not yet been considered at the higher strategic planning level (de Silva et al, 2014). Governing bodies such as Ministry of Water Resources and Meteorology (MOWRAM) do not encourage its extensive use due to concerns about sustainability (MOWRAM, 2011, Johnston, 2012). Nevertheless, since fairly recently, farmers that have supplemented surface water with groundwater irrigation have been able to improve establishment and save wet season crops during dry periods (Roberts, 1998), early establish dry season crops which have significantly higher yields than wet season crops, and have more flexibility to grow high value crops such as vegetables in between wet and dry season rice crops. From the mid-1990's the use of groundwater for irrigation, through the installation of tube wells has spread rapidly. In Prey Veng the number of tube wells being used for irrigation grew from 1600 in 1996 to 25000 in 2005 (Johnston et al, 2012). About 2000 manually operated tubewells are being installed annually (WEPA, 2010).

There have been some groundwater quality surveys and hydrogeological studies (Bradman and Rasmussen, 1977, Roberts, 1998, JICA, 1999, 2002, IDE 2009) but it is well recognised that assessment of the resource is not comprehensive. Estimates range from 17.6 (AQUASTAT, 2011) – 52 km^3/yr (Kazama et al. 2007) in volumetric terms (1-2 times annual rainfall in effective terms). There is also high variability in estimates of recharge rates both spatially and temporally and uncertainty in the relative importance of different recharge mechanisms (Johnston et al, 2013). Recent reviews of earlier work and recommendations for where future research should be targeted to assist in the development of a plan for sustainable groundwater use have been summarised by Johnson et al, (2012, 2013). Groundwater management in the context of Cambodia's complicated socio-economic situation of trying to increase rice exports whilst reducing poverty was mentioned by de Silva et al (2014). Generally, the recommendations have included: monitoring - to build the existing datasets for improved quantitative analysis, groundwater resource assessments and hydrologic analysis (Landon 2011).

All of the groundwater quality research that has been carried out for Cambodia to date is focused on urban and peri-urban use and the impacts that it may have on human health caused by arsenic, manganese, fluoride, iron and microbial contamination. The studies have determined concentrations of these elements in groundwater that is extracted for drinking purposes and provided information on which regions offer the greatest hazard (Buschmann et al, 2007; Polya et al, 2008, 2014 Bennet et al, 2010). Other studies have examined the intake levels of arsenic that Cambodians are exposed to through consumption of rice and the uptake of arsenic in rice physiology.

Taking into account the previous hydrological, geological and groundwater quality literature related to Cambodia, and considering the rapidly expanding use of groundwater, regardless of regulation and governance, the work described here, rather than focussing on water planning, has focussed mainly on understanding how groundwater irrigation fits into small landholders systems, how rice productivity may be improved through the use of groundwater irrigation and the benefits or any hazards it is presenting, or may present to soil quality.

Generally, it is considered that groundwater quality is good for irrigation (MOWRAM, 2003). Elevated concentrations of arsenic occur in groundwater but seem to be sharply restricted to the lowlands and close proximity of the Tonle Sap, Bassac and Mekong River banks and the alluvium between these rivers with relatively low concentrations to the west of the Bassac River (Buschmann et al, 2007). Elevated manganese concentrations in extracted tube well water samples have been identified west of The Bassac River where intermediate redox conditions favour the release of Mn^{2+} to the aqueous phase, making it available to plants (Buschmann et al., 2007). However, generally manganese does not present a significant hazard to rice productivity. Whilst iron levels have been shown to exceed WHO standards for drinking water in many situations (JICA, 2002), especially when domestic bores are sourcing water of < 6 m using manual pumps from shallower aquifers, this tend to be less of a problem in rice field tube wells which are accessing water with high clarity from 25 - 50 m using motorised pumps.

As can be seen from the above rice production and its water management is undertaken in a myriad of ways depending upon the local landscape, soils, groundwater availability, infrastructure availability, water sources and social networks. This is a highly heterogeneous farming landscape with many varying approaches to water management. There is no convenient one size fits all approach - there are few big irrigation schemes that reliably deliver water, there is not a ubiquitous aquifer that can be tapped as occurs in other parts of Asia. As such typical technical and social 'solutions' to water management as found in other parts of Asia cannot be assumed to apply. The Cambodian farming systems are grassroots approaches that have developed organically in response to varying local biophysical, social and economic conditions. The many irrigation schemes developed since independence generally are in disrepair and operating much below potential. The Cambodian government is undertaking large investments in rehabilitating these schemes. Even when rehabilitation does occur there is a policy that farmers incur the responsibility of maintenance, which they are often unable to meet. As a result farmers adapt to circumstances using what water resources and infrastructure are available, but with no knowledge of actual levels of water availability and crop water requirements. This leads to underutilisation of the water resource (planted areas are restricted) and inefficient use of the water resource as crop water requirement and scheduling, even at a basic level, are not understood, leading to over and under irrigation and significant wastes of resources i.e. water and labour.

The Ministry of Water Resources and Meteorology (MOWRAM) has a strategic plan (2009-2013) that contributes to the National Strategic Development Plan. This document emphasises the abundance of water resources in Cambodia and yet the problem that farmers experience water shortage. Suggested requirements to overcome some of these problems are:

- Basic data and information on crop water needs;

- Increased technical capacity at Ministry, provincial department and commune levels;
- Improve irrigation management; engagement of communes, encouragement of individual or small farmer groups to provide irrigation water, development of sustainable and equitable irrigation management for effective use of water.

As mentioned a number of studies (e.g. Mainuddin & Kirby 2009, Kirby et al 2009, and Eastham et al 2008) have analysed Cambodian water resources at a basin scale and have determined that there are adequate resources now and into the future. These studies have also indicated that with climate change it is likely that in most areas there will be increased water availability although variability will increase. That overall water availability is not, and likely will not, be a constraint is a great blessing to the country. However, to date this natural advantage has not been capitalised upon. There are institutional, policy, cultural and socio-economic reasons that have led to the failure of the 'traditional' irrigation intervention in developing countries of construction of large scale irrigation infrastructure. This is not to say that this type of scheme will not be appropriate when some of the institutional, cultural and socio-economic factors have changed. At present the irrigation landscape is one of pragmatism at the local level turning local circumstances to best advantage.

The literature does not provide any evidence of farm scale studies of crop water use and management in Cambodia. Somura et al (2004) state that "There have been few studies on the amount of irrigated water and related matters in this country (Cambodia) because of the lack of hydrology and meteorology data following civil strife until 1998." Many papers propose improved cropping, alternate crops, rice double cropping and methods of improving productivity under water constraints e.g. Fukai and Kam (2004), but there are no measures of basic crop water use and management data. Research in Cambodia has been agronomy based to date.

In Cambodia there is information on soils and their management for rice undertaken by CIAP/IRRI (White et al.1997; White et al 1995). This provides a starting basis for understanding rice nutrition, although varietal change and inputs have increased markedly since then. IRRI has undertaken a great deal of research into varietal development and development of appropriate agronomy and fertiliser and water management for rice. However, Cambodia has had little research and extension has been lacklustre. This is the focus now, currently in Cambodia the Irrigated Rice Research Consortium (IRRC) is undertaking extension of IRRI research including plant nutrition and water saving technologies. In SE Asia the IRRC is providing demonstrations of alternate wetting and drying, direct seeding and weed management. However, in Cambodia rice intensification and crop diversification appear to be the focus. For India and Bangladesh IRRC has developed direct seeding approaches and weed management for farmers, as reported by Singh et al 2002; Namoura et al (2007) reviewed innovative land and water management approaches including SRI and AWD and found that adoption was low in many countries due to insufficient labour and organic fertilizer availability problems, uncertain irrigation water supply, crop specificity and complexity, lack of capital, high knowledge and technical skill requirements. The issues outlined in the research above in various countries are the same as in Cambodia and the findings of this research needs to be factored into experimental designs and assessment of ‘best practice’. However, a clear difference in Cambodia is that there is not a general shortage of water, but there is a lack of control of water. This means that water saving technologies are not universally of greatest importance at this time, there is a need to increase the per ha and per unit input yield, rather than per unit water yield in many areas.

Direct seeded rice is taking off across Cambodia due to gradual reduction in labour and adoption of high input rice farming as promoted by cross border interchange with Vietnam. The issue of land levelling is critical for direct seeded rice. Interestingly the promotion by researchers of dry seeded rice and AWD for water saving does not appear to have emphasised greatly the importance of land levelling to provide good water control, which is essential for such techniques. In Cambodia, Joe Rickman (IRRI) trialled laser levelling in the period 1996-1999. On a small total area (10ha total) Rickman (2002) showed 24% yield increases (530kg/ha) compared to unlevelled fields. He showed a 4% yield decrease for every 20mm reduction in land levelness.

Research strategy

There is a clear need for further research in Cambodia on irrigation water management and drainage. This project has focused on water management on farm and providing research and information that can be used to increase on farm productivity.

The project has targeted lowland rice based systems that have the capability of supplemental and full irrigation. The project was aimed at farming systems where there is some control available over irrigation and drainage and there is opportunity for a dry season rice crop. The control over water and drainage is to avoid the crop becoming completely submerged and the ability to apply irrigation either supplementally or fully. Full irrigation in the dry season provides greatest control. Supplemental irrigation in the wet season is largely an insurance against crop failure not a tool for high yield. There is always the risk of flooding that reduces the incentive to invest heavily in the crop. In the dry season the full control of water with irrigation only, (no rainfall), provides the certainty necessary for investment in inputs to produce high yield. This project has targeted these scenarios as this is where farmers are likely to be willing to invest in inputs, technology and new knowledge as they have greater certainty over being able to control water. The project aspects related to groundwater have relevance to dry season and wet season rice, as often groundwater is a supplemental irrigation supply rather than a full supply. Project aspects related to land levelling are applicable to all types of rice cropping, but especially those that use direct seeding rather than transplanting. The most rapid uptake of direct seeding is in dry season rice, but there is also a steady increase in wet season rice, especially where supplemental irrigation is available to maintain seedlings.

4 Objectives

Objective 1:

Develop an improved understanding of farm-level water management constraints and opportunities.

Activities:

- Review literature on rice water management for this region regarding increasing water use productivity and managing variable water supplies
- Collate and review all known meteorological records for improved crop water requirement assessment
- Undertake farmer and water/agricultural agency surveys to determine opportunities and impediments to current farmer irrigation water management and scheduling practices
- Undertake topographical surveys and infrastructure assessments to determine opportunities and impediments to improving rice productivity
- Undertake workshops with farmers and water/agricultural agency staff to develop best bet improved irrigation practices based on current understanding for testing in on-farm field trials
- Install automatic weather stations in the three CAVAC provinces

Objective 2:

Research and develop adapted water management interventions to increase productivity.

Activities:

- Undertake field trials of the identified best bet improved irrigation practices
- Investigate land levelling options at the rice paddy and irrigation scheme level
- Undertake modelling to broaden the understanding from the field trials to include other agronomic and climate conditions
- Develop tools to determine feasible planted areas of dry season rice based on estimated water availability and estimated crop water use and risk for use by water agency and farmer water user groups

Objective 3:

Support extension efforts, providing timely, practical on-farm water management information to activities being undertaken by project partners, CAVAC and NGO's

Activities:

- Develop the information on current irrigation practices and known improved practices for use in extension programs
- Benchmark yields and crop water use, including irrigation (surface and groundwater) through seasonal surveys and develop this information into potential yields and water requirements that can then be communicated to farmers
- Engage and train Cambodian students
- Provide input to and assistance with training programs run by CARDI, TSC, CAVAC and NGO's

5 Methodology

5.1 Integrated socio-economic and bio-physical survey of agronomic and water management factors limiting rice production

Farm-level surveys were undertaken in Takeo Province in 3 agro-ecological zones (no irrigation, limited irrigation and full dry season irrigation available) to understand irrigation and agronomic practices and constraints. Three districts in Takeo province were selected for the study dependent upon the previous surveys for project CSE/2009/037, areas where CAVAC canals have been implemented and the TSC model site. Benchmarks of water use, water quality, fertiliser use, pesticide use and yield where to be developed from the data.

The main purpose of this study was to develop an improved understanding of the varied irrigation and farm-level water management constraints and opportunities of farmers in Cambodia.

The study used both quantitative and qualitative questionnaires through farm household surveys and farmer focus group discussions. In-depth interviews with key focal persons from the management of irrigation sources or farmer water use communities (FWUCs) were also conducted. The survey used a standard questionnaire in all three districts to facilitate a comparative analysis and more efficient data processing. The questionnaire was structured by the socioeconomic team of CARDI with considerable input from other project members and used during the pretesting phase and actual survey.

The farm household interview aimed to capture both quantitative and qualitative data, and the information collected includes information about the respondent and household members, landholdings, farming and non-farming activities, income sources, rice establishment practices, rice cultivar and yield, chemical and non-chemical input use, irrigation practice, access to irrigation sources, and costs and returns. The selected respondent for interviews was the person who managed the farm but was not necessarily the head of the household. General information about the farm and the nature of the constraints to rice production, including the frequency/intensity of abiotic stresses, was elicited from the respondent. During the interview, the unit of measurement recorded was based on local standards and it was subsequently converted to the metric system during data entry. The questions were open-ended which allowed farmers to provide answers based on their own perceptions.

Focus group discussions (FGDs) were conducted for collecting detailed information and understanding the broader aspects of farmers' irrigation practices and constraints and opportunities to access irrigation sources in each season.

In-depth interviews with focal persons in FWUCs in the targeted area were conducted to identify the FWUC role in the community and its importance. The interview was to determine how water was supplied and distributed to farmers' fields and how the FWUCs were managed.

Analysis at the household level, descriptive statistics in tabular form were used mainly to describe and illustrate the farming practices and socioeconomic characteristics and variations across locations. Analysis is based on a few critical points including agro-ecosystem and toposequence, rice intensification, land preparation, irrigation sources and water management, rice varietal use, groundwater usage and quality, production inputs and outputs, and gross margin analysis.

Farmers which took part in the survey provided physical locations for their fields. These fields were then subject to a bio-physical survey which was undertaken by MOWRAM TSC to measure field levelness, distance to water sources and other bio-physical parameters.

5.2 Preliminary Groundwater Assessments

A reconnaissance study of groundwater quality and interviewing farmers about their groundwater irrigation in several villages near Angkor Borei, Takeo was undertaken (2012). Water samples were analysed immediately for EC and pH using a Horiba 10 water quality meter. Using rapid test kits and a small spectrophotometer unit (Orbeco) in the field, iron and alkalinity analysis was quite successful (Figure 5-1). However, subsequent analyses of alkalinity, iron (Fe), nitrate (NO_3^-), arsenic (As), and turbidity were undertaken by other commercial labs as CARDI research staff were unable to obtain test kits.

Figure 5-1 Using the Horiba 10 water quality meter and Orbeco field spectrophotometer to determine water quality parameters in groundwater

5.2.1 Long term Groundwater Monitoring

A draft of the socioeconomic survey prepared by CARDI was used to identify which farmers were most appropriate for groundwater sampling. It was considered the survey could be used to identify the names of the farmers who had answered positively and negatively to the question about having problems with groundwater quality in the past.

The sites that we were able to locate were based on distance from the river, number of years groundwater has been used but mainly willingness and capacity of farmers to participate. It is quite difficult for farmers to regularly sample groundwater due to the design of the wells. The upper pipe, attached to the pump acts as a sleeve which inserts inside the main well pipe (Figure 5-2). The design prolongs the life of the well by reducing the likelihood of collapse

Figure 5-2 Groundwater access is via wells which comprise an inner sleeve upon which the pump head is mounted. To measure the depth using a plum line, this sleeve was taken out and the depth of groundwater was measured from the surface through the main well pipe

Two groundwater monitoring sites were established in the Angkor Borei, Takeo region in 2013. These sites have been monitored, over 24 months for groundwater depth below the ground and electrical conductivity. One tube well was located on Mr Bun Bunphan’s land (BP Site; 11°00’50 82”N, 104’57’48’34E), Toul Sangkor Village. The well is located approximately 3 km from the river channel. It is 53 m deep and groundwater has been extracted for irrigation since 1995. A second ground water tube well monitoring site was established on Mr Chhim Som’s land (CS Site; 11’02’29. 53”N, 104’58’23.39”E), Ta Ei Village. The well is 26 m deep and located approximately 1 km from the river. It has been used to extract groundwater for 4 years.

The farmers were shown how to measure groundwater level using a plum line and recording the measurement. The measurement was taken from the top of the casing with no adjustment. There was also no adjustment for any earth or concrete apron that was present at the sites. Data observations indicate that the measurement was taken to the nearest 10 cm.

Samples for water quality were collected on a monthly basis during the period of groundwater use by CARDI, during the early wet season when groundwater is used in a supplementary way and road access is possible. The major elements such as pH, electrical conductivity (EC), alkalinity, iron (Fe), nitrate (NO_3^-), arsenic (As), and turbidity were analysed once a month. pH meter model HACH senion3 was used to analyse for pH; Thermo ORION STAR A212 EC meter was used to analyse for EC; flame photometer model Orbeco-Hellige 975MP were used to analyse for alkalinity, zinc (Zn), calcium (Ca), aluminium (Al), and iron (Fe); and reflectoquant together with Merck test strip was used to analyse for nitrate (NO_3^-) and ammonium (NH_4^+) in the ground water samples.

5.2.2 Soil salinity levels in groundwater irrigated compared with river water irrigated soils.

Soil samples (0-15 cm) were collected on one occasion in March, 2014 (4 replicates of 8 composited samples) from paddocks where groundwater irrigation had been occurring for ~ 4 years, > 10 years and from a paddock that had only received river water. Analyses of 1:5 EC were carried out at the CARDI labs.

5.3 Crop water use and nitrogen field and modelling studies

5.3.1 Intensive field water balance studies at CARDI

The main objective of study were to assess rice water requirement using three different approaches which are water balance equipment (WBE) utilising lysimeters, Bowen ratio energy balance (BREB) and the Cropwat model under the current farm management practice and climate conditions of Cambodia.

The investigation was undertaken during 3 dry seasons in row from 2012 to 2014 and was conducted at research station field (2650 m2) at the Cambodian Agricultural Research and Development Institute (CARDI) (Figure 5-3).

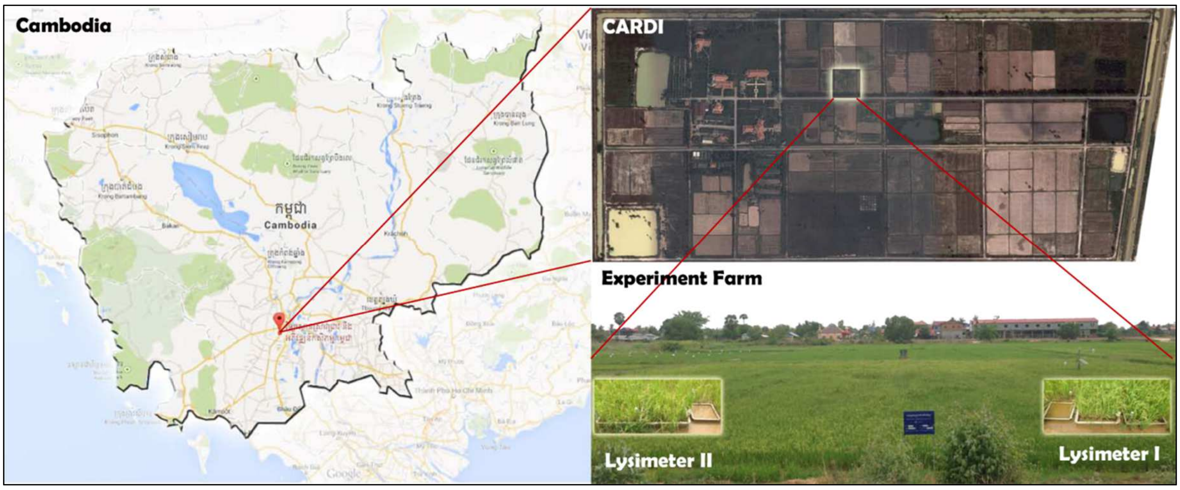


Figure 5-3 Location of CARDI experimental field station and lysimeters

The climate of study area can generally be described as tropical monsoon with two distinct seasons: the Rainy Season and the Dry Season. The rainy season, which runs from May to October, in which temperatures can drop to 18 °C and is generally accompanied with high humidity. The dry season lasts from November to April with the driest period occurring from January to February (temperatures can rise up to 40 °C). Annual rainfall is approximately 1200 mm, of which 80% is concentrated in the rainy season from May to September.

The study paddy field was managed using farm management practice (e.g. rice cultivar, sowing and harvesting date, fertilizer application rate, standing water level after sowing time) recommended from CARDI. The Chul'sa rice variety was used in the experiments with potential high yield (4.0 – 6.0 t/ha) and maturity period range between 95-110 days. Direct sowing method was applied using a drum seeder.

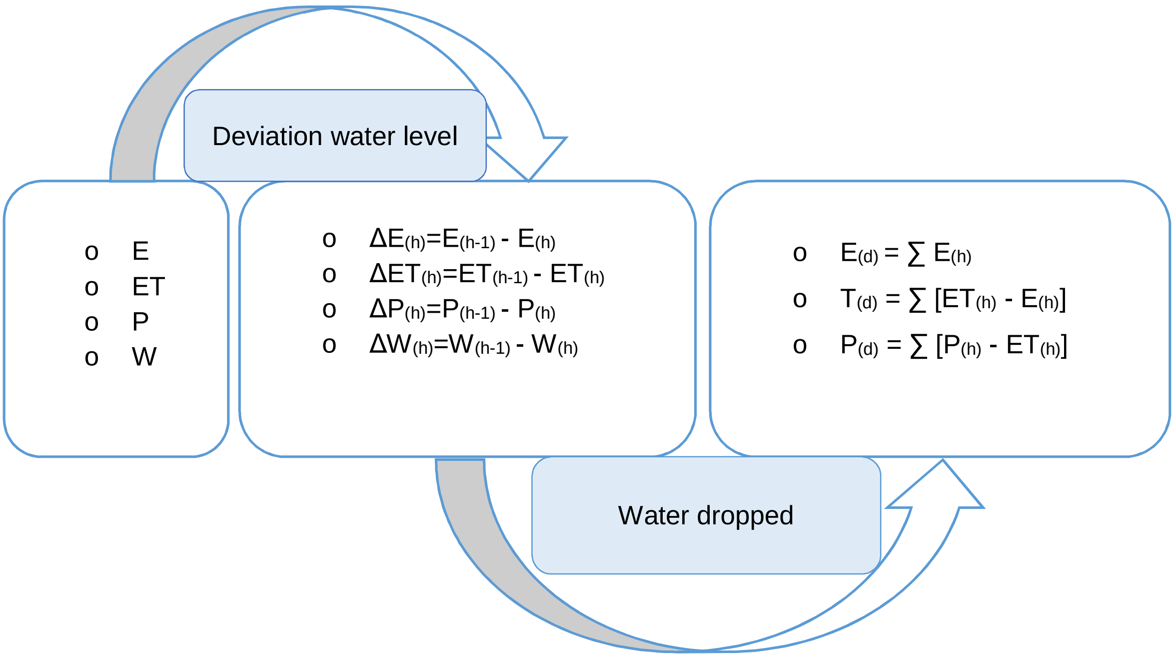
A water balance is a crucial basic step for making sustainable decisions about farm scale irrigation. Inputs, losses and distribution within a site must be quantified. Water balance equipment known as a lysimeter was used in the experiment to determine water balance components. The lsyimeters/pans were constructed from stainless steel and placed partly below the ground surface and filled with a layer of in situ natural soil, on which rice was cultivated. Estimates of evapotranspiration, evaporation and percolation can be made by measuring and balancing all the other water budget components of individual lysimeters. Namely, evapotranspiration lysimeter, evaporation lysimeter, and percolation lysimeter. Each water balance component can be determined based on the concept of the field water balance equation as follows:

(I + R) – (E + T + P + S) = Storage change

Where: ***I*** denotes as irrigation, ***R*** is rainfall, ***E*** is evaporation, ***T*** is transpiration, ***S*** is the seepage and ***P*** is percolation

A monitoring site within a research field at CARDI was initially set up by installing 2 sets of water balance equipment in an attempt to gather direct rice water requirement. Each set included three different lysimeters/pans (evapotranspiration pan_ET pan; percolation_P pan and evaporation_E pan) to monitor the water level change consumed by a developing rice crop. Data from the two sets of water balance equipment were averaged if both were available, otherwise data from a functioning single set were used. The dimensions and other detail are presented in Figure 5-4. Continuous flood irrigation was provided, when the soil reached the drained upper limit, to each pan for maintaining a floodwater depth corresponding to crop development stage.

Temporal water level variation in each pan and paddy field were measured and recorded automatically hourly by water level sensors (http://www.intech.co.nz/products/minipd/wthr.html). To calculate the water component we used a framework as follows:



In which:

$\Delta E_{(h)}$, $\Delta ET_{(h)}$, $\Delta P_{(h)}$, $\Delta W_{(h)}$ denotes the hourly deviation of water level in the E pan, ET pan, P pan and paddy field respectively.

$E_{(d)}$, $T_{(d)}$, $P_{(d)}$ denote the water use by daily evaporation, transpiration and percolation.

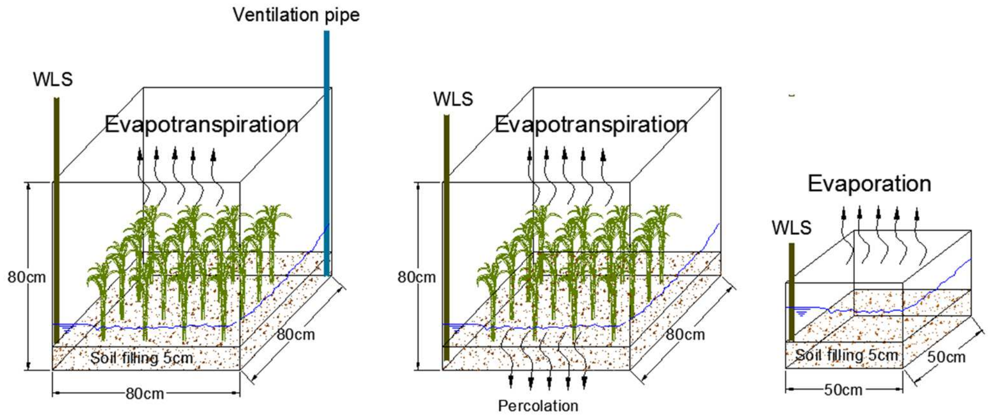


Figure 5-4 Schematic diagram of experimental set up placed in water balance equipment (ET pan, P pan and E pan).

Bowen Ration Energy Balance (BREB)

The Bowen Ratio Energy Balance method (Bowen, 1926) can be used to estimate crop evapotranspiration from the measurement of differences in water vapour concentrations and air temperatures at two heights on short time scales (less than an hour). The method can also provide continuous unattended measurements (Arya, 2001). It is an indirect method compared with the water balance equipment method detailed above.

A set of Bowen ratio energy balance systems (BREB) were installed in the middle of the monitoring field at CARDI research station. A BREB instrument was utilized to directly record parameters necessary for calculation. Two parameters, air temperature and air humidity, are measured by air temperature and air humidity sensor respectively and solar radiation was recorded by a net radiometer. The soil heat flux at the surface was detected and computed by adding the average heat fluxes sensed by the plates, to the energy stored in the soil layer above them. Wind direction and wind speed, were obtained from an anemometer and weather vane. Two thermometers and two water vapour sensors were able to be moved upwards and downward periodically to detect two alternative heights and remove sensor measurement error. All the parameters were automatically detected and recorded every 30 minutes using a Campbell Scientific CR1000 datalogger.

The method estimates the ET by calculating the partition of convective fluxes between latent heat and sensible heat (Peacock and Hess, 2004):

$$\beta = \frac{H}{LE} = \frac{[P_a C_p (\Delta T)]}{[\lambda \varepsilon (\Delta e)]}$$

In which, ***H*** and ***LE*** are sensible and latent heat fluxes *(W m^{-2})*; respectively. $\boldsymbol{P_a}$ is atmospheric pressure *(kPa);* $\boldsymbol{C_p}$ is specific heat capacity of air (1.013×10^{-3} *J .kg^{-1} ^{o}C^{-1}*); Δ***T*** is different air temperature between two heights *(^{o}C);* $\boldsymbol{\lambda}$ is latent heat of vaporization for water (2.45 MJ.kg^{-1}), $\boldsymbol{\varepsilon}$ in the ratio of molecular weights of air and water (0.622); and Δ***e*** is different vapour pressure between two heights *(kPa).* ***LE*** be express as follows:

$$LE = \frac{R_n - G}{1 + \beta}$$

Here $\boldsymbol{R_n}$ is net radiation *(W.m^{-2})* and ***G*** is soil heat flux *(W.m^{-2})*. For ***G, H*** and ***LE***, fluxes away from the surface are positive, the opposite sign convention is used for $\boldsymbol{R_n}$.

Cropwat Model

The Cropwat model was originally developed by the Food and Agriculture Organization (FAO) in 1990 to simulate crop water requirement and develop planning of irrigation schedules under varying water supply conditions in farming systems at the small catchment scale. An essential set of input data includes crop, meteorology and soil data. Meteorological parameters include: maximum and minimum temperature; relative humidity; sunshine hours; wind speed and rainfall. Calculation of the crop water requirement (CWR) can be carried out by successively calling up the appropriate climate and rainfall data sets, working together with the crop phenology files and corresponding planting dates. The soil module is essentially data input which include: total available water (TAW); maximum infiltration rate; maximum rooting depth; initial soil moisture depletion. In the case of the rice water requirement calculation, another set of additional soil data are required: drainable porosity; critical depletion for puddle cracking; water availability at planting and maximum water depth.

Meteorological data from Kmounh weather station (11°33'N, 104°50'E) and on-site measurement data were employed as climate and rainfall inputs. Additional crop data required was collected from the rice varieties description by CARDI and modification from the Cropwat existing variety. Field experiments provided soil texture class and crucial basic data required for soil properties. Table 5-1 show the summary of soil texture and soil physical characteristics at the CARDI experimental field.

Table 5-1 Soil texture and soil physical characteristics at CARDI experimental field

Table 1: Soil texture and soil physical characteristics at CARDI experimental field

Parameters	Soil texture	Wilting point (%vol) or (cm/m)	Field capacity (%vol) or (cm/m)	Saturation (%vol) or (cm/m)	Available water (cm/m)	Sat. Hydraulic conductivity (%vol) or (cm/m)
characteristic	loamy sand	4.20	11.10	42.00	0.07	77.07

M

5.3.2 Modelling Irrigation, sowing date and nitrogen management with APSIM-Oryza

The objectives of the simulations were to investigate the effects of irrigation management and sowing date, using recommended N fertiliser practice on yield and water productivity on the loamy sand soil at the CARDI experimental station. Initial conditions for each simulation were set 2 days before sowing and simulations were carried out using 14 years (2001 – 2014) of historical weather data principally from the Phnom Penh international airport with CARDI weather data substituted when available. Long term, historical weather data in Cambodia is intermittent at best with radiation data particularly difficult to source. This was overcome by converting sunshine hours to incoming shortwave radiations by means of an empirical relationship using the Angstrom formula (Pickering et al. 1994). Initial soil water in the loamy sand to 120 cm depth was set to half of the available plant water to simulate the typical dry start to the rice season. In reality, this condition does not occur as the soil is irrigated at least once before sowing and therefore will be close to drained upper limit in the upper soil layers. Initial ammonium-N of the soil profile was 18 kg ha-1 and nitrate-N was 22 kg ha-1. All simulations received an initial 100 mm irrigation as a pre-puddling event prior to dry seeding using the Chul'sa variety. Nitrogen management was in three applications using the CARDI recommended fertiliser application practice of 50% at sowing, 25% approximately 20 days after sowing and 25 % approximately 40-45 days after sowing. Grain yields and water productivities are for dry grain (t ha-1).

A simulation experiment may be made up of many treatments and may be replicated through time using different seasonal climatic conditions. The seasonal aspect relates to the fact that what is being run are experiments of single cropping seasons and while these may be replicated; there are no carry-over effects (achieved by an annual reset in the simulation) from one season or crop to the subsequent season or crop. Seasonal analysis is useful for comparing methods of managing a crop in particular environments, such as different planting dates, varieties or fertiliser application strategies.

If such comparisons are made across many different types of seasonal climates, then the variability associated with crop performance, as a function of the interactions between weather and other factors of the physical environment, can be isolated and quantified.

Simulations with different combinations of inputs were run for dry season rice using APSIM-Oryza. The model was run for 14 years of Phnom Penh weather, and cumulative probability distributions were developed for yield, irrigation, evapotranspiration and water productivity. The model assumes best management practice in weed, pest and disease control and there is no effect from these factors to yield

5.3.3 Effect of water irrigation regimes and nitrogen rates on rice growth and yield on Prateah Lang soil

In order to test the effects of water and nitrogen interactions in field based settings on yield a small scale field trial was undertaken at the CARDI experimental station during 2014. The objective of the study was:

- To determine the separate effects of i) nitrogen (N) rates and ii) water regime on rice growth and yield

- To determine the interaction effect of irrigation water regimes and N rates on rice growth and yield.

This experiment was carried out on Prateah Lang soil at CARDI and it was conducted in the dry season from February to June, 2014 (sowed on 21st February, transplanted on 21st March and harvested on 6th June) and using Sen Pidao (aromatic) early rice variety that has a 110 days duration. The experiment was laid out in a split plot design with 3 replications and 2 factors (1) three water irrigation regimes as main plot and (2) two N rates as subplot. The standard plot size of 5m x 5m (total 18 plots) was installed with measurements being taken from the centre 9m^2 of each plot and transplanted in a spacing 20cm x 20cm (Figure 5-5).

The water and nitrogen treatments consisted of:

-Water treatments:

W1 CF: Continuous Flooding (Planting through to harvest)

W2 AFN: 15 days flooding and 15 days wetting

W3 NF: Non Flooding (Wet Soil, from planting through to harvest)

-Nitrogen treatments:

F1: Recommendation Rate (N=100; P_2O_5=40; K_2O=80) (kg/ha)

F2: 1.5 Recommendation Rate (N=150; P2O5=40; K2O=80) (kg/ha)

Fertilizer type (kg/ha)	F1 (1RR: 100-40-80)		F2 (1.5RR: 150-40-80)	
	Basal	PI	Basal	PI
Urea	74.67	108.7	129.0	163

DAP	86.96	-	86.96	-
KCl	133.33	-	133.33	-

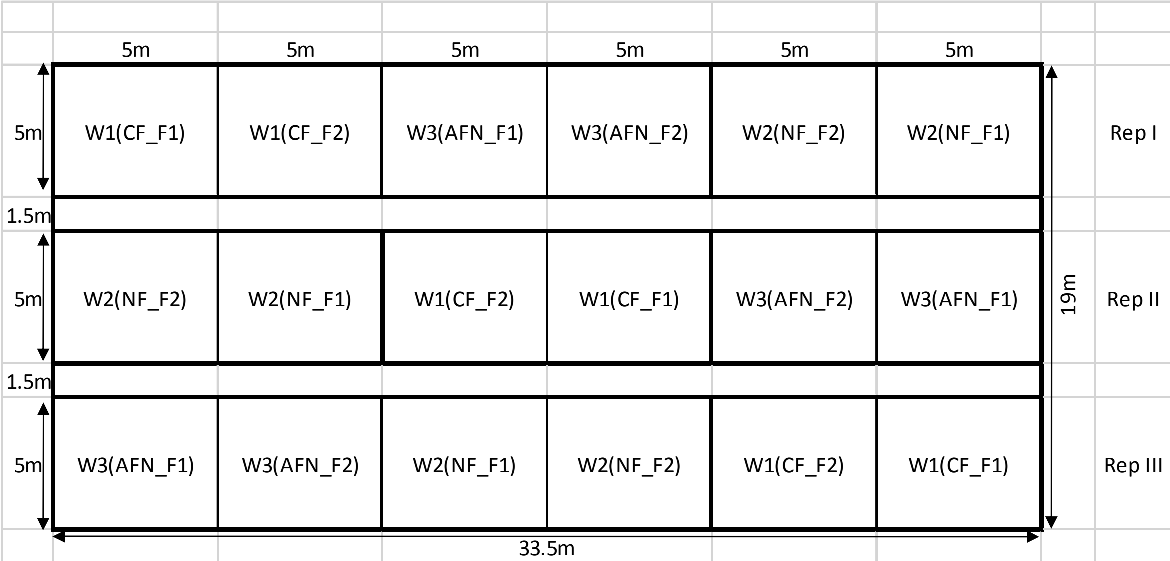


Figure 5-5 Diagram showing plot layout and treatments

Soil samples were collected at 0-15 cm before planting and after harvesting for the analysis of mineral N, TN, P, K and pH. Irrigation water which was applied to the plots was directly measured through a flow meter and recorded. Crop data measurement included tiller number, date of 50% flowering, panicle number, plant height, straw yield and grain yield.

5.4 Establishment of laser land levelling

5.4.1 On-farm farmer experimental sites

Three farmer fields were used for experimental demonstration in the Takeo province. Farmers were selected based of community consultation and from results of the socio-economic survey undertaken in the project. These farmers were Keav Yinteang, Doum village, Ta O commune, Kirivong district, Se Nary in Taey village, Basre commune Angkor Borey district and Sok Sarath, Krapom Chhuk village/commune, Koh Andeth district. The field demonstration experiments consisted of laser levelling the demonstration paddies and leaving a remaining non-laser levelled area which could be used to collect comparison data with the same farmer management applied over both areas. A plan view of the three farmer fields is shown in Figure 5-6.

Site: Doum village, Ta O commune, Kirivong district, Takeo

Farmer: Yin Tearng

			1	2	3	4	5	6	7
NL	15m	8	0.21	0.81	0.41	0.31	0.11	-0.69	-0.29
		7	0.11	-0.29	-0.09	-0.19	0.01	-0.29	-0.09
Level field	45m	6	-0.46	-0.16	-0.26	-0.56	-0.16	-0.06	-0.16
		5	-0.26	-0.16	0.04	-0.16	0.14	-0.16	-0.06
East		4	0.24	0.64	0.04	0.34	0.04	-0.16	0.44
		3	0.44	0.54	0.04	-0.16	0.04	-0.26	0.24
		2	0.24	-0.26	-0.06	-0.46	0.24	-0.16	-0.06
		1	0.34	-0.06	0.24	-0.36	-0.06	0.14	0.24

Road

Site: Krapum Chhouk village, Kropum Chhouk commune, Koh Andeth.

East

		1	2	3	4	5	6	7
47m	8	-10.1	-4.1	-6.1	-6.1	-11.1	-17.1	-8.6
	7	-8.1	-1.1	0.9	-3.1	-0.1	-4.1	1.4
	6	-1.1	-5.1	6.9	1.9	4.9	0.9	-0.6
	5	-0.1	-7.1	10.9	2.9	3.9	3.9	0.4
	4	-2.1	-3.1	1.9	1.9	14.9	-5.1	-2.6
	3	-6.1	-6.1	0.9	-0.1	0.9	0.9	-1.6
	2	2.9	6.9	2.9	4.9	6.9	2.9	8.4
	1	-4.1	-2.1	3.9	5.9	8.9	7.9	3.4
		30m						10m
		Level field						NL

Road

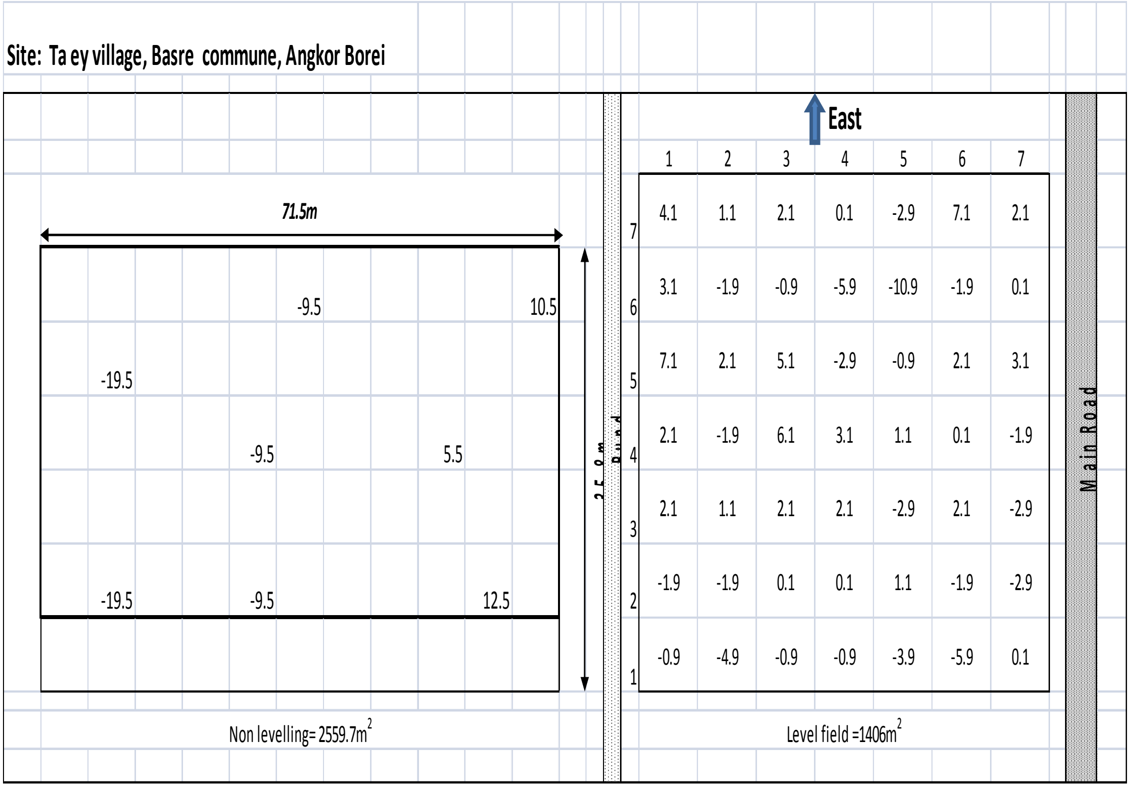


Figure 5-6 Layout diagrams for the three experimental farmer field trials

The fertilizer application applied was based on CARDI recommended rate with differences on the different soil types and fertilizer timing as described in Table 5-2.

Table 5-2 Fertilizer rates and timing

Fertilizer type(kg/ha)	Basal	PI
Main wet season(MWS) 50:23:30 for Prateah Lang soil type		
Urea	34.8	54.4
DAP	50	
KCL	50	
Dry season(DS) and Early wet season(EWS) 100:40:80 for Prateah Lang soil type		
Urea	74.7	108.7
DAP	87.0	
KCL	133.3	
Main wet season(MWS) 75:30:30 Bakan soil type		
Urea	56.0	81.5
DAP	65.2	
KCL	50.0	

The demonstrations and experiments were re-measured following ploughing and levelling to identify any evenness following leveling. A second ploughing was conducted before planting. For the non-level treatment, the field was ploughed twice than harrowed before the crop was planted.

The WS rice variety used was Phka Romduol, the DS/EWS rice variety used was Chul'sa. The rice was planted by Drum seeder (wet seed) and dry seeding machine (CSE-37 project). The DS and EWS seed rate was 150kg/ha and WS seed rate 80kg/ha. The weed control used contour and manual weeding. The crop emergence was measured, amount of water supplied, weed biomass and rice grain yield.

An additional farmer experimental site was established in the Bati, Takeo Province to look at the effect of cut vs fill areas on rice crop yields. The experiment was proposed of three treatments

1. Cut soil (high soil surface removed),

2. Original soil

3. Fill soil (low soil surface filled)

Three sampling points in these areas across the field were used to take measurements on weed biomass and also rice yields. The soil analysis was undertaken at the CARDI labs and crop establishment and management was undertaken as indicated above across the wet and dry seasons in which the experiment was undertaken. Figure 5-7 shows the layout of the experiment and sampling locations on the cut, original and fill areas.

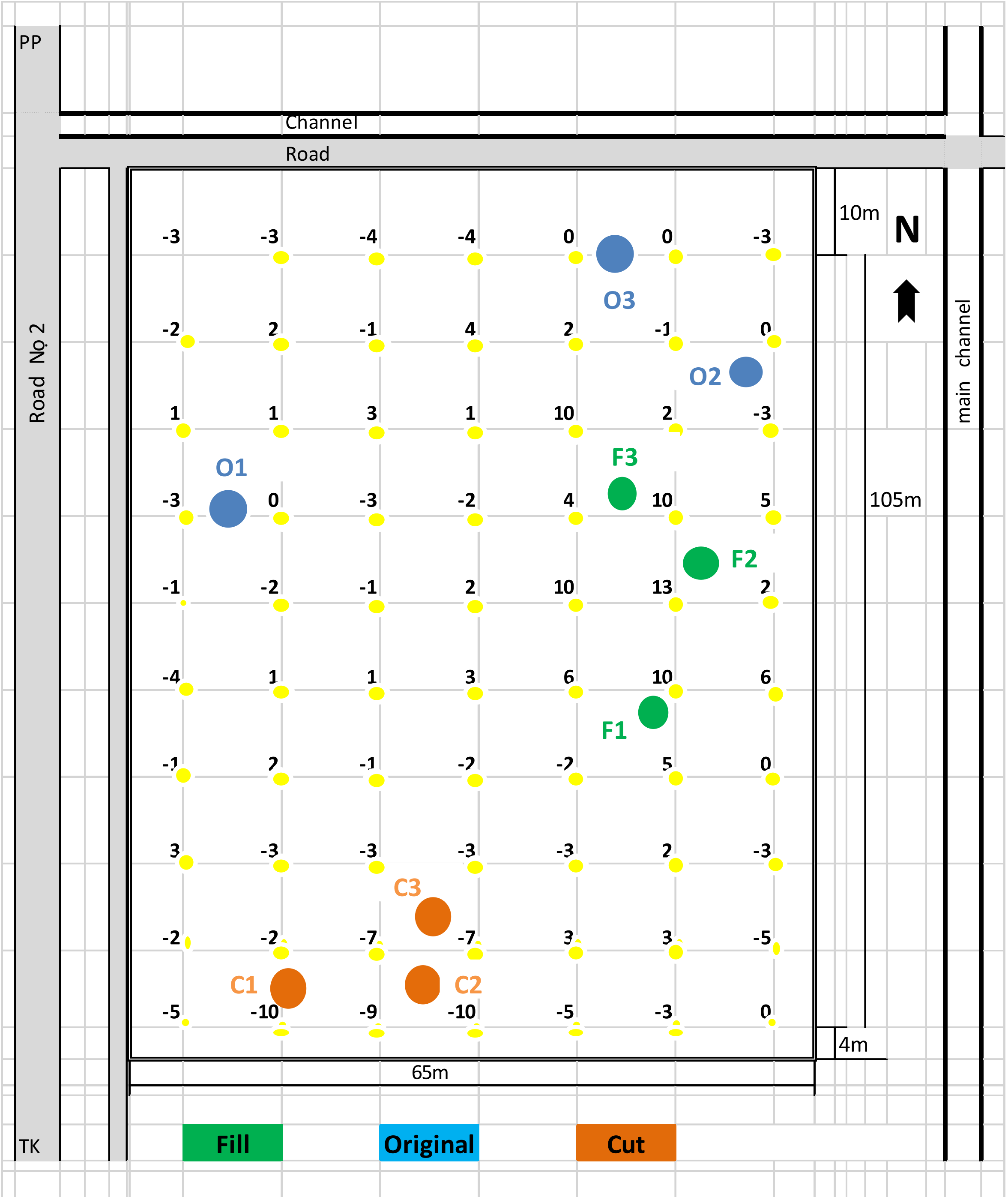


Figure 5-7 Diagram showing cut and fill areas and sampling positions across, cut, original and fill areas.

5.4.2 Developing laser land levelling capacity in MOWRAM TSC

Prior to the project there was no experience or capacity for undertaking laser land levelling in the Ministry of Water Resources and Meteorology (MOWRAM). MOWRAM is leading irrigation development and also rehabilitation of irrigation areas in Cambodia. In order to develop this capacity the Technical Services Centre (TSC) in MOWRAM went through a program of gaining the necessary skills to allow MOWRAM to undertake Laser Land Levelling as part of the LWR/2006/046 project.

Steps and methodologies involved in this process of knowledge transfer between project partners CARDI and MOWRAM TSC involved:

<u>Constructing a laser levelling bucket and bund builder in Cambodia</u>

Design of the laser levelling bucket was based off earlier designs by Rickman (2002). The equipment was constructed by a local Engineering firm based in Phnom Penh specialising in agricultural implement construction - Roesey Keo Engineering. Details provided below. Cost the bucket was $3900US for the original bucket with later versions which were constructed in the project also using an external hydraulic pump and oil cooler which was an additional $600US. Some tractors do not have the ability to run the external hydraulic control of the laser arm efficiently enough from on-board tractor hydraulic systems hence an external oil cooler and hydraulic pump was developed and used.

Roesey Keo Engineering

National road 5, Roeusey Keo Khan, Phnom Penh, (855) 12 879 932,
email pennovouv@gmail.com

<u>Assembling levelling bucket and Trimble laser with tractor</u>

A Trimble laser levelling unit was sourced from Vietnam from Ideal Farming Corporation (details below) for use on the laser levelling systems developed in the project. This is a straight forward process and there is no issue in bring in these units to Cambodia from Vietnam. Current pricing of a laser levelling unit with hydraulic controller is - $7255US.

The Trimble laser unit was then integrated with the laser bucket and Russian 80 HP tractor and assembled and tested at the Agricultural Machinery Department on March 09, 2012 with assistant of Mr.Touch Khun Deputy Director of Agriculture Machinery Department, Mr Pen Nov local engineer and for technician from TSC Prum Kanthel, Mr. Noun Vannarith and Mr. Teng Tongheng.

IDEAL FARMING CORPORATION

13 THU KHOA HUAN STREET

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<u>Undertake training (theoretical and Practical) on using laser levelling equipment by CARDI</u>

The laser land levelling training was conducted by Mr. Som Bunna (CARDI) on the process and benefit of laser land levelling on March 13-14, 2012 at the CARDI field station. This involved a theoretical session followed by practical demonstrations and hands on learning on the CARDI paddy fields. A series of workshops and smaller training activities were then held between CARDI and TSC and a joint manual and set of farmer information notes where developed for future use by project partners.

Demonstration and dissemination of laser land levelling to Government officials, private sector and farmers

Laser land leveling demonstrations were then conducted on 03/04/12 at Kandal Stung TSC Model Site and 04/04/2014 conducted at Kpob Trabek TSC Model site with approximately 0.5 ha being levelled at each site.

In following years the laser levelling activities were expanded and included:

- Two locations in Ta Keo and Kampong Thom Province around 16 ha in 2013
- In at Pursat province around 10 ha in 2014
- In Kampong Thom Province around 15 ha in 2015

At each of these campaigns local farmers and local authorities were invited to demonstration days where the project team demonstrated the laser levelling techniques and provided information on the benefits on laser land levelling. This included handouts on the benefits of land levelling (yield increase, water saving, weed control, reduce time and labour). Additionally, information on direct seeding and crop management was provided with most farmers switching to direct seeding after laser levelling had occurred.

Monitoring of the effects of laser levelling

At the sites in which laser levelling was undertaken in subsequent years during the project farmers were surveyed on the yield performance and basic experiences (weed management/ crop establishment) after laser levelling. Topographical surveys were also undertaken to investigate the long term effects of laser levelling. This was done using a total station/Auto-level with the grid from 5 to 15 meters.

Slides below show various activities of the above process.

Testing Trimble Laser levelling equipment with local engineer and assisted by Agricultural Machinery Department

Training on laser land levelling (field work) in CARDI compound

Ploughing before laser land levelling




Distributing handouts to participants and explaining the benefit of laser land levelling to participants during demonstration days



Laser land levelling demonstration


Re-topography survey after laser land levelling in Kampong Thom Province

Training to MOWRAM and PDWRAM staff on laser land levelling

5.4.3 Establishing private sector laser land levelling services

The project sought to develop a private sector laser levelling industry in Cambodia. In order to do this an initial meeting with CARDI, MOWRAM TSC and MAFF was convened and all three partners agreed to work together to formulate a model to assist this process. The model involved jointly training private sector individuals in laser levelling and supporting private industry partners interested in offering laser land levelling surveys to undertake demonstration trials and then supporting them through a land subsidy to help them establish. In addition training on using laser levelling equipment was undertaken.

5.5 Establishment of an Agricultural Weather Station (AWS) Network

Four automatic weather stations were installed and one Bowen ratio station have been installed with the project funds.

The four stations were installed at Kampot, Takeo, Kampong Thom and at CARDI and the Bowen ratio was installed also at CARDI.

A database server was setup to accept the data from each of the stations via the mobile phone network in Cambodia. At the same time a website was created on the server that queries the database and displays the data for the public to access and view.

The weather stations consisted of the following equipment and sensors

Equipment used at Kampot, Takeo, Kampong Thom:

Data logger-	Campbell Scientific cr800
Temp and RH sensor-	Vaisala HMP45c
Wind speed sensor-	Vaisala WMT52 or Lufft WS200
Wind Direction sensor-	Vaisala WMT52 or Lufft WS200
Barometric pressure-	61302V Young Barometer
Solar sensor-	Li-Cor Li200x Pyranometer
Rain sensor-	Hydrological Services 0.2mm tipping bucket rain gauge

These stations have a 10 meter space frame tower with the Wind direction/speed sensor fixed at the top. They have the temp/RH and solar sensors attached at 2.0 meters high, and the rain gauge mounted about 2 meters away and one meter above the ground. The logger enclosure is mounted on the northern face of the mast at 1.0m height and contains the logger, solar regulator, battery and GSM modem. The solar panel mounted on the southern side of the tower at 2.0 meters high.

Figure 5-8 Installation of weather station at the Takeo MOWRAM field station

Equipment used at CARDI:

CARDI AWS:

Datalogger-	Campbell Scientific cr800
Temp and RH sensor-	Vaisala WTX-520 all in 1 weather sensor
Wind speed sensor-	Vaisala WTX-520 all in 1 weather sensor
Wind Direction sensor-	Vaisala WTX-520 all in 1 weather sensor
Barometric pressure-	Vaisala WTX-520 all in 1 weather sensor
Rain sensor-	Vaisala WTX-520 all in 1 weather sensor
Solar sensor-	Li-Cor Li200x Pyranometer

CARDI Bowen Ration station:

Datalogger-	Campbell Scientific cr1000
2 x Temp and RH sensors-	Rotronic HydroClip2 with fans
Wind speed sensor-	Lufft WS200 sonic anemometer
Wind Direction sensor-	Lufft WS200 sonic anemometer
Total solar radiation sensor-	CR-1 net pyrradiometer
Heat flux plate-	Hukeseflux soil heat flux plate

Physical Description of the CARDI AWS:

This station consists of a vertical 1.8 mast with the all in one Vaisala weather sensor mounted on top. The Solar sensor (pyranometer) is mounted on a 1.0m horizontal arm at the same height of the Vaisala.

The logger enclosure is mounted on the northern face of the mast at 1.0m height and contains the logger, solar regulator, battery and GSM modem. The solar panel mounted on the southern side at the same height.

Physical description of the CARDI Bowen Ratio station:

This station consists of a 2 meter vertical mast with the wind speed and direction sensor mounted at the top and the solar net pyrradiometer mounted to the south and at 1.8 meters high.

The two temp and RH sensors are at the ends of a 2 meter long seesaw arm that the logger, through the use of an actuator, automatically alternates the height of the sensors 15min before taking a reading. The solar panel is mounted to the south at 1.2 meters high and the logger box is mounted to the north at 1 meter high.

Figure 5-9 Installation of bowen ratio system at the CARDI experimental field station

The Cambodian ministry of water resources had older weather stations located at Kampot, Takeo, Kampong Thom, because of a memorandum of understanding and the physical location of these older stations was quite secure the decision was made to locate these newer stations at these same locations.

The site for the CARDI stations was also made on the basis of security but also to collaborate with the CARDI group at their physical location.

This weather station network was installed as part of the project to demonstrate the modern collection of reference evapotranspiration data which is a fundamental information when undertaking crop water use studies.

6 Achievements against activities and outputs/milestones

Objective 1: To Develop an improved understanding of farm-level water management constraints and opportunities.

No.	Activity	Outputs/ milestones	Due date	Comments
1.1	Literature review of current irrigation water management practices and research in Cambodia and surrounding countries (1.1) CSIRO/CARDI/TSC/ITC	ACIAR benchmarking report based on review of current literature and data only	Aug 2012	A CSIRO science report has been published. It contains a literature review and also benchmarks irrigated rice water productivity of neighbouring countries. There was very little Cambodian literature on rice water use. Some data from Laos and Vietnam, which has been included in the report. https://publications.csiro.au/rpr/download?pid=csiro:EP1310226&dsid=DS6

1.2	Farmers in Takeo province across 3 agro-ecological zones surveyed on their irrigation and agronomic practices. (1.2) CARDI/ CSIRO/TSC/ITC	ACIAR report and data for the Cambodia country almanac	Dec 2012	Surveys (180 households) have been undertaken in the three districts of Takeo province- Koh Andeth, Angkor Borei and Kirivong. A linked bio-physical survey of 220 fields has also been completed. This information has been provided in a joint report by TSC and CARDI. Over the last 12 months the initial report and data has been redeveloped and completely re-analysed into a report that more thoroughly examines the inter-relationships driving dry season productivity. Collins, M., Men Pagnchak, R., Prum, P., Hornbuckle., J. & Seng, V. (2015) Integrated analysis of socio-economic, agronomic and water management factors driving / limiting rice production in Takeo province, Cambodia, Cambodia Agricultural Research and Development Institute, Phnom Penh, 2015

1.3	Benchmarking water availability, infrastructure assessments, paddy field land levelling TSC/CSIRO/ITC	ACIAR report and data for the Cambodia country almanac	Mar 2013	Irrigation infrastructure survey matching with socio-economic survey (above) completed for all 9 villages across 3 districts. Specific mapping and surveying of farmers' fields (~220) have been completed.
1.4	Groundwater survey and impact on soils and crops in Angkor Borei district of Takeo CSIRO/TSC/CARDI	Groundwater quality ascertained for Angkor Borei in Takeo and limitations to use. Impacts of groundwater on soils and crops assessed.	April 2014	Two long term groundwater monitoring sites were established in Angor Borei. Farmers have been trained to measure and record water depth on a monthly basis for >1 year. Soil and groundwater samples have been collected . There appears to be minimal impacts or risk of groundwater irrigation to rice productivity.
1.5	Collate historic weather data for Cambodia IDE/ITC/TSC	A compilation of all available meteorological data for Cambodia	Jan 2014	Completed. All available data has been collated. Metadata has been prepared. Available historical data has been included on the website. http://weather.irrigateway.net/cambodia/

Objective 2: Research and develop adapted water management interventions to increase productivity.

No.	Activity	Outputs/ milestones	Due date	Status and Comments
1	Field trials to demonstrate current best practice land levelling, water, fertiliser management CARDI/CSIRO/TSC/ITC	First season field trial and report	Aug 2012	Five field demonstrations have taken place in Takeo (three by CARDI and two by TSC). Detailed field trials have been undertaken at the CARDI experimental site now over two dry-season rice crops.
2	Identify and use laser levelling machinery in irrigation area redevelopment TSC/CSIRO	Up to 50 ha laser levelled	March 2012	Two locations levelled by TSC. One area recently redeveloped (Kandal Stung one of MOWRAM's model irrigation areas) and one irrigation area at Upper Slaku Takeo province.
3	Assess methodologies for the determination of crop water requirements ITC/TSC/CSIRO	Report on methodologies	June 2012	Methods were assessed using three different methodologies. Based on results there were good agreement between the three approaches. Results indicate that simple crop water requirements can be accurately determined with the Cropwat model. Results have been published and this information used by researchers and government departments for water use planning https://publications.csiro.au/rpr/download?pid=csiro:EP1310226&dsid=DS6
4	Field trials to demonstrate land levelling, water, fertiliser management CARDI/CSIRO/TSC/ITC	Second season field trial and report with updated recommendations on improved irrigation water management.	April 2013	A series of field demonstration have been conducted in multiple locations on laser land levelling and improved water management. This information has also been incorporated into a range of extension and reporting material that has been disseminated widely in Cambodia.

5	Laser levelling machinery in irrigation area redevelopment TSC/CSIRO	Up to 75 ha laser levelled	April 2014	An additional 25 ha has been laser levelled by TSC during the previous 2 years in the Ta Keo and Kampong Thom provinces. This combined with previous laser levelling activities in Pursat area, and TSC have conducted re-topography survey of 16 ha in 2012 & 2013 along with farming surveys on crop yields and changed practices.
6	ITC undergraduate studies ITC/CSIRO	Student reports	Dec 2012	5 undergraduate students have completed honours thesis associated with the project
7	Field trials and water management modelling CSIRO/CARDI/ITC	Field trials and report on field data combined with modelling results.	June 2014	A combination of field trials and modelling work has been undertaken in the project. This information has been used to show how improved water management can increase crop yields. This information has been used demonstrate achievable potential yields for dry season rice cropping in Cambodia both farmers and also policy makers. https://publications.csiro.au/rpr/download?pid=csiro:EP1410035&dsid=DS1
8	ITC undergraduate studies ITC/CSIRO	Student reports	Dec 2014	16 undergraduate students have completed honours thesis associated with the project. Many of these students have now gone on to undertake Masters and PhD studies.

Objective 3: Support extension efforts, providing timely, practical on-farm water management information to activities being undertaken by project partners, CAVAC and NGO's

No.	Activity	Outputs/ milestones	Due date of output/mile stone	Comments
3.1	Identify best practice farmers to be used as case studies of success CARDI/CSIRO	“Case studies of success” that feature benchmark farmers and irrigation areas. Short 1-2 page description of farmers and activities showcasing best practice	Dec 2014	A number of farmers have been used as case studies in the project with demonstration farms and farmers being used in the project for sowing the potential of laser levelling and changed water management on crop yields. These farmers have been show cased by CARDI and TSC in various field days.
3.2	Develop a laser levelling promotion and training package CARDI/TSC/ CSIRO	Laser levelling package which includes information on sourcing laser, bucket and associated training material for operation. Also includes basic information on the costs and benefits of levelling suitable for operators to make a business plan.	April 2014	A series of documents from farmer notes to manuals have been developed in the project for laser land levelling. These documents are listed in section 10.2 of this document. Additionally an information hub has been developed that provides key documents and information for those interested in laser land levelling activities. This site provides downloadable documents and links as well as information on importing laser levelling equipment and contact details and information for constructing a laser bucket in Phnom Penh. The website hub provides a one stop shop for sourcing information on laser levelling in Cambodia and can be used by project partners to help commercial operators to uptake laser levelling activities. https://sites.google.com/site/cambodialaserlevelling/
3.3	Develop a simple document and extension material for best practice water and nitrogen management in dry season rice CSIRO/CARDI/ TSC/ITC	A simple ‘Farmer Note’ developed that gives best practice guidelines for water and nitrogen management in dry season rice production.	June 2014	A range of extension material has been developed in the project by project partners (See Section 10.2). This includes Farmer notes on laser levelling and short information communications developed by CARDI which have been used in farmer training activities also distributed through Provincial PDWRAM offices.

3.4	Extend laser levelling activities and promote commercial uptake of technology TSC/CARDI/CSIRO	300 ha of laser levelled fields	April 2015	42 ha has been laser levelled by TSC during the previous 4 years in the Kandal, Takeo, Pursat and Kampong Thom Provinces. An additional 10 ha have been levelled by CARDI as farmer demonstrations. In collaboration with CAVAC and MAFF Department of Agricultural Engineering an additional 350ha as part of the CAVAC irrigation area rehabilitation efforts has been made. Three private sector laser levelling contractors have been helped by the project to establish a laser levelling contractor service have levelled 13.5 ha as part of 1st season demonstration trials in Battambang, Kampong Thom and Takeo Provinces. One large scale independent Cambodian farming operation has laser levelled 80 ha of land in Kandall Province with guidance from CARDI on bucket design and operation.
3.5	Reporting CSIRO/CARDI/ TSC/ITC	Final report to ACIAR	Dec 2015	Final report has been completed.

7 Key results and discussion

7.1 Integrated socio-economic and bio-physical survey of agronomic and water management factors limiting rice production

Farm-level baseline survey

Characteristics of households

In Takeo province, surveyed households have an average size of 4.9 people with an average age of 37. Most farmers owned the land they cropped (>99%) with an average farm size of 2.6 ± 0.2 hectares (ha). The largest farm surveyed was 14.3 ha and the smallest farm was 0.3 ha. Across the province, 70% of household income is generated from rice growing, with the remaining household income derived from off-farm work (11%), livestock (11%), non-rice crops (3%), other income (3%) and fish (2%). Other studies have found that 94% crops grown in Takeo are rice, with the remaining used for vegetables, fruits, legumes and other crops (Wang et al. 2012). Average annual household income was US$3,363, which is equivalent to just under US$10 per day, or US$1.90 per household occupant per day (Figure 1).

There are small differences in household income between the three surveyed districts, with household income in Koh Andeth (US $3,700) the highest, followed by Kirivong (US $3,403) and Angkor Borei (US $3,116) (Figure 1a). With the exception of income generated from non-rice crops in Kirivong ($P < 0.01$), most of the differences, including rice and total household income are not significantly different between districts (Figure 7-1). Overall, rice-derived income is closely related to farm size (Figure 7-1, $R2 = 0.99$) with increased income in Koh Andeth a consequence of significantly larger farms (3.5 ha; $P < 0.01$). Farms in Angkor Borei (2.4 ha) and Kirivong (2.2 ha) were significantly smaller compared to farms in Koh Andeth (Figure 7-1). This confirms data from the Asian Development Bank (ADB) which concludes that farm size, as measured by area of land cultivated or operated, is the most important determinant of increased rice production, value of production, commercialization and sales (ADB 2014). The farm sizes surveyed are larger than the Cambodian average of 1.8 ha / household and the size found by other studies in Takeo at 1.6ha (Wang et al. 2012). Across all 180 farmers surveyed, productivity in terms of rice income per hectare ranged from US$63/ha to US$3,750/ha. The extremely high figure was from a highly productive small paddy.

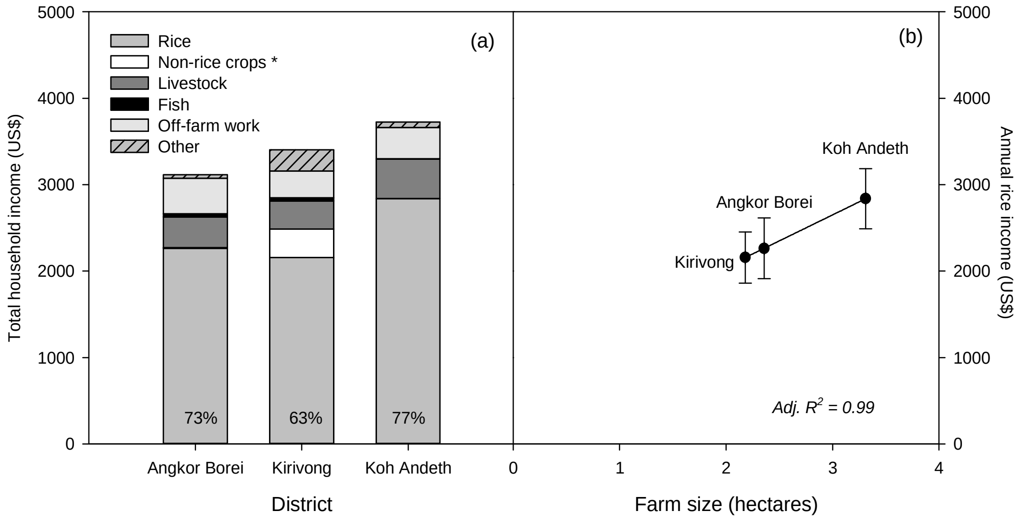


Figure 7-1 Annual household income by (A) district, incomes source and amount; and (B) relationship with size type between the districts. Where differences are significant in (A) P values are specified. Income from rice crops is detailed as a % on figure.

Soils and land preparation

Two main soil types occur in the areas surveyed in the province, Prateah Lang (sandy soil type) and Kbal Po (clay soil type). Prateah Lang soils, covered 25-30% of rice areas, are considered low potential soils while Kbal Po soil type is less common (13% of rice areas) and this soil type is considered fertile and high in organic carbon.

Kbal Po soils dominated across the districts accounting for all soils surveyed in Koh Andeth and two-thirds of the soils in Angkor Borei and Kirivong (Figure 7-2). In Kirivong, the lighter Prateah Lang soils are associated with water stress, with 75% of farmers with these soils reporting they regularly experience water stress. In comparison, only 30% of farmers in Kirivong on the heavier Kbal Po soils reported regularly experiencing water stress in their crops (Figure 7-2). In Angkor Borei, approximately half of the farmers reported regularly experiencing water stress in their crops, irrespective of soil type. Of course, the reporting of water stress in crops may be function of the water sources they use to irrigate their crops and the size of the crops, rather than a direct function of the soil type. In fields where corresponding yield data was available there were significant differences in crop yields grown on the two soil types ($P < 0.01$) with Kbal Po soils averaging 4.8 ± 0.1 T ha-1 (n = 235 fields) and Prateah Lang 3.9 ± 0.2 T ha-1 (n = 87 fields). There were also differences in yield by soil type in different seasons, with lower yields in the lighter Prateah Lang soils in MWR and DSR crops (Figure 7-3). These yields are higher than previous studies have found but nonetheless illustrate the high potential of Kbal Po soils compared to Prateah Lang soils.

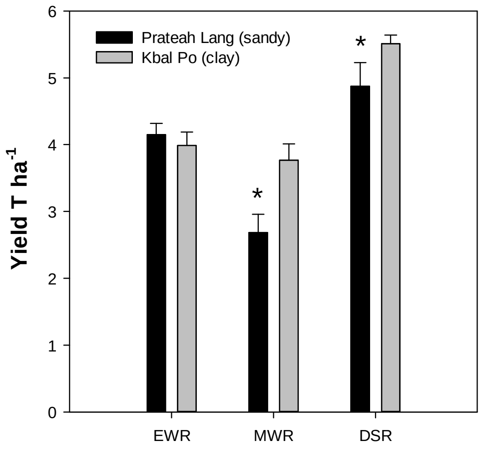


Figure 7-2 Influence of soil type on yield in early wet, main wet and dry season rice (T ha-1). Significant differences between soil types are indicated by * (P< 0.05; n = 354 fields).

In preparing land for rice crops, most farmers (89%) used some form of levelling (animals, hand tractor and standard tractor) to prepare fields for sowing. Of the farmers that supplied details about field levelling (n=112), the majority used hand-tractors (64%) to level their fields, followed by tractors (16%) and animals (5%). Only 16% of farmers did not level their land. We were unable to measure a yield difference between levelled fields (irrespective of method) and fields that were not levelled across all seasons (Figure 7-3). However, it is not accurate to conclude that land levelling does not result in improved yields and increased ease of water management, with 145 out of 180 farmers reporting they experience negative effects on crop yield from uneven fields. It is more likely this is a consequence of the socio-economic survey not being an accurate measure of this question, particularly as the number of farmers surveyed that didn't use some form of levelling was very low (16%).

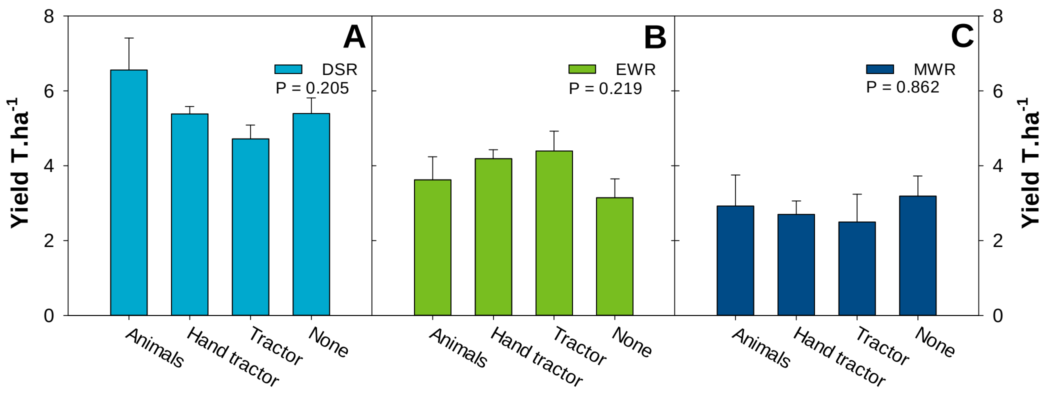


Figure 7-3 Impact of land levelling by animals, hand tractor and tractor on seasonal yield (A) dry season rice, (B) early wet season rice and (C) main wet season rice. There was no significant differences in yield by levelling (n = 112), P-values are indicated.

Cropping systems

In the survey area, rice growing was dominated by dry season crops (DSR; 90% of farmers), followed by early wet season (EWR; 56%) and main wet season crops (MWR; 49%, Figure 7-4). This changed between the districts with farmers in Angkor Borei growing more MWR compared to the other districts, compared to Kirivong where farmers grew more EWR and less DSR and MWR (Figure 7-4). Farmers in Koh Andeth grew less EWR compared to the other districts. Three quarters of the farmers grew crops in a minimum of two seasons, with 56% in two seasons and 19% in all three seasons. Only a small proportion of farmers (25%) grew a single season crop. Amongst single and double season crop farmers, nearly all grew DSR (> 86%). Most farmers growing crops in a single season grew DSR (91%) which is unusual for Cambodia where the majority of farmers traditionally grow wet season rice. It is likely this is a reflection of increased access to irrigation in Takeo compared to other regions, with other studies finding that 44% of agricultural holdings in Takeo use irrigation, which is much higher than other regions such as Tonle Sap (23%), coastal (18%), plateau and mountainous (21%) regions (NIS MAFF 2013) .

There were differences between districts in the average number of seasons that farmers grew crops with Angkor Borei farmers growing significantly more crops (2.2 crops/year) compared to Kirivong (1.9 crops / year) and Koh Andeth (1.8 crops / year). It is possible that the higher profitability of the larger farms in Koh Andeth decreased the requirement for farmers to grow multiple crops throughout the year or potentially water security may have been a factor. Unsurprisingly, most of the farmers practising triple season cropping were in Angkor Borei (60%) and over half the farmers planting single crops were in Koh Andeth (51%). Differences in number of crops per year is driven by field location and whether or not fields are flooded during the wet season. For example, farmers with only low fields often only grow two crops per year, whilst upper fields can be triple cropped if irrigation is accessible. The increased number of farmers in Angkor Borei growing three crops is facilitated by higher fields and access to groundwater which supplements surface irrigation and increases flexibility of establishment for early wet and main wet season rice.

There were seasonal differences in yield with dry season crops yielding 5.5 T.ha-1 compared to 4.0 T.ha-1 for early wet and 3.3 T.ha-1 for main wet season crops (Figure 7-6).

In this study, rice varieties were categorized into three groups: CARDI (which consisted of modern and improved traditional varieties), traditional and introduced (modern). Crops in Takeo were dominated by modern variety IR504 accounting for 73% of crop sown, followed by 21% traditional and 6% CARDI varieties. However, this did change with the seasons, with both DSR and EWR crops being 95% IR504 and a small percentage (5%) CARDI varieties (Figure 7-7). In the main wet season, traditional Cambodian varieties made up 72% of rice grown, 20% rice was IR504 and 8% CARDI varieties (mostly IR66; Figure 7-7)

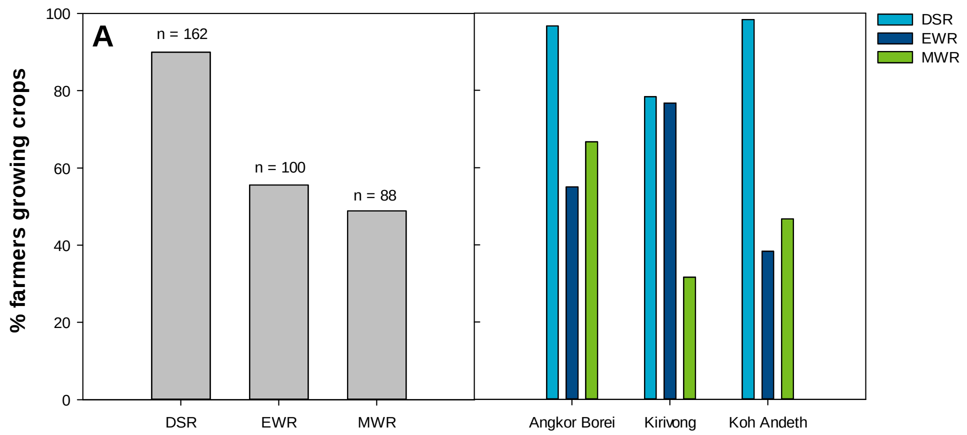


Figure 7-4 Percentage of farmers growing rice crops in (A) the three seasons and (B) districts. Data is from all 180 survey farmers. Significant differences are indicated by different letters and P-values are included.

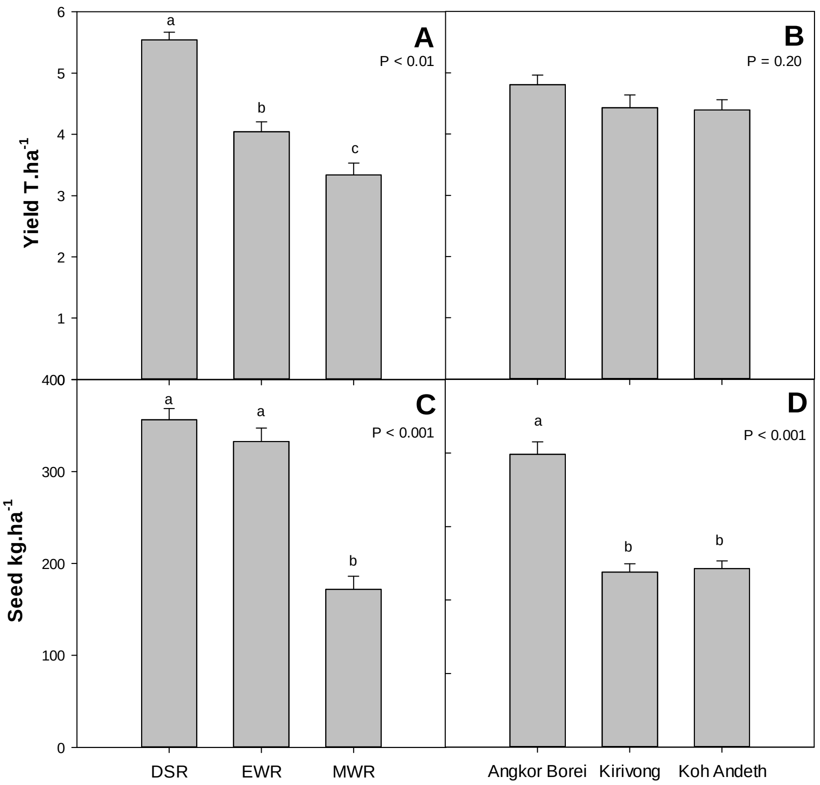


Figure 7-5 Yield (A, B) and seeding rate (C, D) by season (A, C) and districts (B, D) districts in Takeo province. Yield and seeding rate is based on data from 372 fields across the 180 farmers surveyed (n = 374). Significant differences are indicated by different letters and P-values are shown on all graphs.

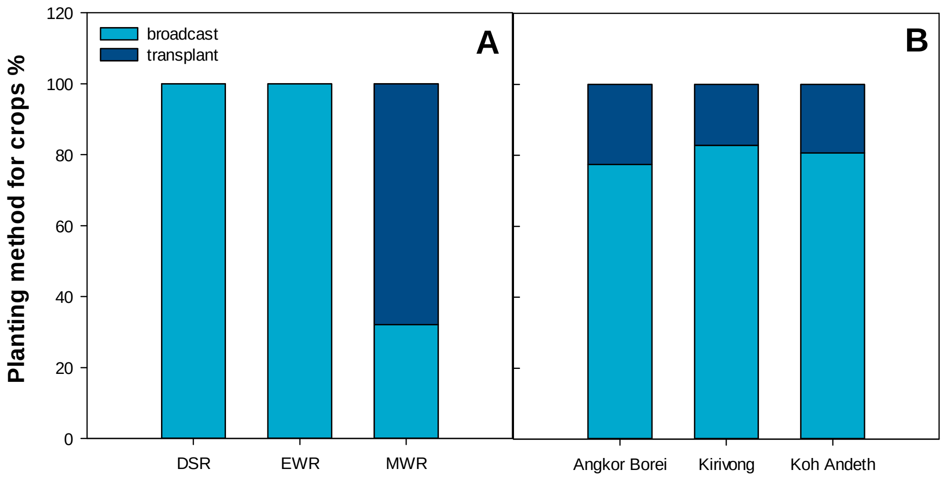


Figure 7-6 Planting method (broadcast or transplanting) by (A) season and (B) district (n = 372).

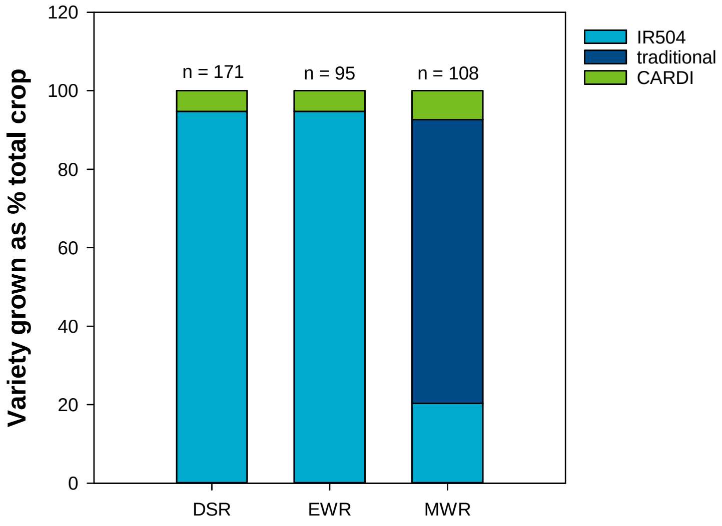


Figure 7-7 Rice varieties grown in dry season (DSR), early wet (EWR) and main wet season (MWR). Split of varieties for each season is measured as a percentage of total crop grown with n values for each season specified on figure.

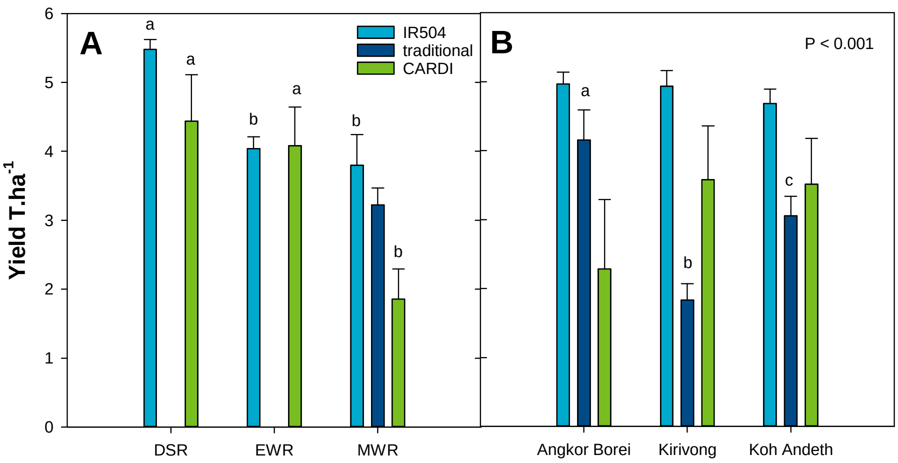


Figure 7-8 Yield of different varieties by (A) season and (B) by district. Differences between seasons and districts within varieties are indicated by different letters on the figures (all P < 0.001; n = 374).

The study also found that in both early wet and dry season crops, the type of field where the crops were grown differed significantly. For example, crops grown on flood plains (fields generally flooded in the wet season) that take advantage of rising and receding flood waters are called pre-rising rice and recession rice. The survey found that a large proportion of these fields (86%) are not used for MWR because of being flooded during the main wet season. In the early wet season, 83% of rice grown was pre-rising rice (Figure 7-9) which takes advantage of rising flood water in the wet season to finish the crop. While most of these farmers have access to supplementary irrigation (92%) the extent to which this is utilised is unclear from the dataset. However, as a very high proportion of EWR is pre-rising rice, the availability of water for supplementary is potentially a limiting factor in crop production and in most years would be critical for crop establishment. Interestingly, all fields used for pre-rising rice in the early wet season were then planted with recession rice in the dry season. In the dry season, 45% of the rice grown was recession rice. All dry season rice, including farmers growing recession rice have access to supplementary irrigation. The high proportion of farmers growing pre-rising and recession rice in the early wet and dry season confirms that utilising flood water is a key factor in their productivity. Other studies have estimated that only 21% of the 255,000 ha of dry season rice is fully irrigated with the remainder being recession rice receiving supplementary irrigation (Nesbitt et al. 2004). With recession and pre-rising rice being highly dependent on seasonal rainfall patterns, increased water security through increased access to irrigation schemes should lead to significant gains in both yields and area cropped, increasing overall rice production and farmer income.

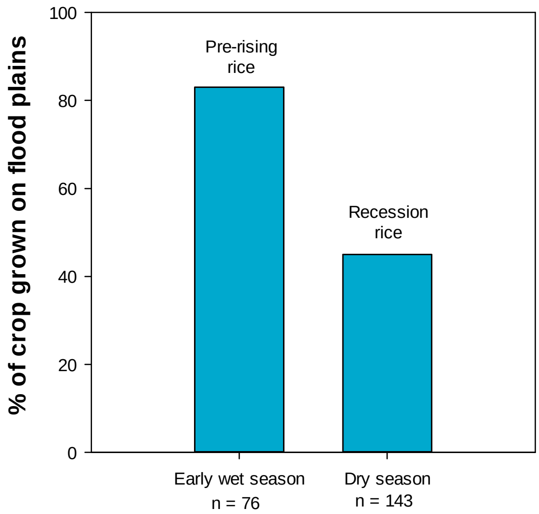


Figure 7-9 Proportion of crop grown on flood plains in Takeo (n = 180 farmers). In the early wet season, rice planted on flood plains is called pre-rising rice and in the dry season recession rice as farmers take advantage of rising and receding flood waters.

Fertiliser

Our study found that farmers in Takeo applied both inorganic (chemical) and organic fertiliser to their crops in all seasons (Figure 7-10). In EWR and DSR nearly all farmers (98%) applied inorganic fertiliser to their crops, in MWR it was slightly lower at 90%. Farmers applied inorganic fertiliser in the form of urea, DAP and NPK (20:20:15) to crops in all seasons at an average rate of 101 kg ha-1 N, 46 kg ha-1 P and 11 kg ha-1 K with the amount applied varying by season (Fig. 10). Irrespective of source, the amount of chemical fertiliser applied to MWR crops was significantly lower for N, P and K compared to EWR and DSR (Fig. 10). As a rule, farmers applied 30% more N, 44% more P and 41% more K to early wet and dry season crops compared to MWR.

Across the districts, the amount of N and K was consistently applied, but lower amounts of P were applied in Angkor Borei (Figure 7-10) compared to Kirivong and Koh Andeth. It seems likely the lower levels of P application were offset by increased application of organic fertiliser in Angkor Borei (2 to 23 times higher) compared to the other two districts (Figure 7-10). Use of organic fertiliser in Kirivong was particularly low at 0.1 T ha-1 compared to both Koh Andeth (0.8 T ha-1) and Angkor Borei (1.7 T ha-1). Application of organic fertiliser was 5 - 25 times higher in MWR compared to EWR and DSR, which offset low levels of chemical fertiliser applied (Figure 7-10). This reflected personal preferences for low chemical application to wet season rice grown for household consumption rather than trade. Application of fertiliser to traditional varieties is also a factor in these trends, which will be discussed later. In addition to the seasonal differences in use of organic fertiliser (MWR > EWR > DSR), organic fertiliser use also differed according to soil type. Organic fertiliser was used in larger amounts on lighter sandy Prateah Lang soils (3.9 T ha-1) compared to heavier clay Kbal Po soils (1.6 T ha-1; P < 0.001). This difference was consistent across all seasons. Presumably, this would help increase both the fertility and organic carbon levels of the lighter sandier soil, possibly also increasing soil water holding capacity. Higher levels of phosphorus were also applied to DSR grown on clay Kbal Po soils (55 kg ha-1) compared to the lighter sandy Prateah Lang soils (34 kg ha-1; P<0.001).

Yield was positively correlated with N fertiliser across all nine villages within the three districts (Figure 7-10). There was no correlation between yield and P or K application. These results should be interpreted cautiously as there are differences between villages in crops grown (seasons) and varieties that will influence these relationships. However, considering that soils are generally poor and historically use of fertiliser is at very low levels this is also not a surprising observation. There was an interaction between yield and rates of N / P applied with random forest analysis giving both N and P high importance ranking (1.00 and 0.97 respectively) compared to K (0.55).

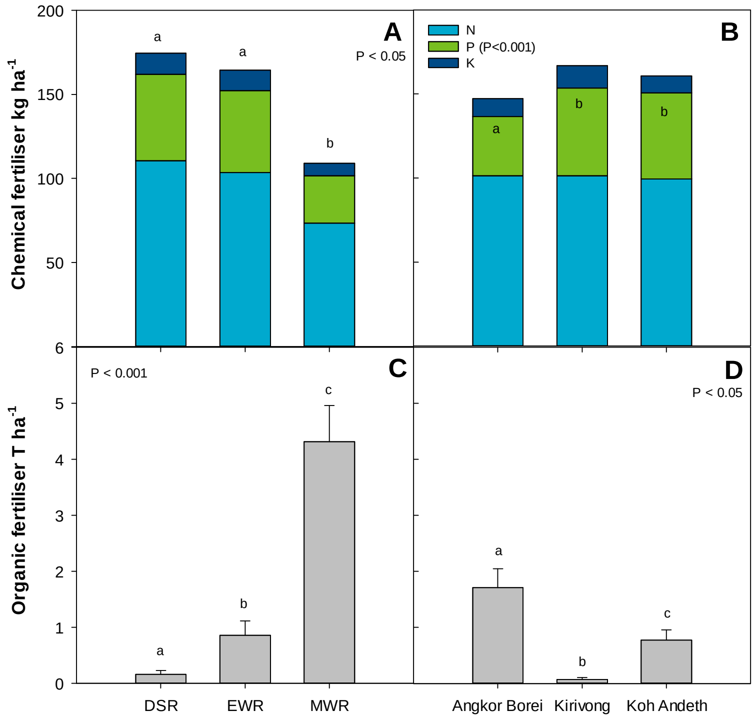


Figure 7-10 Rate of chemical (A, B) and organic (C, D) fertiliser application (T ha-1) across seasons (A, C) and districts (B, D) in Takeo province. Significant differences as determined by ANOVA are indicated by different letters and P-values where significant are specified. Data was collected across 323 fields (n = 163 DSR, n = 90 EWR, n = 70 EWR).

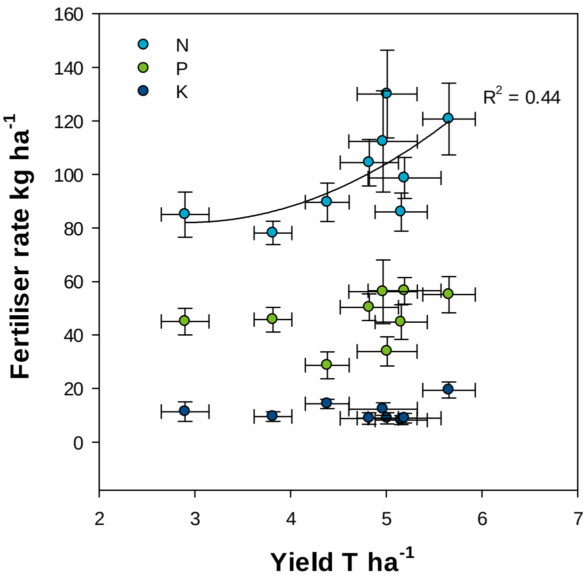


Figure 7-11 Relationship between inorganic chemical fertiliser (N-P-K) and yield in nine villages in Takeo province (n = 9).

Chemical, labour and production costs

Between the districts, there was no difference in chemicals applied (as measured by cost), labour and total production costs (Figure 7-12). Total production cost was defined as inputs (fertiliser and sprays) and paid labour. Labour by farmer and family was not included in costings as it was not a surveyed factor. There was also no difference in production costs across the districts, however the distribution of the costs differed with the seasons with MWR having significantly higher labour and chemical costs (Figure 7-12) compared to EWR and DWR. Chemical costs for MWR were 64 - 69% higher than for EWR and DSR, while labour costs were 32 - 45% higher. These differences were driven by high chemical application to specific varieties (IR504) in the wet season (Figure 7-13). Chemical costs for traditional varieties (US $253 ha-1) were significantly lower than for the dominant non-traditional variety IR504 at US$874 ha-1, although this was highly variable as indicated by large standard errors (Fig. 13). Other studies have found the input costs for rice crops to be approximately US$206 ha-1 (Wang et al. 2012) but these studies do not differentiate between seasons and / or varieties.

Chemical costs for non-traditional varieties such as IR504 were four to five times higher in MWR compared to dry season and early wet season rice (Figure 7-13). This may be as a consequence of increased pest pressure in this season or the smaller 0.4 ha fields commonly planted in the main wet season (Fig. 3) creating a distortion in this data. For example, are farmers simple buying the same amount of chemical for all seasons but applying it to a much larger area of crop in the dry and early wet seasons, diluting the impact of the chemical cost per hectare?

In dry and early wet season rice, production costs are characterised by high inorganic fertiliser costs, low chemical and labour costs, while main wet season rice has low inorganic fertiliser costs and high chemical / labour costs. Potentially, the higher labour costs in MWR are a consequence of transplanting rather than broadcast seeding. Therefore, production costs (fertiliser, chemical spray and paid labour) for the different seasons are not significantly different, however if yields are significantly different between the seasons this will increase profitability in higher yielding crops.

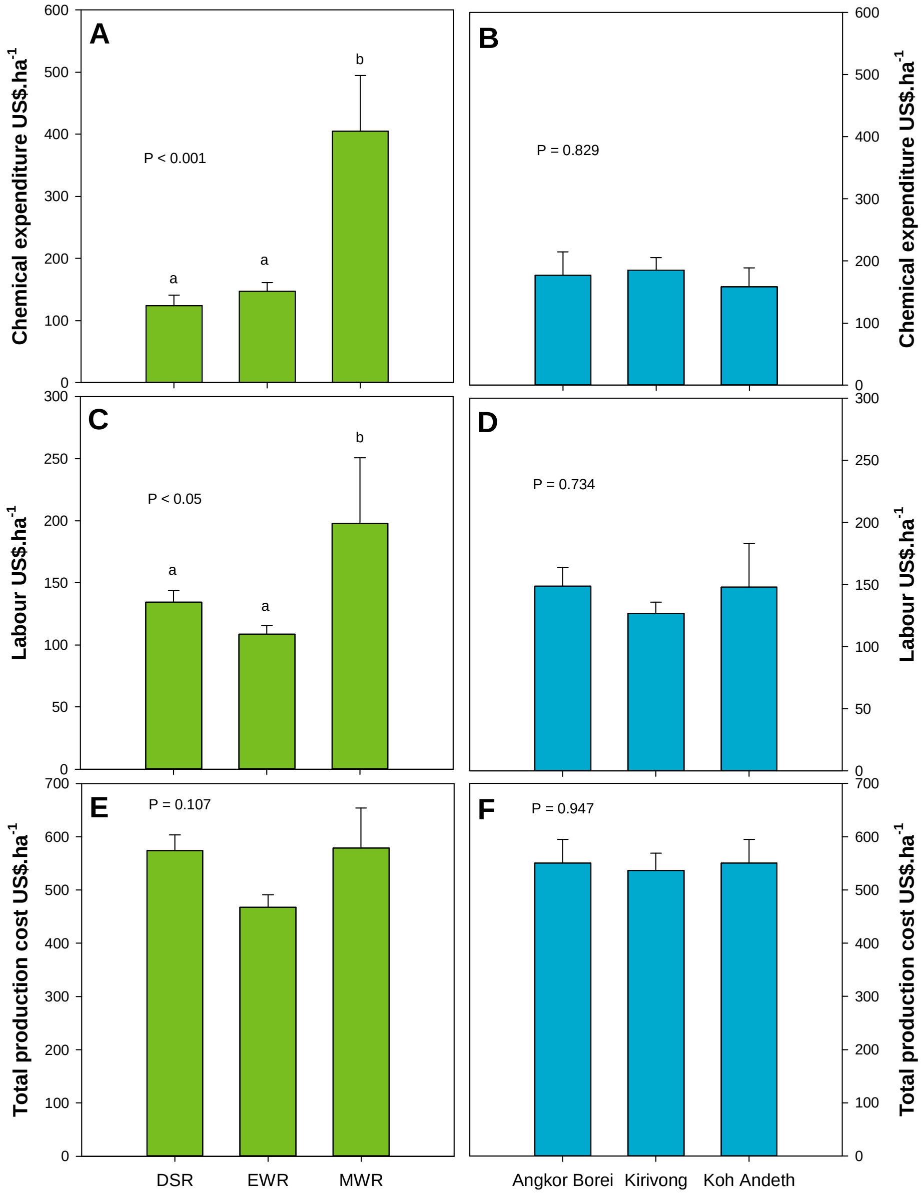


Figure 7-12 Chemical (A, B), labour (C, D) and total production costs (E, F) for rice grown in the three districts (A, C, E) and seasons (B, D, F). Chemical costs are inclusive of insecticides and herbicides and all values are in US$ per hectare with production costs including costs for chemicals (insecticide/herbicide), fertiliser and paid labour. Data for chemical / labour / production costs was available on 270 fields across the 180 farmers surveyed (n = 270). Significant differences are indicated by different letters and P-values shown.

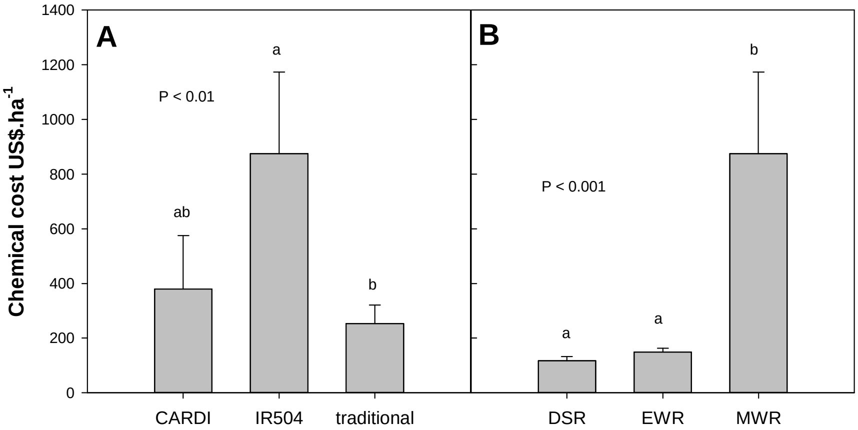


Figure 7-13 Chemical cost analysis for (A) different rice varieties (n = 270). (B) Breakdown of chemical costs for IR504 by season (n = 226). All costs are in US$ ha-1. Significant differences are indicated by different letters and P-values are included on figures.

Water sources

Of the farmers surveyed, 96% used some form of supplementary irrigation (ground or/and surface) to grow their crops (n = 180, Figure 7-14). The primary source of supplementary irrigation was surface water (92% growers). Surface water sources included river and canals (main, secondary and tertiary) followed by ground water (25%). Nearly all farmers using groundwater did so in conjunction with surface water (Figure 7-14). The survey did not differentiate between water sources used for different seasons.

The farmers with access to ground water were primarily located in Angkor Borei, with 65% of farmers in this district using ground water (Figure 7-14). The percentage of farmers using groundwater in Kirivong and Koh Andeth was very low (< 5%) with all farmers in these regions using surface water for irrigation (Fig. 22). The reasons for differences between districts in use of groundwater were unclear from the survey, however it is plausible to suggest that insecurity in surface water availability in Angkor Borei has led to increased demand for groundwater pumping. In Angkor Borei, the proportion of farmers using surface water was lower than the other two districts (78%) and it is unclear whether this is a consequence of limited access to surface water or increased access to groundwater. A small number of farmers relied solely on rain water to grow their crops in Kirivong district (Figure 7-14). There was no relationship between crop yield and the type of water source closest to farmer's fields (data not shown).

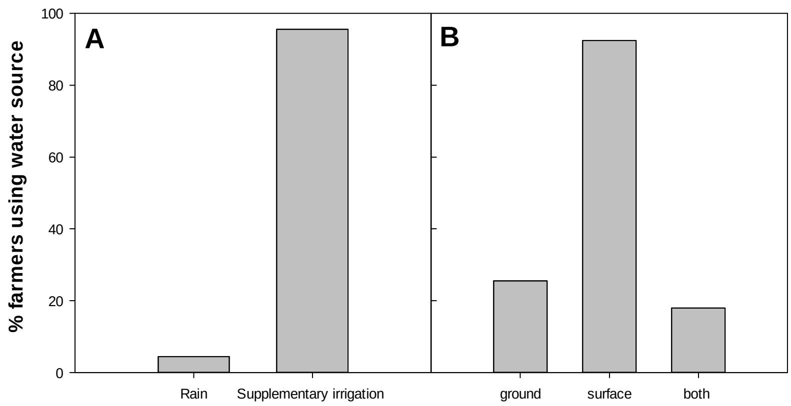


Figure 7-14 Source of water used for cropping by farmers in Takeo. (A) Primary water source used for cropping and (B) proportion of farmers using ground, surface or both ground and surface water for growing rice crops (n = 180).

Distance from water sources

In order to understand the drivers of rice productivity, the combined socioeconomic and biophysical surveys were analysed to investigate the impacts of water availability.

The distance between fields and surface water sources (river / main, secondary and tertiary canal) is a significant factor in farmers experiencing water stress. There is a very strong relationship between the distance to water source and percentage of farmers experiencing water shortages (R2 = 0.98, Figure 7-15). Distance to water sources was also highly negatively correlated with yield in the different seasons (R2 = 0.98, Figure 7-16). High yielding (> 5 Tha-1) and irrigation dependent dry season rice was grown less than 150m away from water sources, while EWR and MWR were grown 500-800m away from water sources (Figure 7-16). As there were no differences in yield between the districts the relationship between distance to water source and yield by district is not significant.

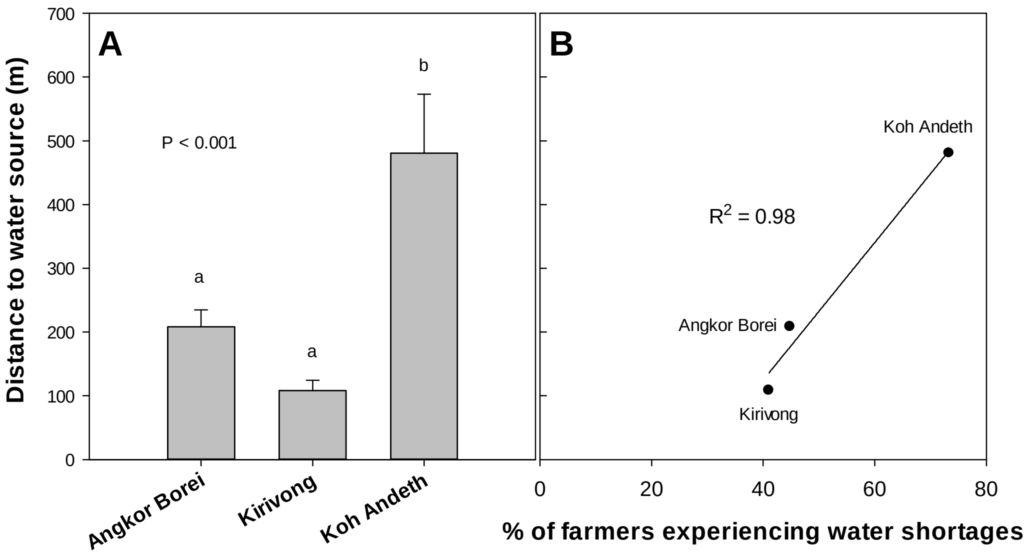


Figure 7-15 Average distance to water source by district (A) and relationship between distance to water source and percentage of farmers experiencing water shortages (B) across the districts. Significant differences between districts in (A) are indicated by different letters, with P-values included on figure. Linear regressions and R2 values are marked on (B).

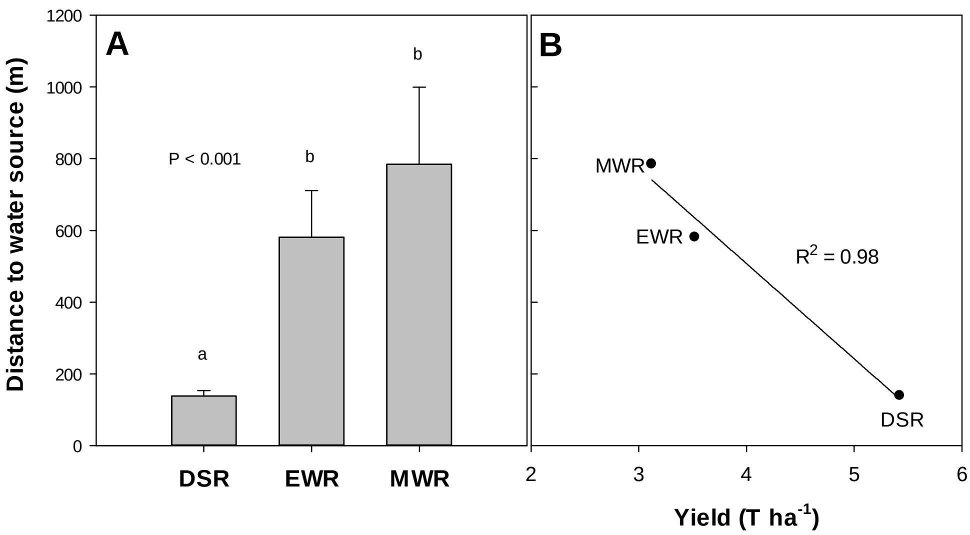


Figure 7-16 Average distance between paddy and surface water sources by season (A) and relationship between distance to water source and yield (B). Different letters indicate differences between seasons (A) with P-values on figure and linear regressions are included on (B) with R2 value specified.

In order to assess the relative importance of factors influencing farm productivity measured as yield (T ha^{-1}) and rice income (US$ ha^{-1}) random forest analysis was performed on the full data set. Random forest analysis is an alternative regression method that produces a single measure of importance for each predictor variable that takes into account interactions among variables without requiring model specification. Interactions increase the importance for the individual interacting variables, making them more likely to be given high importance relative to other variables. The output from random forests can be used to rank the importance of variables in a regression problem in a natural way. Values are given a ranking score from 0 to 1 that is a measure of their importance on the dependent variable (in this case yield and income).

From this analysis, the three most important factors affecting yield (T ha^{-1}) were season (early wet, main wet and dry season; rank 1.0), seeding rate (0.74) and variety (0.59; Figure 7-17). Other factors had decreasing impact on yield including planting method (0.49) and production input (cost US$ fertiliser, chemicals and labour; 0.46), N kg ha^{-1} (0.39), input cost ($US on fertiliser + chemical, 0.39), number of crops farmers planted each year and distance from water source (Figure 7-17). Water related factors such as supplementary irrigation (0.16) and farmers experiencing water shortages (0.07) were the lowest ranked of all variables. While water related factors ranked low in this analysis it is possible that as most farmers used supplementary irrigation and experienced water shortages they simply were not a very informative data classification for the purpose of this analysis.

In extending the analysis for variables affecting farm productivity as measured by rice income in US$ ha^{-1}, the results varied slightly. Compared to yield ha^{-1} more factors strongly influenced rice income with the most important variables driving income from rice per hectare were factors that drove farm economics including yield (1.0), farm size (0.90) and production cost (0.82). Seeding rate (0.77), fertiliser cost (0.75), season (0.70), variety (0.65) and input cost ha^{-1} (0.63) were also strong drivers of productivity as measured by USD ha^{-1}. Being located closer to water sources (0.58) also increased rice income per hectare for farmers.

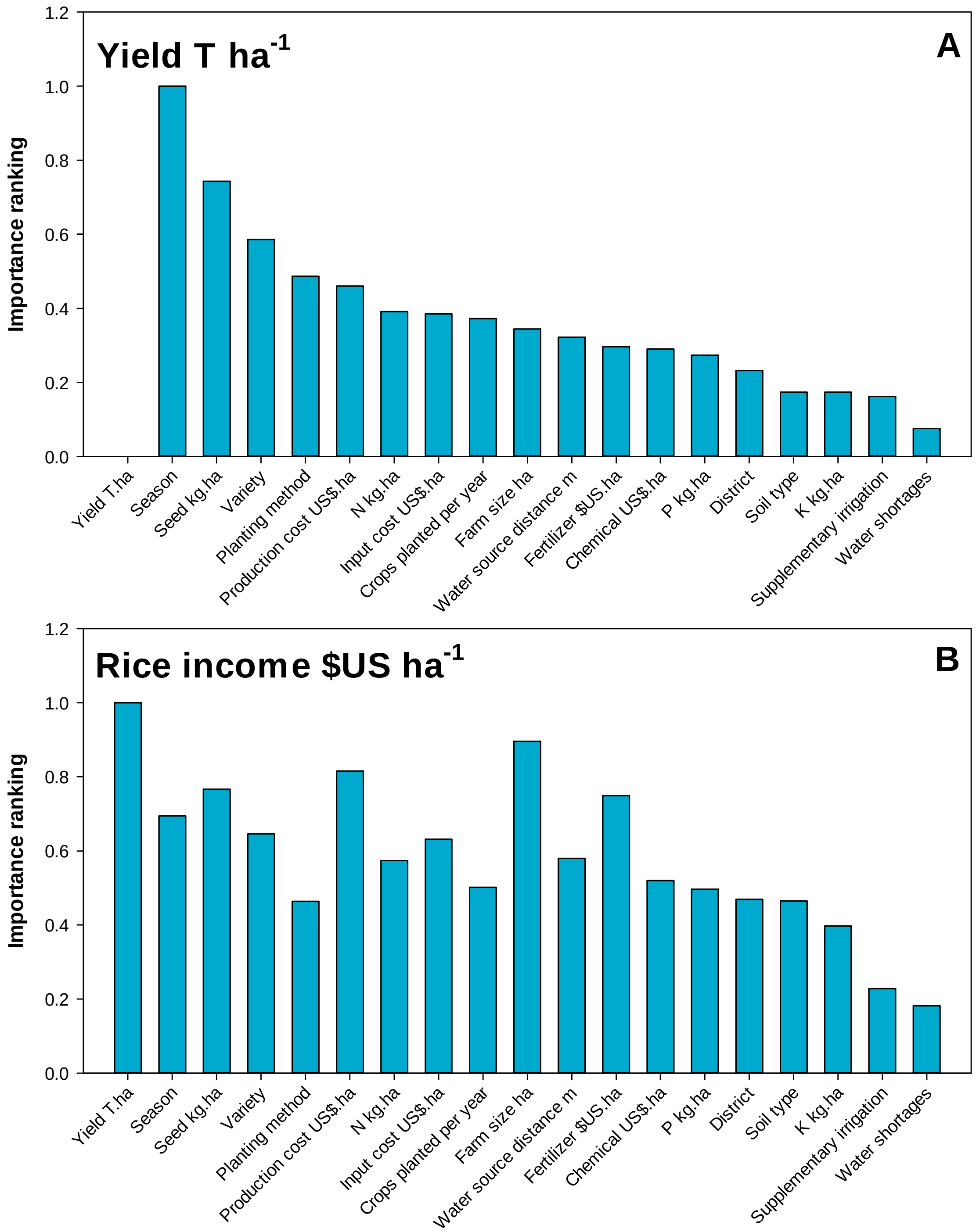


Figure 7-17 Importance ranking for variables affecting (A) yield T ha-1 and (B) rice income $US ha-1 as determined by random forest analysis. Details about variables are as follows: season (early wet, main wet and dry), variety (traditional, CARDI and other country), input costs (fertiliser and chemical cost per hectare), soil type (Kbal Po / Prateah Lang), supplementary irrigation (surface, ground, both), water shortages (yes/no).

The random forest analysis confirms the influence of individual components developed early in the report. Overall, there was an economy in scale with larger farms that invested more into inputs (seed kg ha^{-1}, inputs such as fertiliser, chemicals and labour) being more profitable. Major factors affecting yield were season, seeding rate and sowing of non-traditional rice varieties. Crops grown in the dry season, using higher seeding rates and fertiliser, planted by broadcast seeding of non-traditional rice varieties yielded higher than main wet season rice which typically was traditional transplanted sowing of low yielding traditional varieties with low fertiliser. Combining the GIS mapping of fields / water sources with farmer recorded yields confirms that higher yields are achievable with increased access to irrigation.

This study has been one of the first of its kind to begin to link biophysical surveys with socio-economic surveys in Cambodia. The survey has shown that there are a number of areas which could be focused on to increase rice production and productivity across Cambodia. It is clear that DSR has a high potential in Cambodia to produce high yielding crops provided sustainable water resources can be found to meet the crop water requirements.

7.2 Preliminary Groundwater Assessment

The study was conducted to monitor the quality and variation of groundwater quantity for agricultural production.

Data collected in the socioeconomic surveys of this study, indicated that most of the groundwater use was in Angkor Borei and there was no yield differences between districts (M.Collins pers. comm.). It was unclear from the data collection whether farmers in this region used groundwater as a consequence of uncertainty in surface water supply or for some other reason. Previous socioeconomic survey indicated that most profitable use of groundwater was on small vegetable plots that could be most carefully and intensively managed. However, a heavily irrigated dry season crop in combination with a supplemental irrigated wet season crop gave higher net profit than a single wet season crop. Anecdotal evidence from some farmers and from the socioeconomic survey results indicate that adverse crop effects were experienced when using groundwater only, compared with when groundwater was shandied with rain or river water. This was particularly the case when ground water was being used to establish early wet season crops. The reliability of these observations and the cause remain under investigated. Mr Chimm Som informed us that in 2013- 2014 he grew two crops of rice (~4 ha) and one crop of melons (~0.5 ha). The marketing of the melons is at the very local level and he is able to get a price that he can negotiate himself. He considers this is much more advantageous for him than the way rice is marketed. He is currently only using groundwater for irrigation purposes and no surface water. This is due to the greater cost of surface water pumping and the fees being charged by the Farmer Water User Community (FWUC). This is a change in practise to what he described previously, (2012- 2013) where he irrigated dry season rice using river water and only used ground water for supplementary irrigation during the early wet season if the river water remained limited. He noted that rice crop performance is affected (yellowing of leaves on newly established rice plants) if there is little or no rain during the early dry season rice suggesting a quality issue. The farmers currently have no ability to shandy groundwater and surface water through channels or dams. The demonstration of how farmers may use on-farm dams to improve water quality, harvest and store water and recycle irrigation water may be something to consider for irrigators in future.

pH. The groundwater samples were neutral to slightly acidic therefore the levels pose no risk for irrigation

Turbidity. Groundwater had high levels of clarity and without odour.

Salinity Field measurements within this study have indicated groundwater salinity levels can reach up to 2 dS/m which is within the normal range for irrigation water (FAO, 1985). Although research carried out on Australian rice crops has shown that rice productivity can be negatively impacted when floodwater salinity exceeds ~1 dS m^{-1} (Production of Rice in South Eastern Australia, RIRDC, 2000), the recommendations for agricultural water use for rice indicate that irrigation water with EC of up to 2 dS/m and soil EC of up to 3dS/m provide potential yields of 100%. Both of these criteria were met in the limited measurements that were made within this study. Rigorous elucidation of the reason for leaf yellowing when irrigating exclusively with groundwater compared with blended ground-surface water requires pot trials and further field follow up in future.

Arsenic is known to present a hazard to water quality for drinking and agricultural use throughout the Lower Mekong region and is a cause for concern in some provinces, such as Kandal in Cambodia. Therefore, it was considered, arsenic should be considered in the groundwater analyses presented here. Arsenic concentrations in groundwater samples taken here were undetectable (CARDI). Previous investigation (Buschmann et al, 2007) suggests As contamination of groundwater is relatively low in the study area (9 µg L^{-1}), which lies west of the Bassac River and in a relatively elevated part of the landscape.

Iron. The reconnaissance analyses of field groundwater for iron in this study were trace (< 0.1 mg L^{-1}), Greatest concentrations were measured as 2.6 mg L^{-1} in this region (Buschmann et al 2007). Maximum recommended concentrations for iron in irrigation are typically 5 mg L^{-1} (FAO, 1985). Therefore, iron toxicity from groundwater irrigation is apparently unlikely. Diseases such as bronzing and discolouration of young rice plants are known to occur when rice is exposed to very high concentrations of dissolved Fe^{2+} soon after planting and the effects are aggravated at low pH and salinity. Approximately 365 mg L^{-1} of water soluble Fe^{2+} causes toxic symptoms in rice at planting (Foy et al, 1978). .

Table 7-1 Result of groundwater analysis of some critical parameters in 2012.

No.	pH	EC (dS/m)	TDS (mg/l)	Nitrate (NO_3^-) (mg/l)	Alkalinity (mg/L $CaCO_3$)	Turbidity (NTU)	Arsenic (ppm)
1	7.10	0.94	na	nd	230	na	nd
2	7.22	1.52	715	nd	221	0.55	nd
3	7.32	0.71	333	nd	229	0.39	nd
4	7.32	1.34	605	nd	270	1.47	nd
5	7.29	1.96	925	nd	200	0.27	nd
6	7.28	2.03	936	nd	166	0.12	nd
7	7.96	1.99	894	nd	178	0.29	nd
8	7.48	1.64	753	nd	241	0.14	nd
	Slightly alkaline	Medium-Very high	No-increasing problem	nd	Moderately Risk of soil problem	na	nd

Note: nd= note detectable, na= not available

Long term groundwater monitoring sites

Both sites follow a similar hydrograph to that recorded previously (MOWRAM, 2011) whereby water levels are at the surface (2013) in September and October and tend to be at maximum depth in April-June with the fluctuation being up to 6 m. In the dry season of 2014 the country was experiencing drought and groundwater levels remained low throughout August – October at ~-2m.

Both of the sites were relatively close to the river (1- 3 km) and the groundwater dynamics are closely coupled to the river hydrograph which acts as both a gaining and a losing stream according to season (Ramskey et al 2009).

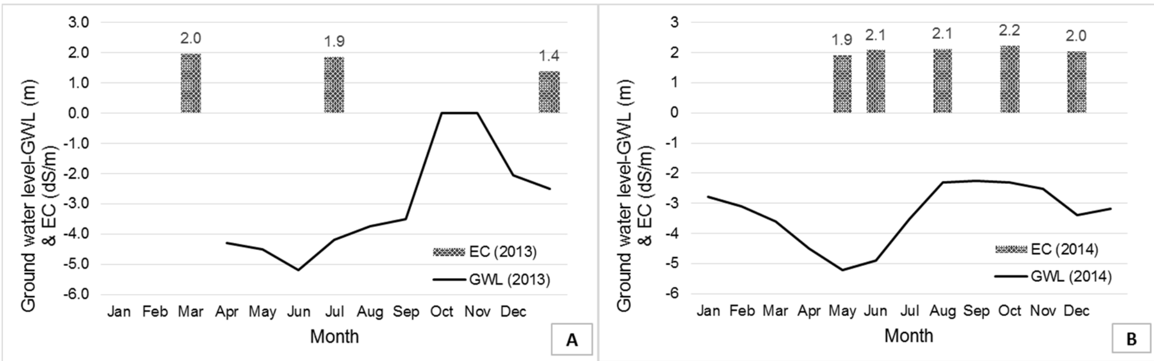


Figure 7-18 Trends in groundwater dynamics and salinity at two tubewell sites in Takeo.

The result of groundwater analysis collected from 2013 to 2015 from soil and water laboratory show that Fe, Al, NO_3^- and NH_4^+ were below detected range, pH value were around 7 which is suitable for the growth of crops (Table 7-2).

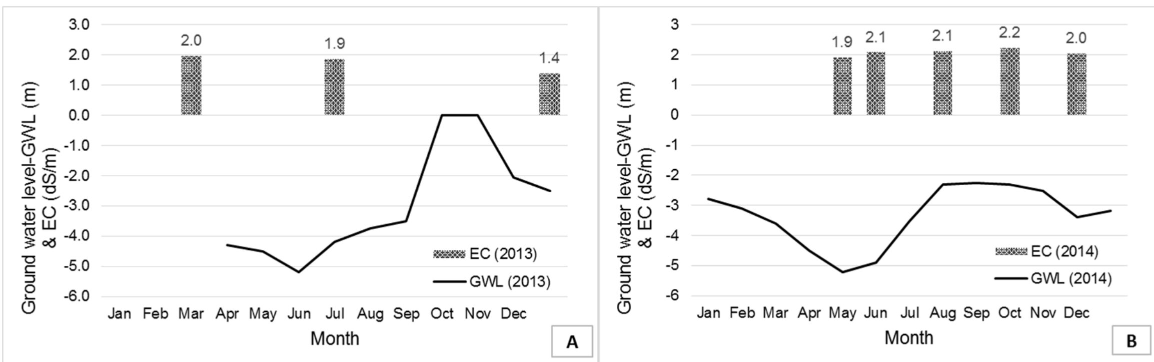


Figure 7-19 Monthly change of EC and groundwater level (GWL) observed in site # 1, Farmer's name Mr. Chhim Son in 2013 (A) and 2014 (B)

Table 7-2 Result of groundwater analysis of the critical parameters in 2013-15

No.	Sampling date	pH	Fe^{2+} mg/l	Al^{-} mg/l	NO_3^{-} mg/l	NH_4^{+} mg/l	Ca^{2+} mg/l	Alkalinity mg/l	Tubility NTU
1		7.1	nd	nd	nd	nd	71.7	237	20.2
2	26-Mar-13	7.2	nd	nd	nd	nd	47.9	221	20.6
3	08-May-14	7.0	nd	nd	nd	nd	51.5	206	0.3
4	11-Jun-14	7.0	nd	nd	nd	nd	66.2	189	0.9
5	15-Jul-14	7.0	nd	nd	nd	nd	38.3	205	0.3
6	14-Aug-14	6.9	nd	nd	nd	nd	87.3	201	0.8
7	18-Oct-14	7.0	nd	nd	nd	nd	56.1	203	0.4
8	08-Dec-14	6.9	nd	nd	nd	nd	54.0	205	1.9
9	26-Feb-15	7.0	nd	nd	nd	nd	22.3	213	94.3
10	22-Apr-15	6.9	nd	nd	nd	nd	nd	203	23.9
	MIN	*6.85*	*0.00*	*0.00*	*0.00*	*0.00*	*22.30*	*189.00*	*0.33*
	MEAN	*6.98*	*nd*	*nd*	*nd*	*nd*	*55.03*	*208.30*	*16.36*
	MAX	*7.19*	*0.00*	*0.00*	*0.00*	*0.00*	*87.30*	*237.00*	*94.30*

Note: nd= not detectable

Table 7-3 Result of groundwater analysis of the critical parameters in 2013-15 of site # 2

No.	Sampling date	pH	EC mS/cm	Fe(LR) mg/l	Al mg/l	NO_3^{-} mg/l	NH_4^{+} mg/l	Ca mg/l	Alkalinity mg/l	Turbidity NTU
1	2013	7.0	1.0	nd	nd	9.0	nd	19.6	230	21.0
2	26-Mar-13	7.0	1.6	nd	nd	73.0	nd	86.4	296	20.6
3	08-May-14	6.8	1.6	nd	nd	59.0	nd	51.5	274	0.4
4	11-Jun-14	7.1	1.3	nd	nd	21.0	nd	44.5	289	1.6
5	15-Jul-14	6.9	1.9	nd	nd	86.0	nd	83.3	303	0.6
6	14-Aug-14	6.8	1.8	nd	nd	77.0	nd	116.0	261	1.4
7	15-Sep-14	7.1	1.8	nd	nd	71.0	nd	71.3	288	0.9
8	08-Dec-14	7.0	2.0	nd	nd	72.0	nd	0.0	319	1.6
9	16-Jan-15	7.1	1.3	nd	nd	33.0	nd	40.7	224	0.6
	MIN	6.8	1.3	nd	nd	21.0	nd	0.0	224	0.4
	MEAN	7.0	1.7	nd	nd	59.9	nd	58.2	280	1.0
	MAX	7.1	2.0	nd	nd	86.0	nd	116.0	319	1.6

Note: nd= not detectable

Soil salinity levels in groundwater irrigated areas compared with river water irrigated soils.

Preliminary soil salinity data indicates significantly higher EC levels (*p =0.05)* in soils that had consistently received groundwater irrigation vs those which had not (Figure 7-20 Electrical conductivity in 1:5 soil extracts taken from groundwater irrigated sites Bun Phan (BP) and Chhim Son (CS) compared with a wholly surface water irrigated site (KS).). Although the cations were not measured individually and so sodium adsorption ratio is unavailable, even the maximum EC values are < 1 ds/M in 1:5 soil extracts and so are unlikely to present a particular concern for crop growth . None of the groundwater or surface water irrigated soil sampling sites contained EC in 1:5 extracts that may suggest sodic behaviour. However, the Chhim Son (CS) site had significantly higher levels of soil EC than the Bun Phan (BP) site. The CS site was also the site with the higher groundwater EC levels which could suggest that groundwater irrigation maybe causing some soil salt accumulation. Both of these sites which are groundwater irrigation sites have significantly greater EC than the surface water irrigated KS site. All sites have similar soil texture and all have had wet and dry season rice grown over many years. The data suggests that there are elevated soil salinity levels at the groundwater irrigated sites compared to surface water irrigated sites. However, currently the levels are unlikely to be a major driver of yield decline compared with other agronomic factors such as pest and weed control, fertilizer use and land levelling

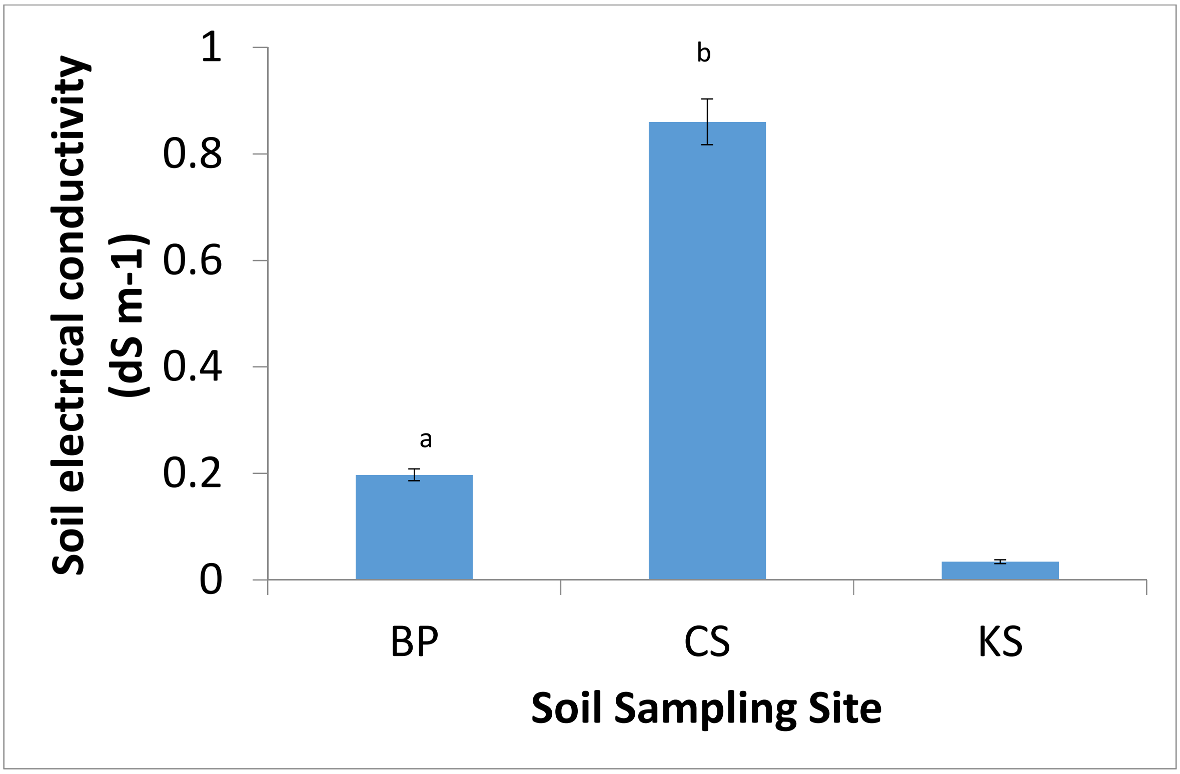


Figure 7-20 Electrical conductivity in 1:5 soil extracts taken from groundwater irrigated sites Bun Phan (BP) and Chhim Son (CS) compared with a wholly surface water irrigated site (KS).

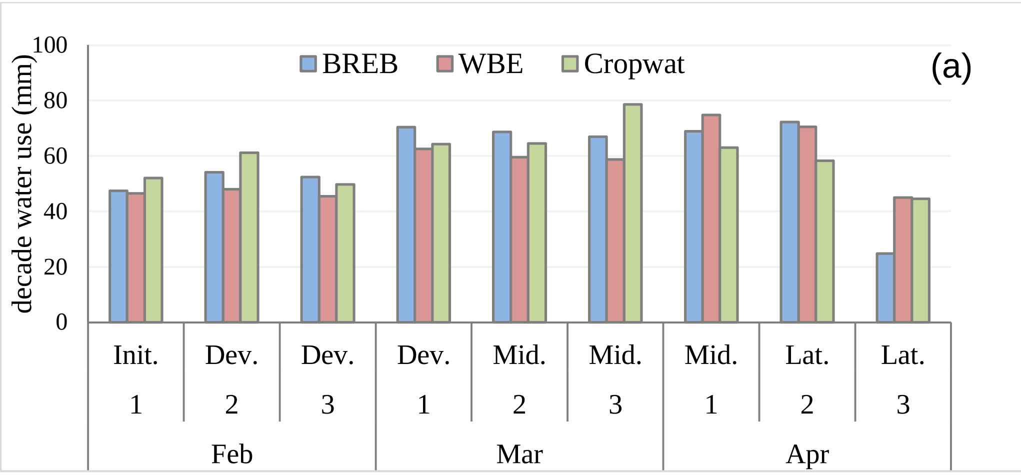
The greatest impact has arisen through the confirmation that groundwater is of suitable quality for supplementary irrigation to alleviate short periods of water stress in the main wet and dry rice production seasons or for high value vegetable crops between rice crops.

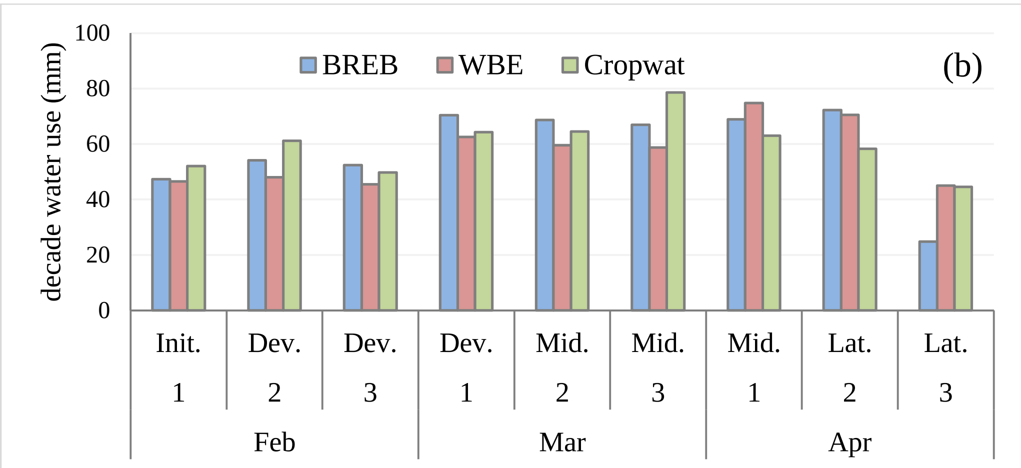
Irrigating with groundwater that is unblended with river water or when there has been no rain dilution has been anecdotally observed to cause rice growth constraints. It was not ascertained what may be causing this effect (salinity was the only element measured that may offer a mild to moderate effect on rice growth at 2 dS/m). However, it suggests that farmers may take a grass roots approach and begin to consider building small storage dams or having areas where they may effectively blend river and groundwater to improve quality, if space is available. In the Angkor Borei area longer term irrigation with groundwater does not apparently pose a salinity threat to soil quality although it is recommended that occasional soil tests are repeated over the longer term.

7.3 Crop water use and nitrogen field studies and modelling

7.3.1 Determination of rice water use from different measurement methodologies

The collected data from the CARDI experimental site enabled us to establish a complete crop evapotranspiration in each decade (10-days) for the entire growing season from rice seed sowing until the end of rice plant harvesting. The ETc of investigated paddy rice is calculated by multiplying 10-days crop coefficients of each growth stage and 10-days ETo values. Figure 7-21 illustrated the results from 3 different approaches computed through the Bowen Energy Balance Method (BREB), Cropwat and Water balance Equipment (WBE) of each 10-days in the study periods. The decade ETc values displayed an increasing trend with the increase in crop growth days, and are influenced by various factors such as temperature, solar radiation, and rainfall from February to April/June. In monitoring periods, trends of water consumption by crop reached the peak (from 60 mm/decade to 80 mm/decade) in the decades of development stage and lowest at the start and end of growth season. This trend showed the importance of cropping pattern for local water management with irrigation planning.





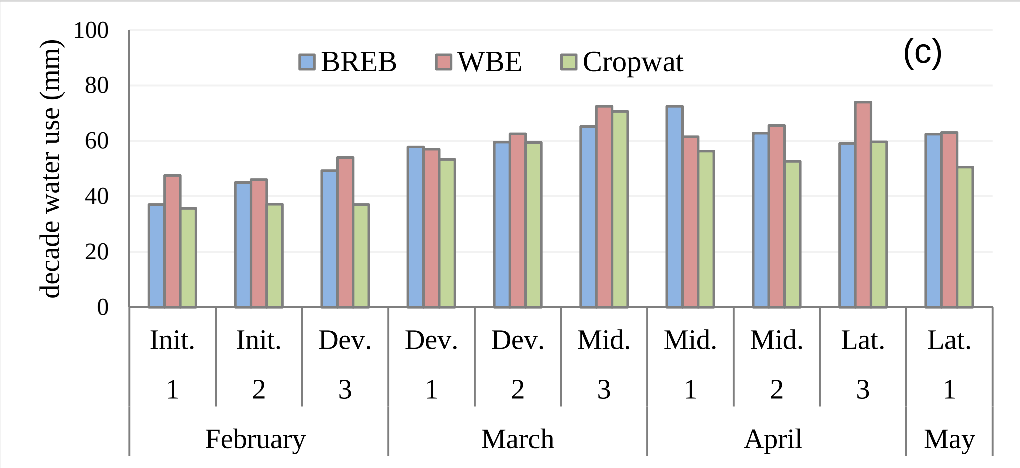


Figure 7-21 ETc Results from 3 different approaches computed through the Bowen Energy Balance method (BREB), Cropwat and water balance equipment (WBE) of each 10-days in 2012 (a), 2013 (b) and 2014 (c)

7.3.2 Cropwat Vs BREB

Cropwat and computation from BREB results concerning comparison of 10-days ETc showed that preliminary results highlighted correlations between the simulated values in each 10-days ETc. Those results derived from the weather data and input data using Cropwat show the difference ranging from -44% to +24% in season of 2012, -25% to 26% in season of 2013 and -8% to 33% in season of 2014. As previously mentioned the required input data of these two approaches varies. BREB instrumentation requires extensive high cost instrumentation, which is often difficult to maintain. Cropwat uses physical soil parameters include: total available water (TAW); maximum infiltration rate; maximum rooting depth; initial soil moisture depletion, which need to be estimated or measured.

7.3.3 Cropwat Vs WBE

Result from WBE were considered as the benchmark result. Results of the model showed preliminary results highlighted correlations between the simulated values in each 10-days ETc. The deviation of each 10-days was in the imitation from -25% to +20% in season of 2012, -29% to 18% in season of 2013 and 3% to 46% in season of 2014. WBE evidently provided lower results in dry season 2012 and 2013 but higher result in dry season 2014.

Figure 7-22 Crop evapotranspiration calculated from 3 different approaches for the period of growth in dry season 2012 (a), 2013 (b) and 2014 (c) at CARDI Experimental Field. Table 7-4 shows accumulation of seasonal rice water requirement resulting from BREB, WBE and Cropwat. Seasonal results from these three approaches indicated that ETc of Chul'sa variety estimated by direct approach (WBE) tended to consume slightly water more than indirect approaches (BREB and Cropwat). But results still emphasized a good correlation between these three approaches. The three approaches determined the seasonal water requirements range from 511 mm to 604 mm or in daily value ranging from 5.1 mm.day-1 to 6.0 mm.day-1 at peak crop growth times (Table 7-4).

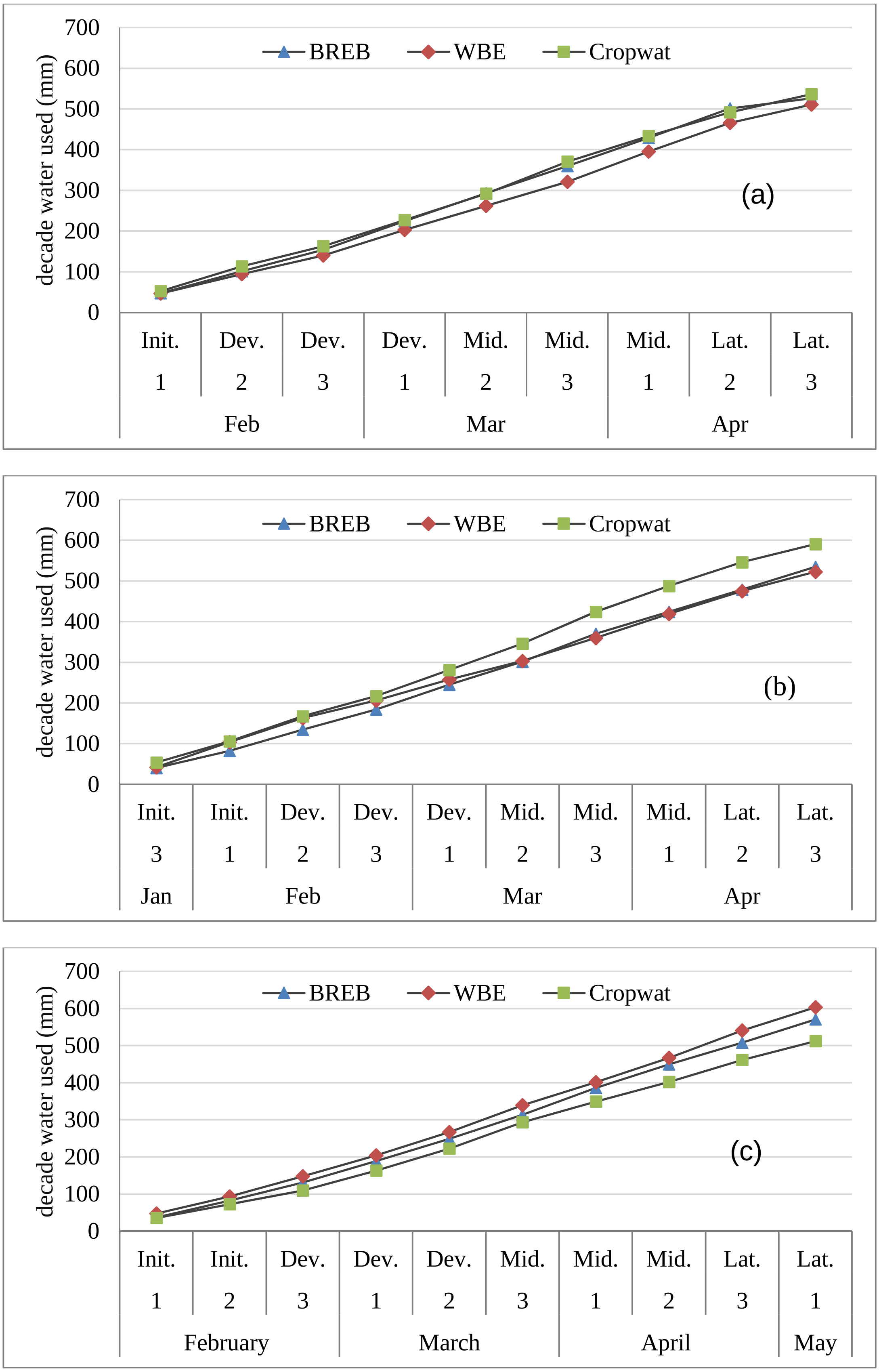


Figure 7-22 Crop evapotranspiration calculated from 3 different approaches for the period of growth in dry season 2012 (a), 2013 (b) and 2014 (c) at CARDI Experimental Field.

Table 7-4 Summary of seasonal crop evapotranspiration calculation from three different measurement approaches

Table 4: Summary of seasonal crop evapotranspiration calculation from 3 different approaches

Dry season 2012			Dry season 2013			Dry season 2014		
BREB	WBE	Cropwat	BREB	WBE	Cropwat	BREB	WBE	Cropwat
526	511	536	535	523	590	571	604	512

unit in mm

Regardless of the land preparation and percolation, the total season water requirement values during the growth seasons of Chul'sa in dry season 2012 from BREB, WBE and Cropwat are 526 mm, 511 mm and 536 mm, respectively. We did notice that the three different approaches produced similarly seasonal outcome with low deviation (from -3% to +2 %). In 2013 they displayed higher deviation but still acceptable from -2% to +10% (BREB=535 mm, WBE=523 mm and Cropwat=590 mm). Not much difference was observed in the 2013 dry season. Dry season studies in 2014 also produced similar results compared to previous seasons of BREB, WBE and Cropwat are 571 mm, 604 mm and 512 mm, respectively with seasonal deviation of -10% to 6%.

The result showed good agreement with previous studies. The seasonal water consumptions from this study were between 5.1 mm. day^{-1} and 6.0 mm.day^{-1}. Similar results between 5.0-7.0 mm.day-1 evapotranspiration have been measured in tropical Asia (Tomar and O'Toole, 1980) and between 4.8 and 5.5 mm in semi-arid region (Hendrickx et al., 1986) and typical ET values of rice in the tropical area is 6–7 mm per day in the dry season was found by Datta (1981).

This study showed that Cropwat model could provide acceptable results compared with BREB and direct measurement method (WBE) with less time and input parameters. Consequently, CROPWAT model could be widely promoted to be adopted as an alternative approach to estimate rice water requirement and also further estimation related to irrigation scheduling programs where meteorological stations are developed or are currently being developed. This trend showed the importance of understanding cropping patterns for local water management and irrigation planning to optimizing water supply.

7.3.4 Irrigation, sowing date and nitrogen management with APSIM-Oryza

Results from the APSIM-Oryza modelling efforts are presented below. The model was calibrated using data collected on the crop water use study at the CARDI field mentioned above.

Effect of irrigation management on yield, irrigation applied, water productivity and evapotranspiration

There is a gradual decline in average rice yields as the irrigation frequency decreased from CF to 2d (4% yield decline) to 4d (8%) and 8d (15%) (Figure 7-23, Table 7-5Table 7-5 Mean grain yield, irrigation, rainfall, evapotranspiration and water productivity of Chul'sa sown on the 20th Jan with 50 kg N ha-1 with varying irrigation management*). The CF treatment has the highest yields due to higher above ground biomass, grain number and panicle numbers in all years. This is a direct result of nitrogen being more limiting in the 2, 4 and 8d irrigation treatments. Nitrogen stresses and losses (from denitrification and volatilisation) in these irrigation treatments ultimately result in reduced nitrogen uptake and hence reduced biomass and yield. The yield response to irrigation frequency is generally consistent with field studies in Punjab, India which demonstrate lower yield when irrigation is scheduled 2d and more after the disappearance of floodwater from the soil surface (Arora et al. 2006, Singh et al. 2009, Sudhir-Yadav et al. 2011). A review by Bouman and Tuong (2001) which concentrated on field water management also concluded that rice performs optimally when grown under CF conditions and that yields decline as the soil dries below saturation.

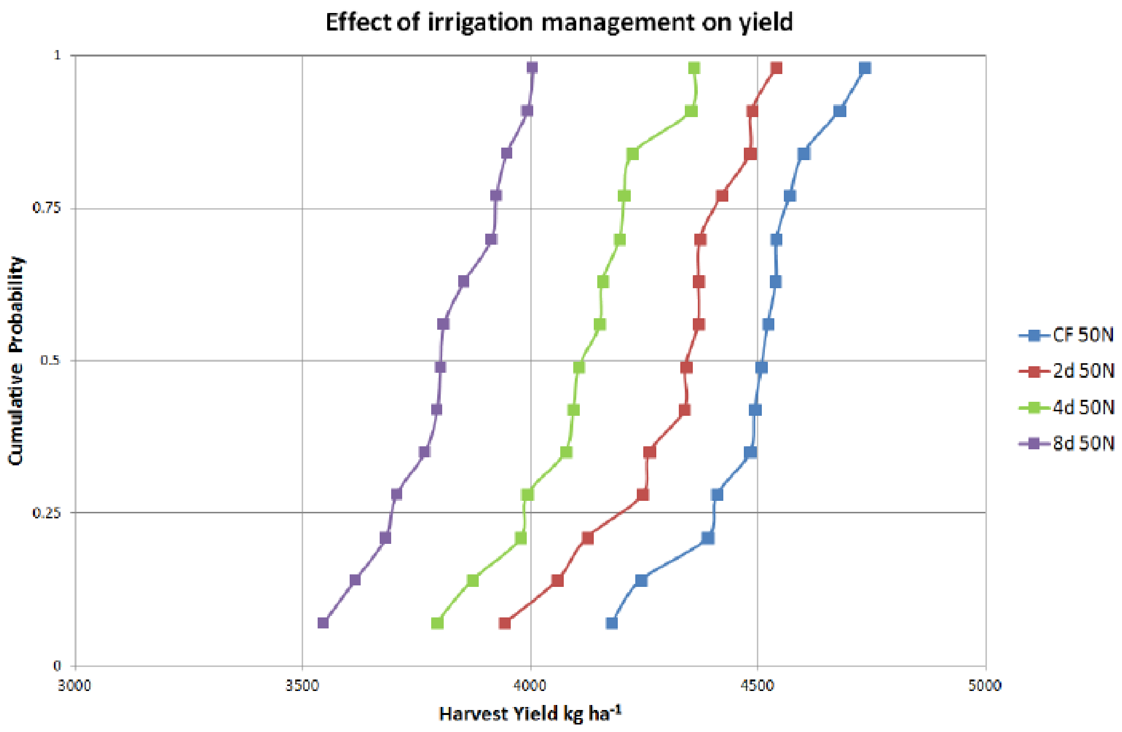


Figure 7-23 Effect of irrigation management on simulated grain yield of Chul'sa sown on the 20th Jan with 50 kg N ha-1

Table 7-5 Mean grain yield, irrigation, rainfall, evapotranspiration and water productivity of Chul'sa sown on the 20th Jan with 50 kg N ha-1 with varying irrigation management*

Irrigation Management	Grain yield (t/ha^{-1})	Irrigation (mm)	Rainfall (mm)	ET (mm)	WP_{I+R} (g grain kg^{-1} irrigation + rain)
CF	4.49 (4.2-4.7)	835 (752-923)	148 (21-329)	705 (603-855)	0.46 (0.39-0.52)
2d	4.31 (3.9-4.5)	756 (625-880)	148 (21-329)	694 (599-834)	0.47 (0.40-0.53)
4d	4.11 (3.8-4.4)	704 (605-795)	148 (21-329)	689 (589-830)	0.48 (0.41-0.56)
8d	3.81 (3.5-4.0)	648 (560-718)	148 (21-329)	678 (571-810)	0.49 (0.42-0.56)

*Values in parentheses give the range

There is an average saving of 79 mm of irrigation applied with 2d irrigation compared to CF, representing a 9% reduction in irrigation applied with minimal impact on yield (< 0.20 t ha-1) (Table 4). A decreasing irrigation frequency from CF to 8d has the potential to save on average 187 mm of irrigation water representing a saving of 22% with some yield penalties (< 0.7 t ha-1). The reduction in irrigation applied is principally due to a substantial decrease in the drainage rate. There are various tradeoffs between yields, irrigation amount applied and water productivity. Whilst maximum simulated yields are achieved under CF conditions, WPI+R are highest (range 0.42 -0.56 g kg-1) at an 8d irrigation interval across all years (Table 4). The simulated evapotranspiration over the seasonal analysis is very similar across all irrigation treatments and only declined slightly from 705 mm under CF to 678 mm at 8d. This is also a reflection of the similar biomass simulated across the irrigation treatments. The key message here is that irrigation scheduling has very little effect on water depletion through evapotranspiration (i.e. it does not save real water). While delaying irrigation will decrease the irrigation amount applied there will be a yield penalty (greater than 0.20 t ha-1) if the delay is greater than 2 days after the disappearance of floodwater.

Effect of sowing date on yield, irrigation applied, water productivity and evapotranspiration

Only sowing dates from the 10th Dec – 30th Jan were considered (Table 7-6, Figure 7-24). These dates allow the timely harvest of the previous wet season crop and preparation for the upcoming dry season crop as well as a timely harvest of the dry season crop and preparation of the next wet season crop.

Table 7-6 Mean grain yield, irrigation, rainfall, evapotranspiration and water productivity of Chul'sa on selected sowing dates (10th Dec – 30th Jan) with 50 kg N ha-1 under CF irrigation management*

Sowing Date	Grain yield (t/ha^{-1})	Irrigation (mm)	Rainfall (mm)	ET (mm)	WP_{I+R} (g grain kg^{-1} irrigation + rain)
10th Dec	4.76 (4.5-5.2)	768 (684-842)	38 (0-196)	638 (550-738)	0.59 (0.47-0.74)
20th Dec	4.79 (4.5-5.2)	776 (668-848)	47 (0-201)	655 (557-756)	0.59 (0.47-0.74)
1st Jan	4.55 (4.3-4.7)	805 (707-880)	87 (5-249)	672 (576-811)	0.51 (0.43-0.57)
10th Jan	4.45 (4.2-4.6)	822 (725-897)	115 (16-258)	689 (593-835)	0.48 (0.41-0.54)
20th Jan	4.49 (4.2-4.7)	835 (752-923)	148 (21-329)	705 (603-855)	0.46 (0.39-0.52)
30th Jan	4.55 (4.2-4.8)	828 (755-936)	177 (68-342)	708 (604-891)	0.46 (0.38-0.52)

*Values in parentheses give the range

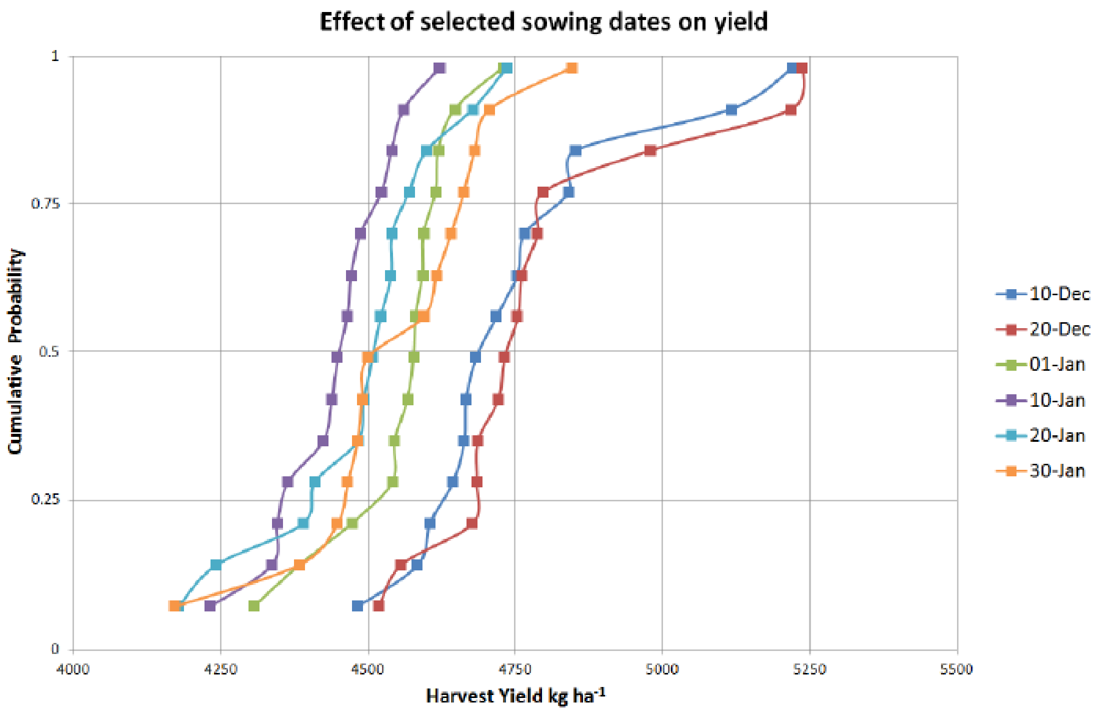


Figure 7-24 Effect of selected sowing dates (10th December – 30th January) on simulated grain yield of Chul'sa with 50 kg N ha-1 under CF irrigation management.

Average rice yields were very similar across the selected sowing dates (4.45 t ha^{-1} – 4.79 t ha^{-1}) indicating that any of the sowing dates is appropriate under the management conditions applied, with a 20th Dec sowing date having the highest yields in 85% of years (Fig. 8) closely followed by a 10th Dec sowing date. Irrigation requirement increased from a 10th Dec sowing date (768 mm) to a 30th Jan sowing date (828 mm) due to an increase in evaporative demand. There is an average saving of 60 mm of irrigation applied with a 10th Dec sowing compared with a 30th Jan sowing (Fig. 9), representing a 7% reduction in irrigation applied with an average yield increase of 0.21 t ha^{-1} (Table 7-6, Figure 7-24). The earlier sowing dates require less irrigation and sowing dates of either the 10th Dec or 20th Dec will achieve the most irrigation water savings and the highest yields. The effect of sowing date has various tradeoffs between yields, irrigation and water productivity. Maximum simulated yields are achieved with a 20 Dec sowing date in 85% of years, whilst WP_{I+R} are highest (range 0.59-0.74 g kg^{-1}) with a either a 10th of 20th Dec sowing date (Fig. 10, Table 5). The average simulated evapotranspiration over the seasonal analysis increased (range 638 – 738 mm) as the sowing date was delayed past the 10th Dec (Table 7-6, Figure 7-24). Overall, the earlier sowing dates required less irrigation and a lower ET requirement (up to 10%) primarily due to lower evaporation from the floodwater. The key message here is that the sowing date has an effect on water depletion (i.e. the earlier the sowing date is, the more potential there is to save real water, up to 150 mm in one year, average saving is 64 mm) whilst maintaining yield (Fig. 11). Taking into account water productivities, water use, yield and the vacation of the field for timely sowing of the next rice crop, a sowing date around the 10-20th Dec ranks very highly.

Effect of nitrogen management on yield, irrigation applied, water productivity and evapotranspiration

There is a substantial increase in average rice yields with a 20th Jan sowing date under CF conditions as the nitrogen amount applied increases from the CARDI recommended base rate of 50 kg N ha-1 to 100 kg N ha-1 (39% yield increase) to 150 kg N ha-1 (68% yield increase from base rate) to 200 kg N ha- 1 (92% increase from base rate) (Figure 7-25, Table 7-7). However, nitrogen use efficiency (NUE) declined as the nitrogen amount applied increased (Table 6). NUE is simply defined as the ratio of grain yield to supplied N which includes the soil mineral N (nitrate-N and ammonium-N) and fertilizer applied.

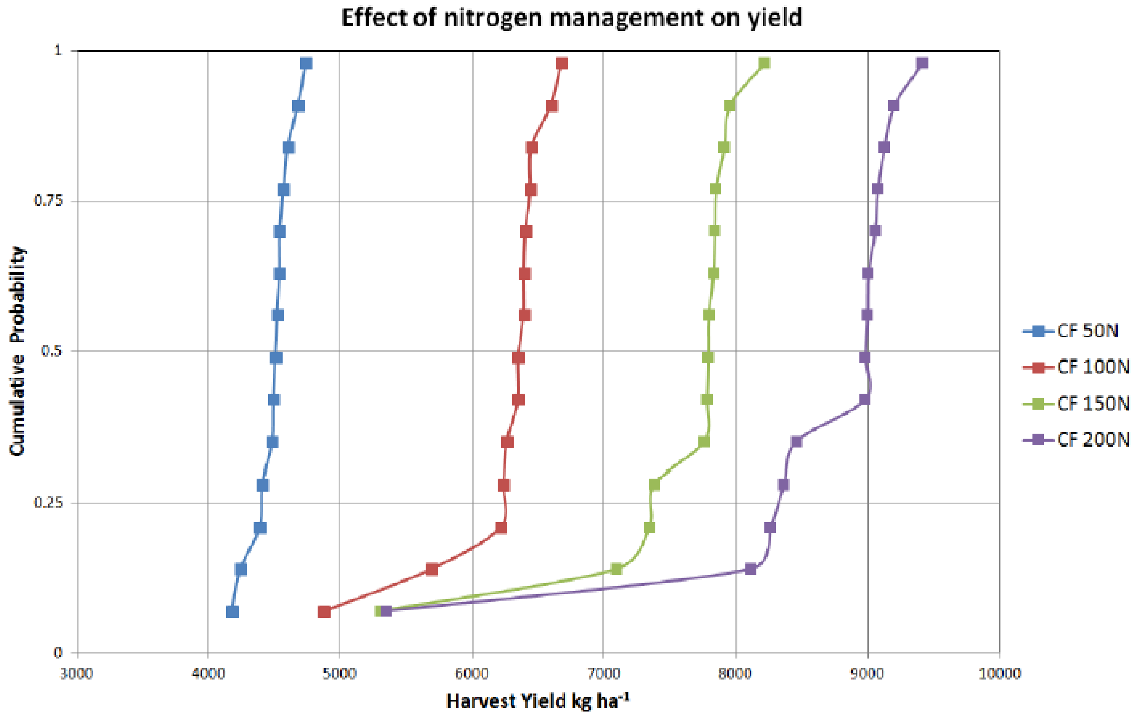


Figure 7-25 Effect of nitrogen management on simulated grain yield of Chul'sa sown on the 20th Jan with varying nitrogen rates applied.

It is interesting to note from Figure 7-25, that there is one particular year in the seasonal run where yields across the higher nitrogen treatments were much lower than the other years. This year was 2010 and the dominant factor was that during the microspore and flowering periods the plants suffered from higher than normal maximum temperatures (up to 3 deg oC higher than normal) which led to a much higher sterility factor, resulting in a reduction in yield. It is more evident in the higher nitrogen treatments than the 50 kg N ha-1 treatment as there were far higher spikelet numbers that were affected.

Table 7-7 Mean grain yield, water productivity and nitrogen use efficiency of Chul'sa sown on the 20th Jan with varying nitrogen management and CF irrigation management

Nitrogen Management (kg N ha^{-1})	Grain yield (t/ha^{-1})	WP_{I+R} (g grain kg^{-1} irrigation + rain)	NUE (g grain kg^{1} nitrogen supplied)
50	4.49 (4.2-4.7)	0.46 (0.39-0.52)	49.9 (46.4-52.6)
100	6.24 (4.9-6.7)	0.69 (0.50-0.80)	44.6 (34.8-47.7)
150	7.56 (5.3-8.2)	0.89 (0.58-0.97)	39.8 (27.9-43.3)
200	8.60 (5.3-9.4)	1.09 (0.64-1.21)	35.8 (22.3-39.2)

To further examine the effects of nitrogen management, five split nitrogen fertilizations were also evaluated at the 100 kg N ha-1 rate where the nitrogen rate was applied in different development stages, such as sowing, tillering and panicle initiation with two sowing dates, the 20th Dec (chosen from the above modelling work) and the 20th Jan (CARDI recommended sowing date) (Table 7-8). Average yields are again higher across all split strategies with a 20th Dec sowing date when compared to a 20th Jan sowing date (up to 0.5 t ha-1) however, there appears to be minimal yield differences between the various split applications, whatever the sowing date is. It is also evident that the range of yields is also higher with a 20th Dec sowing date. This is again due to the climatic conditions experienced in 2010 where a 20th Jan sowing date experienced a much lower yield compared to the other years in the analysis.

Table 7-8 Mean grain yield of Chul'sa sown on the 20th Dec and 20th Jan with varying nitrogen management and CF irrigation management

Sowing Date	Nitrogen Management (kg N ha^{-1})	Nitrogen Management Split	Grain yield (t/ha^{-1})
20-Dec	100	50:25:25*	6.61 (6.3-7.1)
	100	25:25:50	6.76 (6.4-7.3)
	100	25:50:25	6.72 (6.3-7.2)
	100	50:00:50	6.65 (6.3-7.2)
	100	33:33:34	6.70 (6.3-7.2)
20-Jan	100	50:25:25	6.24 (4.9-6.7)
	100	25:25:50	6.28 (4.9-6.8)
	100	25:50:25	6.24 (4.9-6.8)
	100	50:00:50	6.18 (4.9-6.7)
	100	33:33:34	6.20 (4.9-6.7)

* The first application is at sowing, the second application is at early tillering (20-25 DAS) and the third application is around panicle initiation (40-45 DAS). The nitrogen application assumes the first placement is pre-plant incorporated at a depth of 10 cm. Other nitrogen applications are into ponded water.

Recommendations for best management practices of nitrogen fertiliser to achieve target yields

Nitrogen management is critical in irrigated rice. Nitrogen is the nutrient required in the largest quantities while urea is the principal nitrogenous fertilizer for rice production. However, nitrogen from urea is subject to considerable losses to the atmosphere and runoff water in the rice ecosystem, especially where urea is broadcast on standing water. It is important that only ammonium or ammonium-forming fertilizers (urea) be used rather than fertilisers that contain nitrate N, which is quickly lost via denitrification once floodwater is established. Optimum nitrogen rates will vary according to the variety of rice grown, a soil's ability to supply nitrogen over the growing season and environmental conditions (Witt et al. 2002). These factors can cause large differences among sites and seasons in determining an optimal nitrogen application rate. Current fertiliser recommendations typically consist of blanket recommendations with fixed rates and timings for rice growing areas.

Applications of fertilizer N as urea in CF rice systems should ideally be pre-plant incorporated to a depth of 10 cm. Incorporating urea at a depth of 10 cm minimises N losses by preventing N from being dissolved in floodwater or oxidized in soil near the surface. This practice is environmentally friendly and enables higher yields with less fertilizer N (Bouman and Tuong, 2001). In Asian rice growing systems a further application is usually applied at mid tillering and a final application at or around panicle initiation. The efficiency of N fertiliser with the 2nd and 3rd topdressing application can be further improved by simply monitoring the leaf colour at 7-10 day intervals using a leaf colour chart to adjust individual topdressings at critical growth stages to adjust predetermined N rates (IRRI, 2014). By adopting these best management practices for N fertilizer, the highest fertilizer use efficiency possible in the Cambodian rice production system can be obtained whilst promoting sustainable agricultural practices.

Average Cambodian rice yield in 2010 was 4.2 t ha-1 (MAFF, 2011), increasing to 4.35 t ha-1 in 2013 (MAFF, 2013) for dry season rice. Depending on soil classification, recommended nitrogen use can range from 45 kg N ha-1 (Prey Khmer soil group) to 200 kg N ha-1 (Krakor soil group) (Pech, 2013). Average recommended nitrogen use is 125 kg N ha-1 across all the soil groups (Pech, 2013). However, there is a difference between what is recommended and what is actually applied at the farm level (Pech, 2013). Based on the recommended nitrogen use, yields greater than 6 t ha-1 should be achievable.

Modelling efforts suggest that to obtain yields on the Prateah Lang soil group greater than 4 t ha-1, a nitrogen management strategy of at least 50 kg N ha-1 needs to be applied. To target 6 t ha-1, a nitrogen management strategy of 100 kg N ha-1 is required and a target yield approaching 8 t ha-1, would require a nitrogen management strategy of at least 150 kg N ha-1. These target yields are highly dependent on adequate water being available, good nitrogen management and that the paddy fields are weed, pest and disease free.

7.3.5 Field study on the effect of water irrigation regimes and nitrogen rates on rice growth and yield on Prateah Lang soil

Results of the field base experiment at CARDI for one season indicated that applying N 150% of recommended rate (150 kg/ha) did not increase grain yield. However, the irrigation water regimes had a strongly effect on the rice growth and yield (Figure 7-26). Continuous flooding, which required 6760 m^3/ha of irrigated water, produced the highest grain yield with average yield of 3.58 t/ha, followed by flooding and non-flooding condition (15 days flooding and 15 days non-flooding, which required 3970 m^3/ha of irrigated water and non-flooding, required 2740 m3/ha of irrigated water, with average yields 2.9 t/ha and 2 t/ha, respectively. The continuous flooding has low water use efficiency (WUE), which produced only 0.53 kg of rice grain/m^3 of water, where alternative flooding and non-flooding, and non-flooding (wet soil) produced 0.73 and 0.76 kg of rice grain/m^3 of water, respectively.

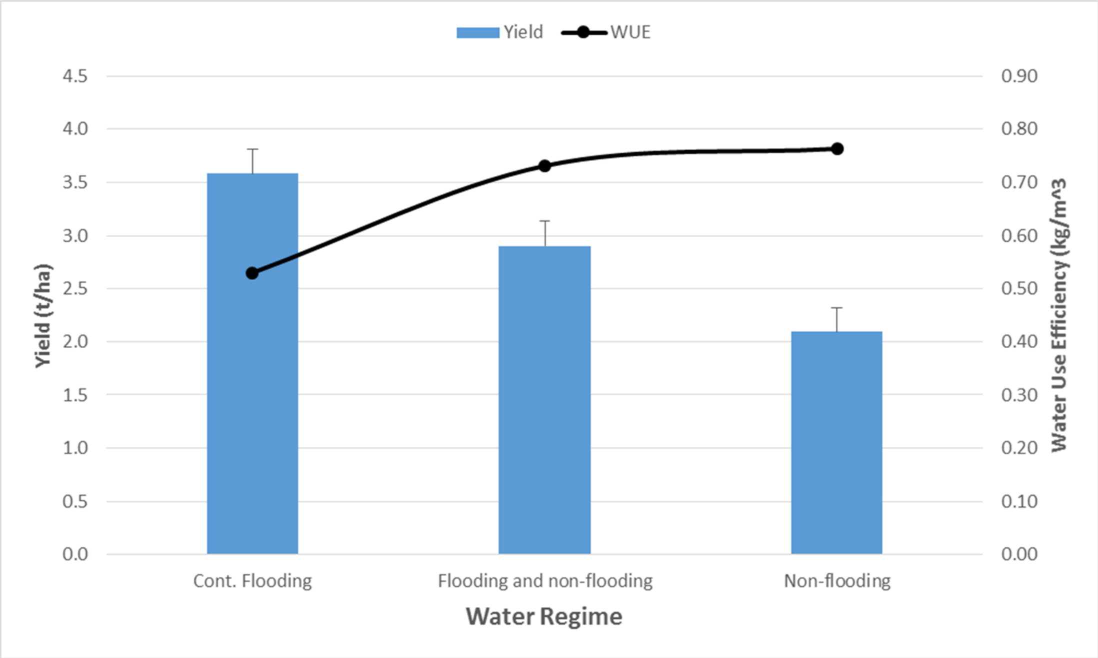


Figure 7-26 Average grain yield and water use efficiency of different water irrigation regimes

There are some factors such as variety, weed, insect, and environment that limited rice growth and yield, but fertilizer and irrigation water are major factors determining rice growth and yield, and to increase rice productivity.

The majority of rainfed lowland and irrigated rice soils (Prateah Lang and Prey Khmer soil groups) are low in essential plant nutrients (NPK), low in organic matter content, and low in CEC (Seng et al., 2001). Poor soil fertility together with fluctuations in soil-water availability strongly influence the effectiveness of applied fertilizers and the availability of plant nutrients resulting in decreased plant growth and yields (Seng et al., 2004).

This initial basic study has highlighted the future role of alternative rice irrigation water strategies that could be investigated in more detail in future. This initial 1 season trial on alternative wetting and drying has been limited but shows potential to further increase WUE once irrigation and nitrogen agronomy is mastered by farmers.

7.4 Establishment of Laser land levelling

Levelling of farmland using a laser based system has been demonstrated in trials in Kandal, Takeo, Pursat, and Kampong Thom provinces. These demonstrations have led to 42 ha of land being laser levelled based on the successful demonstration activities and willingness of early adoption farmers to trial the technology. These sites were used to undertake research into the effect of cutting away topsoil on crop growth and yield performance over the coming dry season rice crops to provide insights into what depth of soil cut is safe and what remediation of negative effects are the most cost effective.

These demonstration sites have been used to compare laser-levelled fields with non-levelled fields and investigate impacts on yield, water use and weed growth. The treatments included both a laser-levelled field and a non-levelled field under the same management at each site and a neighbouring field. Water use was monitored by measuring water applied with a pump of 5.5 horsepower (hp) (20 m3/hour) capacity. All water applied for irrigation, yields and weed biomass were monitored. Pre-levelled field topographies indicated that fields ranged from 10 cm to 30 cm variation in surface elevation. After fields were laser levelled, there was a 1–3 cm variation in surface elevation.

The field trial results indicated that weed biomass was approximately 50% lower (Figure 7-27), pumping-water requirements were lower and there was a 13% higher yield (Figure 7-28) in laser-levelled fields compared with non-levelled fields under the same management. The benefits of levelled fields on water use productivity are quite evident (Figure 7-28). Irrigation water applied to rice grown in laser-levelled fields was approximately 7,000 m3/ha, about 1,300 m3/ha less than non-levelled field (Figure 7-28). The field experiments show that there are significant benefits to water use productivity from the use of laser levelling to improve water management that, in turn, lead to improved water productivity. As increases in farm labour costs occur and farmers move to increase mechanisation, the benefits of laser-levelling technology will further increase, particularly in relation to direct sowing

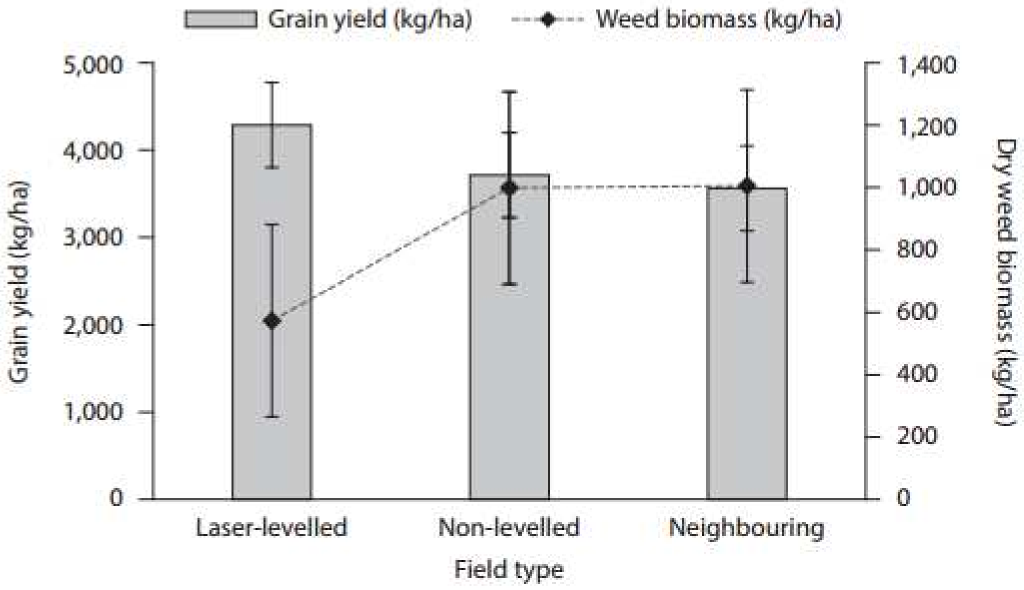


Figure 7-27 Grain yield and weed biomass across fields

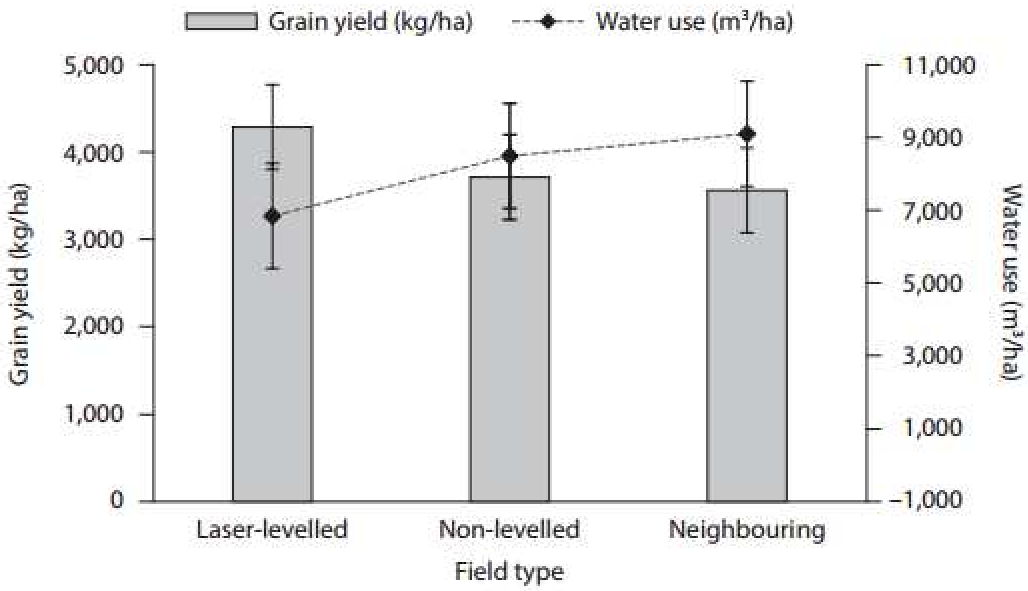


Figure 7-28 Grain yield and water use across fields

Results from the trial at Bati investigating the effects on yields and weed biomass are shown in Figure 7-29 and Figure 7-30. Results of the soil tests from the cut, fill and original soil areas are given in Table 7-9.

Four rice crops were used to identify the effect of cutting of the soil surface due to laser levelling.

The result showed the laser levelled plot decreased weed biomass from crop one to crop four, grain yield increased in all areas (cut, fill and original) from second to fourth rice crop grown in Bati. This indicates laser levelling (cut and fill) didn’t have major effects on rice yields in cut or filled areas provided CARDI fertilizer recommendations were followed.

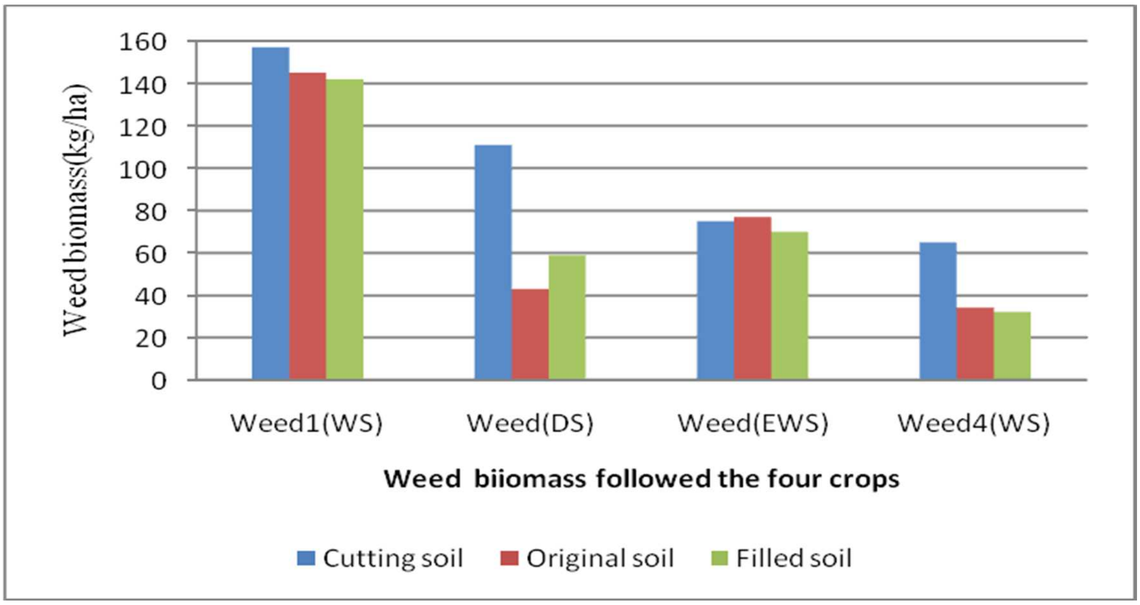


Figure 7-29 Weed biomass across rice cropping seasons

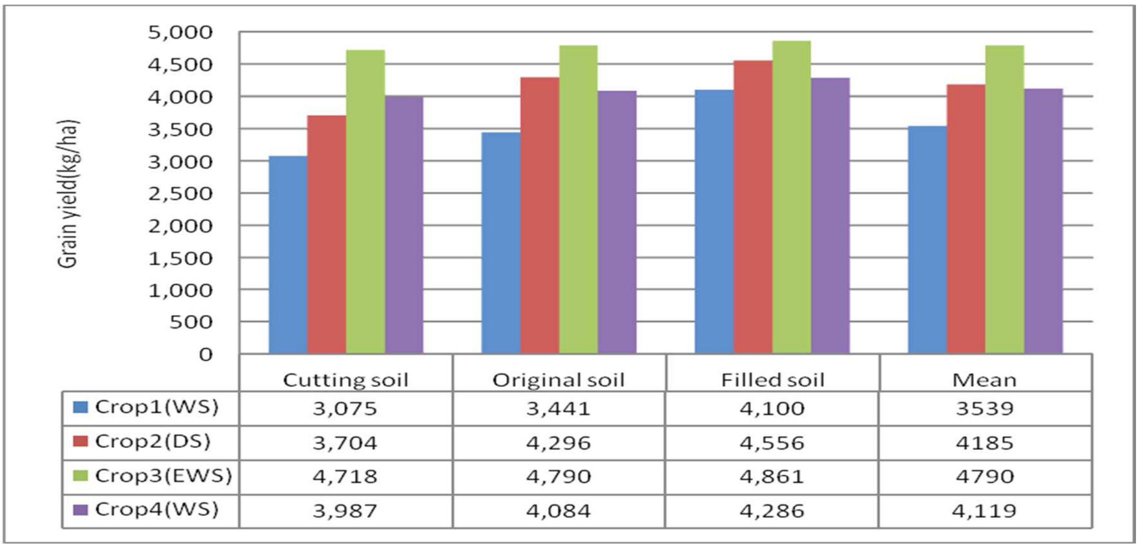


Figure 7-30 Grain yield across growing seasons

Table 7-9 Soil analysis pre and post laser land levelling soil property in Bati/ Takeo

Note : O- Original soil, C- Cutting soil surface high part and F- Filled soil low part

No	Year	SAMPLE DESCRIPTION	SOIL DEPTH (cm)	PROVINCE	pH/H_2O (1:5)		Org.C (%)		Org.M (%)	
					Value	Interpretation	Value	Interpretation	Value	Interpretation
1	2013	O1	0 - 08	Takeo	6.62	Neutral	0.62	Low	1.07	Low
2	2013	O1	08--15	Takeo	6.52	Slightly Acid	0.55	Very low	0.94	Very low
3	2013	O2	0-08	Takeo	6.55	Slightly Acid	0.63	Low	1.09	Low
4	2013	O2	08--15	Takeo	6.4	Slightly Acid	0.63	Low	1.09	Low

5	2013	C1	0-08	Takeo	6.46	Slightly Acid	0.4	Very low	0.69	Very low
6	2013	C1	08--15	Takeo	6.51	Slightly Acid	0.16	Extremely low	0.28	Extremely low
7	2013	C2	0-08	Takeo	6.35	Slightly Acid	0.48	Very low	0.83	Very low
8	2013	C2	08--15	Takeo	6.36	Slightly Acid	0.19	Extremely low	0.33	Extremely low
9	2013	F1	0-08	Takeo	6.17	Slightly Acid	0.62	Low	1.07	Low
10	2013	F1	08--15	Takeo	6.01	Moderately Acid	0.59	Very low	1.02	Very low
11	2013	F2	0-08	Takeo	6	Moderately Acid	0.65	Low	1.12	Low
12	2013	F2	08--15	Takeo	6.24	Slightly Acid	0.78	Low	1.35	Low

The average unevenness (i.e. the difference in height between the highest and lowest portions of the field) in Cambodian rice fields is 160mm with the range from 70-330mm. This means that an extra 80-100mm of water, or nearly 10% of the total water requirement to grow the crop, must be stored in the field to attain complete water coverage.

While the comparative studies have shown that land levelling and appropriate fertilizer usage has increased yields by more than 30%, other benefits have also occurred. Good land preparation and water management has reduced in-crop-weeding time from 21 to 5 labour-days/ha and reduced weed biomass by up to 40%. Levelling has allowed larger fields to be used and this has increased the farming area by 5-7%. Levelling has also increased the opportunity for direct seeding, which has reduced the labour requirement for crop establishment from 30 to 1 labour-days/ha. Water use efficiency has also been improved by using water from higher fields to wet up, to establish, and secure crops, in lower fields.

Improved water management is a key factor in increasing rice production in the Cambodia. Variability in the level of land within a field will have a major effect on crop management and crop yields. Uneven fields require more water to wet up the soil and land preparation and plant establishment is more difficult. Uneven water coverage often result in uneven crop stands, weed problems, uneven rice grain ripening, uneven rice grain yield and most of rice production in Cambodia (approximately 80%) is now harvested by Combine harvester. Land levelling, therefore, remains the technique that offers potential for significance impact on increase water use efficiency, both directly and through the opportunities it provides for improved crop management.

7.4.1 Yield responses to laser levelling at the district level

Yield responses to laser levelling where collected from three provinces in which laser levelling was undertaken in the project. These farmer fields had their fields laser levelled as part of the project and in subsequent years surveys on yield were collected. All farmers after laser levelling of the fields changed their management practice to direct seeding from transplanting, based on information provided to them at the demonstration and training days by the project. It can be seen from Figure 7-31 that in the Takeo Province there was on average a 16% increase in yield in the 1st dry season rice crop after laser levelling. This then increased to 21% in the second year after laser levelling.

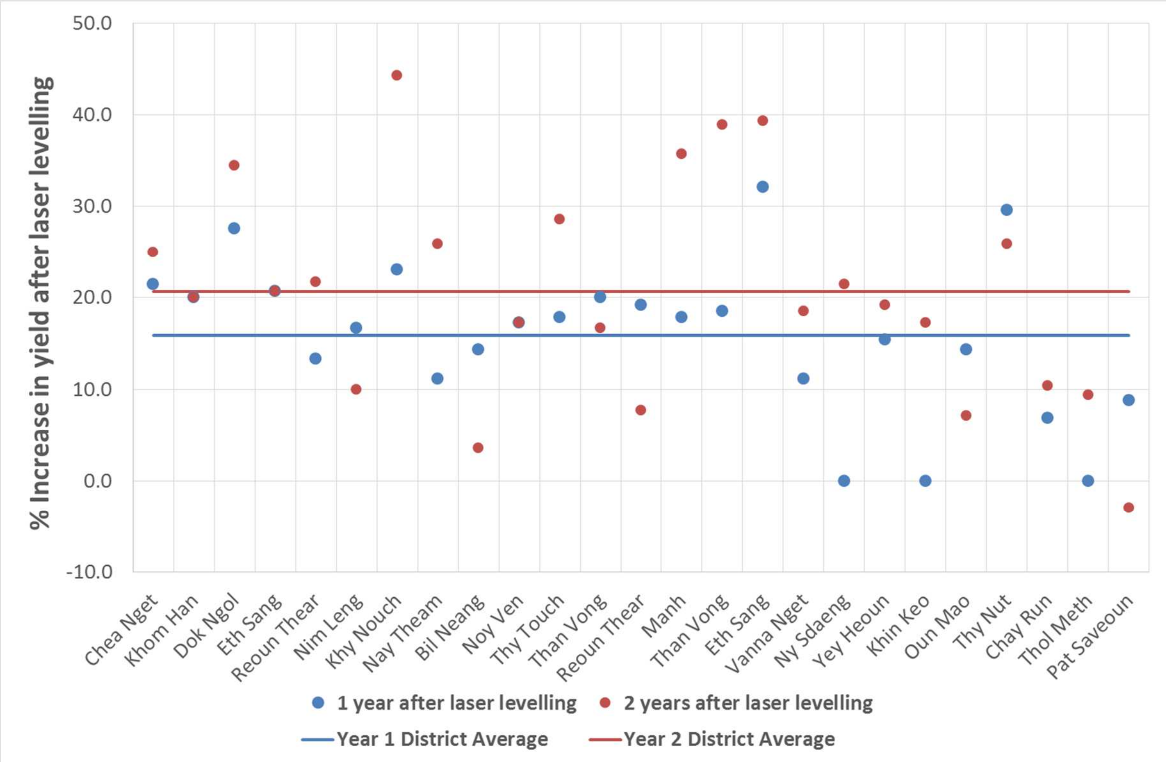


Figure 7-31 Change in yields following laser levelling across famers in the Tram Kok District, Takeo Province. Average yield increase was 16% one year after laser levelling and 21% 2 years after laser levelling

A very similar result was found in the farmers from the Kampong Thom Province with an average yield increase of 15% after the 1st season, increasing to 20% in the second season after laser levelling.

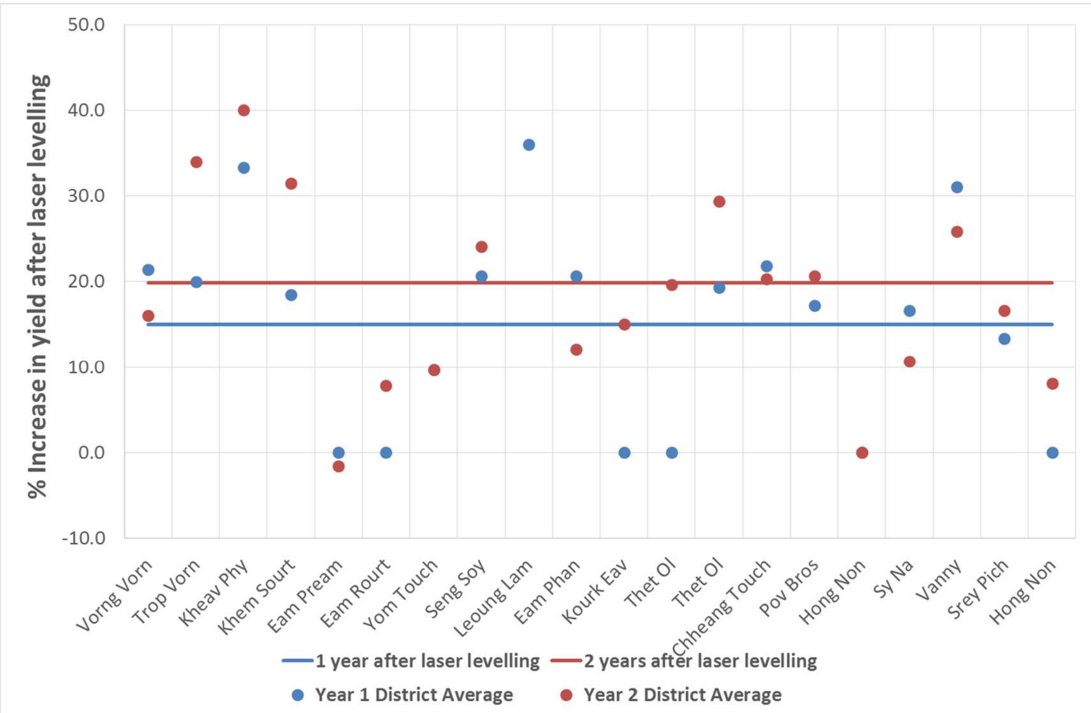


Figure 7-32 Change in yields following laser levelling across famers in the Kampong Svay District, Kampong Thom Province. Average yield increase was 15% one year after laser levelling and 20% 2 years after laser levelling

In both Provinces there were few farmers who had little increase in yield, particularly in the 1st year which may have been due to a significant change in the management practices and time need to be able to adjust to these – i.e. moving from transplanting to direct seeding.

In the Pursat Province there was a much wider variation of yield responses to laser levelling. Only one year of data was collected in the project but it can be seen that yield responses varied from -50% to + 70% for the 1st dry season crop after levelling. However, many of the reduced yields were the effect of water shortages during the season with farmers unable to source enough irrigation water. When these farmers are removed then the average increase in rice yield across laser levelled areas is 31 %.

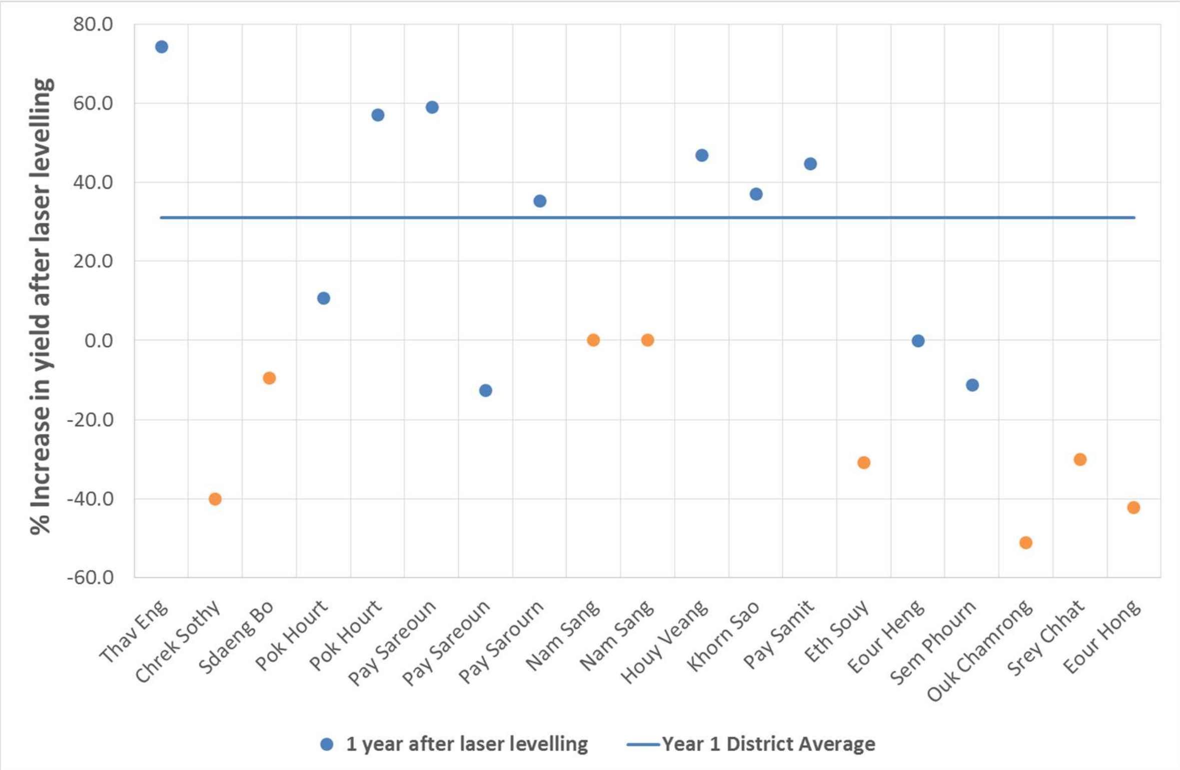


Figure 7-33 Change in yields following laser levelling across farmers field in the Bakan District, Pursat Province. Orange dots includes field which experiences water shortage and could not be completely irrigated. Average yield increase was 31% one year after laser levelling on fields which received full irrigation.

From these follow up surveys, farmers indicated that they saw four main benefits from laser levelling. These were:

- Ease of water management
- Reduced labour by changing from transplanting to direct seeding
- Increased yields
- More effectiveness of applied fertilisers

7.4.2 Simple economics of land levelling

In order to develop some understanding of the economics of laser land levelling a simple analysis was undertaken using the concept of a “Payback” period based on results collected on the farmer demonstration and experimental sites and the larger district yield surveys undertaken by TSC above. Both small scale experiments and larger district scale surveys of laser levelling indicate a likely increase in rice yields after laser levelling in the order of 15 to 20%. Paddy price was assumed to vary between $200US and 350US per tonne.

Figure 7-34 and Figure 7-35 show payback periods for an initial 3 and 4 t/ha crop respectively before laser levelling assuming a 15% increase in yield after laser levelling. It can be seen that at these low yields and paddy price at $200/t, with initial land levelling costs at $400/ha payback periods are between 3-4.5 years. As paddy rice price increases than pay back periods are shortened considerably. At $350/t and an initial laser land levelling cost of $400/ha then payback periods are under 2.5 years in both 15% scenario yield increases.

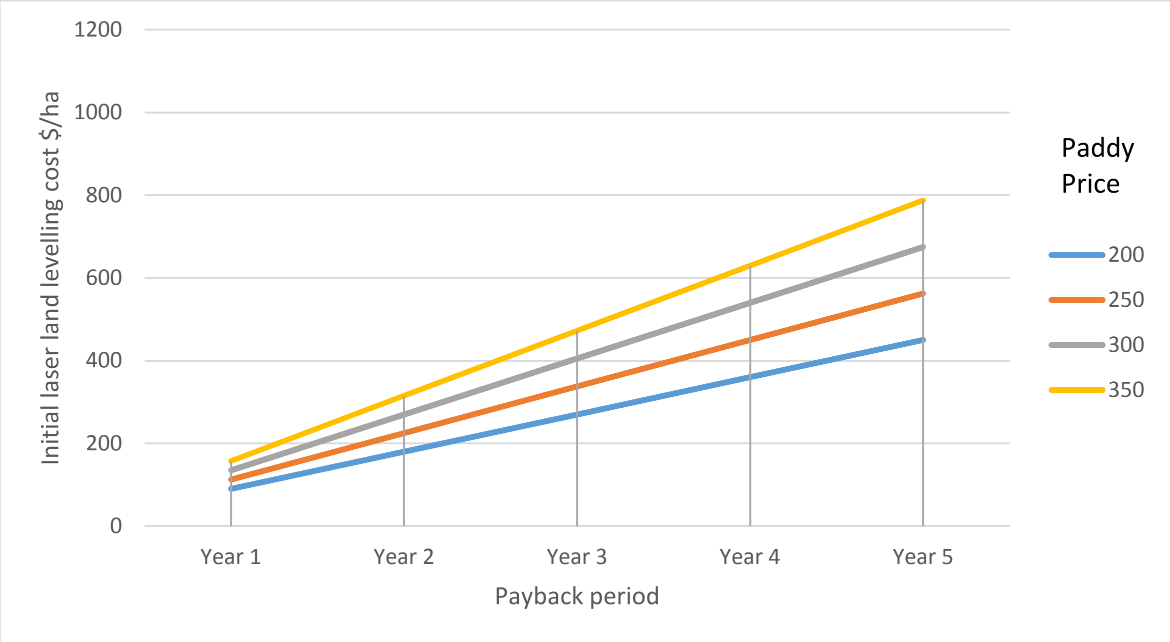


Figure 7-34 Payback period with initial starting yield of 3 t/ha and 15% increase in yield from laser levelling

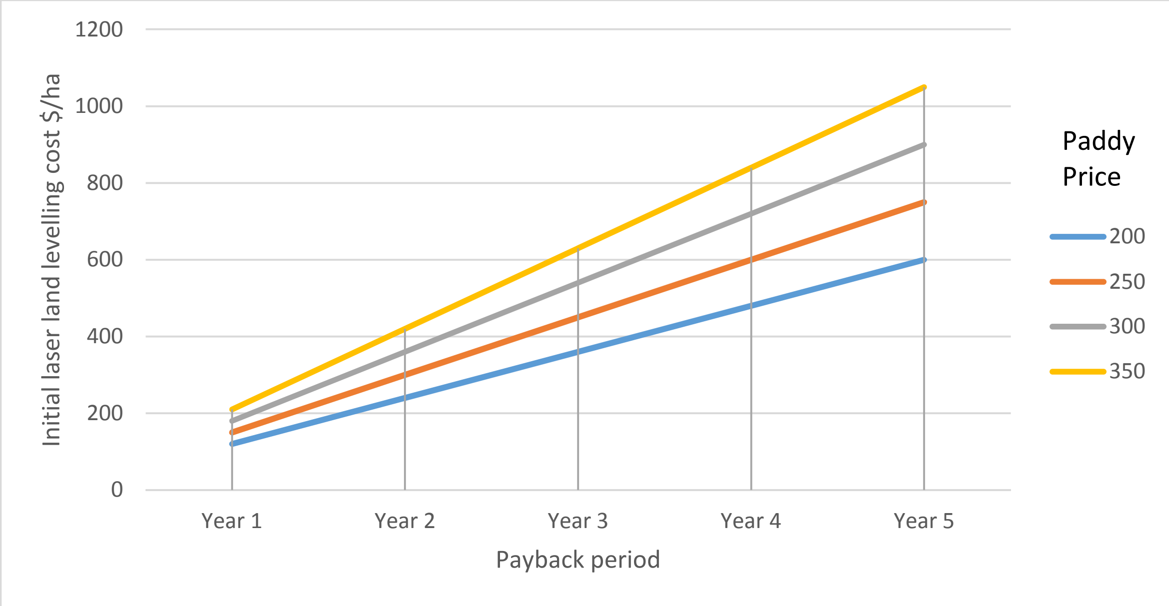


Figure 7-35 Payback period with initial starting yield of 4 t/ha and 15% increase in yield from laser levelling

With a 20% increase in yield on both 3 and 4 t/ha pre laser levelled fields the payback periods are further shortened as expected (Figure 7-36 and Figure 7-37). In both scenarios payback period is under 3.5 years even with a low $200/t paddy price.

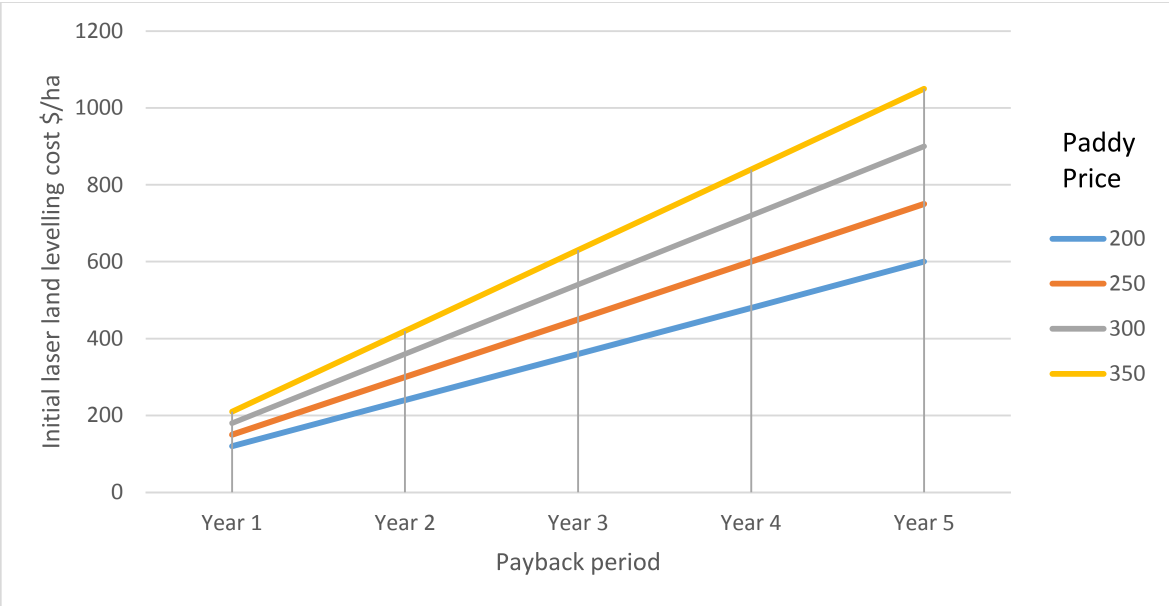


Figure 7-36 Payback period with initial starting yield of 3 t/ha and 20% increase in yield from laser levelling

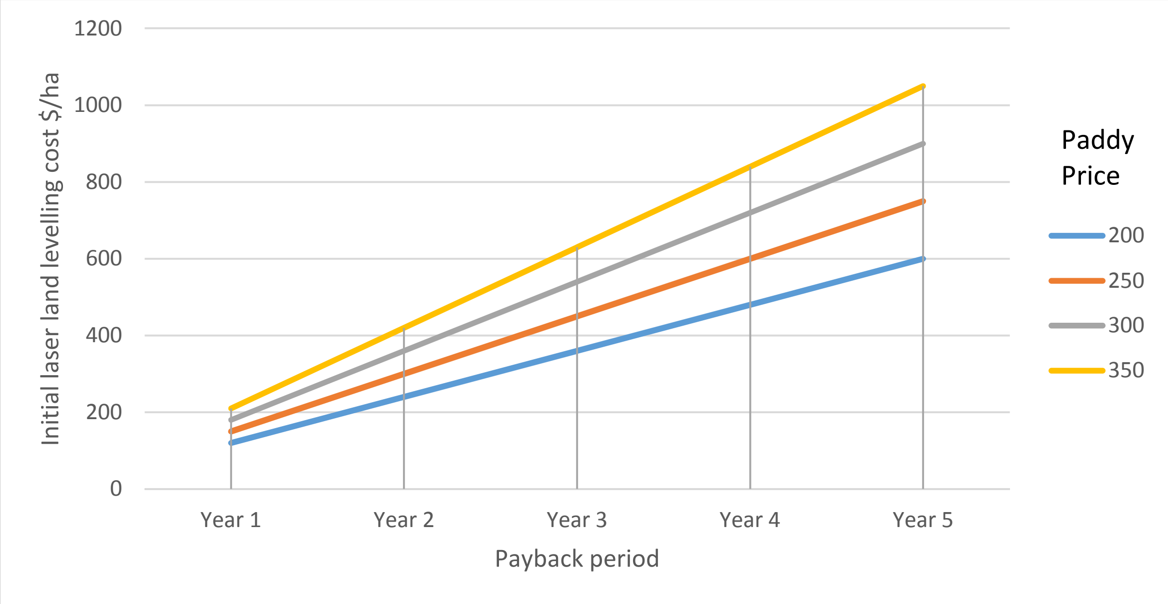


Figure 7-37 Payback period with initial starting yield of 4 t/ha and 20% increase in yield from laser levelling

7.4.3 Establishment of Private Sector laser land levelling service providers

The project undertook a development workshop in Phnom Penh in 2013 with the aim of developing a mechanism to support the establishment of private sector laser levelling service providers. The workshop developed a model with CARDI, TSC and MAFF Department of Agricultural Engineering to support private sector industry partners that are interested in industry developing laser levelling services for farmers. The model focuses on developing training and support to private industry by CARDI, TSC and MAFF DAE partners to train industry staff on operation of laser levelling equipment and help with initial setup of small demonstration areas. So far three private sector partnerships have been developed in Battambang, kampong Thom and Takeo Provinces. Once demonstrations have been undertaken then support is provided as incentives to laser level further areas of land through a subsidy on the area of land levelled for the 1st 20 ha.

Mr Reach Sorin (Battambang)

In the late dry season of 2015 6.5 ha of paddy fields have been laser levelled ny Mr reach in the Battambang Province as field demonstrations. Mr Reach currently operates a contract harvesting and ploughing business and has now purchased a laser bucket to continue to offer a laser levelling service with his current 95 hp tractor. Mr Reach see a logical fit to his current business.

Mr Ou Bossphoan (Kampong Thom)

As of 2015 6 paddy fields have been laser levelled with a total of 4.5 ha. Training has been provided on the use of laser levelling equipment and further laser levelling services will be offered next season with a rental agreement to use the MOWRAM TSC laser levelling equipment behind Mr Ou current front blade tractor.

Mr Phong Sowathana (Takeo)

In Takeo 2.5 ha has been laser levelled using Mr Pongs 95 HP tractor and CARDI laser levelling system. Mr Phong business EMP Ag Pty Ltd are currently looking at purchasing a laser levelling bucket for their seed multiplication business and also currently offer rice transplanting equipment. They see a fit for laser levelling within their business model and have undertaken training by CARDI on how to operate laser levelling equipment and field trouble shoot issues and problems.

Additionally, at a much larger commercial scale the project has assisted Mr Sok Vong from Eng Dypo Aphivath Co Ltd in providing information and advice on laser land levelling in relation to bucket construction and operation and the benefits of laser land levelling. This has seen Eng Dypo Aphivath purchase their own laser levelling equipment. Currently the business offers a fully integrated rice production system with their own rice driers and packaging systems on farm. Currently on their 2000 ha farm in Kandal Province they have laser levelled 80 ha and are looking to level a further 800 ha on this farm before moving to a 20 000 ha farm in Kampong Thom. Their current laser bucket is 3.2m wide and is operated with a 140 HP New Holland tractor. They are currently investigating options for increasing size of the laser levelling equipment. At this stage there is not an option for offering laser levelling services outside company owned farms, however this is something Mr Sok may think about once current land holdings by the company are fully levelled.

Figure 7-38 Contractor operating in Battambang Province with levelling equipment and 95 HP Kubota

Figure 7-39 Contractor working in Kampong Thom Province with Kubota M9000

Figure 7-40 Field based training on laser levelling for private industry contractors

In summary the project has been able to demonstrate the benefits of laser land levelling using both farm scale and district scale approaches. These have indicated a likely average increase in yield of approximately 20% on dry season rice yields. Additionally, weed control is dramatically increased and water management becomes more precise. However, broad-scale adoption is not wide spread yet as initial capital costs are high (approximately US$500/ha) and there is no established laser-levelling industry in Cambodia, which together constitute a major barrier to broad-scale adoption. In order to overcome this hurdle, policies that allow this technology to be implemented, such as farmer subsidies for laser levelling, would assist in kick-starting the industry. Increased yields are not the only benefits anticipated. Water savings arising from less water applied to laser-levelled fields have the potential to be redirected into more irrigated rice area and its associated production outcomes.

The private sector engagement model used in this project will be expanded upon with a $1.2M ADB funded project that will include current partners and collaborators and see an additional 15 laser land levelling providers established and supported across Cambodia in the next 4 years. These efforts should cement laser levelling practices in Cambodia into the future.

7.5 Establishment of Agricultural Weather Station (AWS) Network

Historical Cambodian weather data

The project has completed the collation of all the available historical weather station data from Cambodia. These records have been collated from a number of sources and have been made available online for download http://weather.irrigateway.net/cambodia/

This is a significant resource, particularly for those that maybe interested in scenario modelling activities.

Automatic weather stations (AWS) providing data live to the web have been installed at the Provincial Department of Water Resources and Meteorology (PDWRaM) offices in Takeo, Kampong Thom, Kampot and the CARDI research station at Phnom Penh, to assess the temporal changes in evaporative demand and rainfall during the cropping seasons.

The interest shown by the Department of Meteorology, NGO's and private industry regarding the management of weather data through AWS that deliver data to the web has seen an additional five weather stations added to the original four stations initially planned, a total of 9 stations are on the system at this point in time. The location of the five new stations are at, Kampong Speu, Khmounh, Kampong Soam, Anlong Veng, and Trapaing Prasat.

Each station has mobile phone (3G/GPRS) telemetry to automatically export data to a central database to display real time data and to create an accumulation of historical records for each station. The data can be accessed through the following web address: http://weather.irrigateway.net/cambodia/

This information can be viewed by anyone in the world on a smartphone or through the web online, with information updated every ½ hour. The AWS network is now demonstrating potential to offer a major improvement in meteorological observation collection efficiency for Cambodia and as evidenced by the additional weather stations being added to the system by third parties is increasing capacity to get this information to a wider audience.

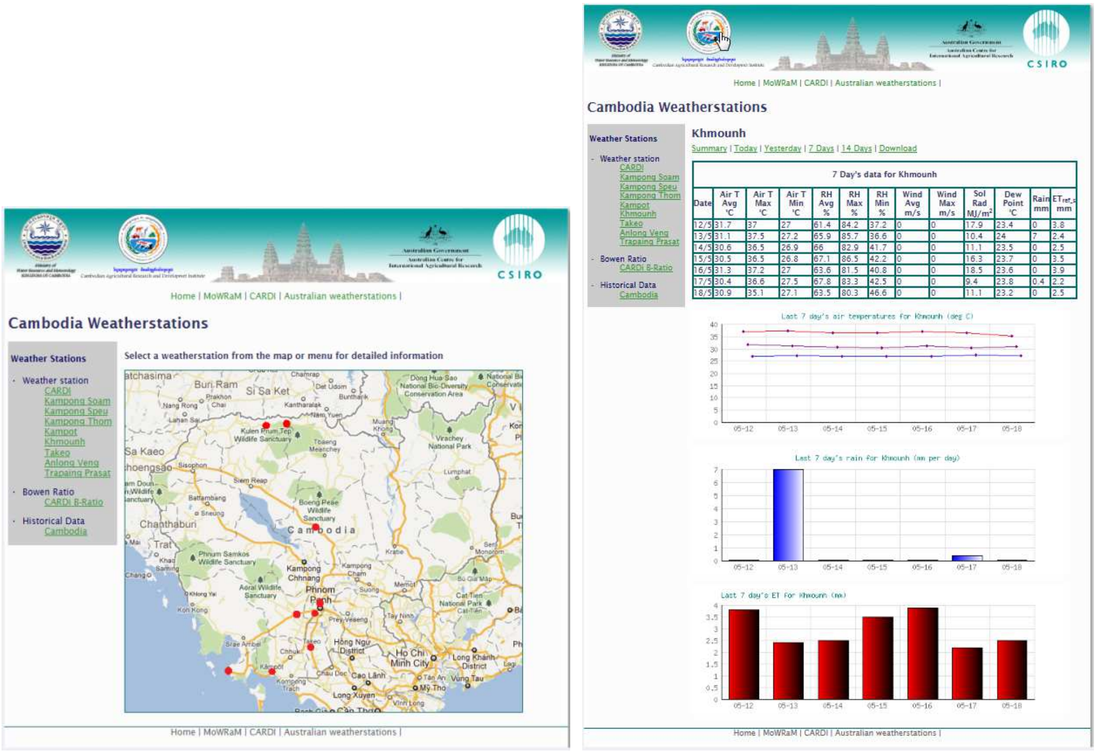


Figure 7-41 Webpage showing Reference evapotranspiration data from the Khmounh Weather Station (AWS).

MOWRAM is now looking to further develop a similar weather station network. A new project is being initiated with the University of Tokyo by Dr Kumiko Tsujimoto, which will see a larger network established. This will incorporate the three stations the project has constructed at the MOWRAM stations and ensure their upkeep and maintenance.

The CARDI weather station will be maintained under SWCN/2012/071 to ensure CARDI researchers and scientists gain experience in operating and maintaining AWS stations with data to be shared with MOWRAM.

8 Impacts

8.1 Scientific impacts – now and in 5 years

The project has promoted scientific investigation and methods for determining crop water requirements for dry season irrigation crops. While these methods such as lysimeters and micro meteorological techniques have been used in developed countries limited use and knowledge of these methods had been applied in Cambodia before this project. The project has been able to provide robust field data on rice crop water requirements. Additionally the project has validated modelling methods using both simple low inputs models like CropWat for determining crop water requirements and additionally more complex models such as APSIM to develop likely yield potential for dry season rice crops grown under Cambodian conditions. These scientific practices and knowledge are being used by Cambodian partners to inform decision making regarding best use of limited water resources. This has led to an improved scientific understanding on crop water requirements and water management at the field scale to maximise rice yield. These skills are being utilised in-country with partners now working on other internationally funded projects and in particular the undergraduate students involved on the project being highly sort after candidates for international scholarships to undertaken masters and PhD studies due to the scientific training they have received in this project.

The full scientific impact of this project in relation to laser land levelling is not yet realised but significant impacts are expected during the next five years. The highly exploratory nature of the research to increase knowledge of laser land levelling, water management and nutrient management for paddy field after levelling is demonstrating important linkages between these components and the need for holistic irrigation and fertiliser management to achieve high yields. One of the previous limitations is some of the research undertaken has been the single issue nature of the research. This project also provides strong evidence of an increase in scientific capacity within the project team over the past four years in relation to laser land levelling leading to measurable practice change in the partner institutions, private sector and farmer groups.

The AWS network has attracted the attention of scientist and government agencies with the Mekong River Commission using the collected data. Additionally, the methodologies in putting this data live on the web have also attracted interest from other organisations and programmes such as the “Seeds for Life” project in Timor which is investigating moving their weather stations to a web based FTP platform similar to the system the project has developed. This resource and collated data also offers a significant scientific resource for Cambodia.

8.2 Capacity impacts – now and in 5 years

A significant effort has been directed to developing skills and capacity in the Cambodian 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 total 16 undergraduate students have been involved directly in the project. 14 students from Institute of Technology Cambodia (ITC) and 2 students from the Royal University of Agriculture (RUA).

The students 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 results collected in 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. This has allowed a number of students to gain international opportunities to undertake further higher education at Masters and PhD levels at international institutes.

Table 8-1 Undergraduate students which have undertaken honours thesis as part of the LWR/2009/046 project through ITC

Academic Year	Name	Current status
2011-2012	KEO Sok Samnang	Masters study in China
2011-2012	MOK Sokun Vichet	Private company
2011-2012	YIN Ratha	Private company
2012-2013	SOK Ty	Masters study in Thailand
2012-2013	SONG Layheang	Masters study in France and now ITC Lecturer
2012-2013	CHHIN Rattana	Masters study in Indonesia and now accepted for PhD in Japan
2013-2014	BUN Sareth	Masters study in Thailand
2013-2014	DIM Wandeth	Masters study in France
2013-2014	SIV Vattana	Successful for John Alwright Masters with CSU Australia
2013-2014	UY Samnang	Masters study in Sri Lanka and Norway
2014-2015	Ang Sovanna	Engineer graduate in July 2015 /Apply Master to Thailand
2014-2015	KHIN Seanghak	Engineer graduate in July 2015 / Apply Master to Thailand
2014-2015	PICH Lin Voleak	Engineer graduate in July 2015 /Apply Master to China
2014-2015	SRUN Chhunheng	Engineer graduate in July 2015

Table 8-2 Undergraduate students which have undertaken honours thesis as part of the LWR/2009/046 project through RUA

Academic Year	Name	Current Status
2014	Nhon Ngoy	Graduate in 2015
2014	Phan Sopha	Graduate in 2015

Capacity building impacts have occurred across all Cambodian partners in accessing scientific literature, designing, testing, conducting and analysing experiment al data. Multi-disciplinary understanding of many of the constraints to crop establishment in Cambodia, 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 systems approach to field experimental design has developed among partners over the life of the project. Partners have been able to identify clear linkages between the irrigation and water supply infrastructure and the on-farm agronomy and how these two aspects need to link together to increase agricultural production. This point was highlighted by MOWRAM TSC who now full appreciate the need to consider on-farm issues when irrigation area refurbishment or development is taking place to ensure the successful outcome of irrigation area refurbishments and greater return on investment.

All Cambodian partners have led field experiments in the provinces and all project partners have produced reports and made presentations to a wide range of audiences throughout the project.

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 benchmarking. This has included training in a wide range of scientific instrumentation such AAS, the use of low cost circular flumes for the measurement of water applications to rice fields, water level dataloggers, crop evapotranspiration measurement instrumentation and soil water monitoring and characterisation equipment. These skills have now been utilised by partners in new projects to develop crop water use measures and identify soil limitations in new projects.

The greatest indicators of success in respect to capacity building for the Cambodian project partners are:

- In research, demonstration and education activities, an increasing quantity of trials implemented by the project team now defaults to using laser land levelling for direct seeding or drum seeding for mechanised wet seeding, on all trials for seed production and agronomic investigations.
- Coordination between partners has been improved with international, national institution, private sector and farmer’s groups being involved in projects
- Provincial Departments and District Offices of Agriculture staff have been exposed to the project and actively involved in implementing the project trials and have a significant capacity to support mechanisation adoption among farmers
- This project has helped to improve the undergraduate curriculum in 1) agricultural machinery, particularly land levelling combined with direct seeding drills, 2) crop production, particularly water and nutrient management at the Royal Agricultural University and improve the undergraduate irrigation hydrology curriculum at the Institute of technology Cambodia
- More than 200 farmers attended field days run by the project, with farmers gaining skills in water and nitrogen management after laser levelling. Cambodian partners have observed changes in rice management methods based on farmers’ interaction with project activities in the three target provinces
- Private sector industry partners have also shown an improved ability to adapt the technologies with developing large scale versions of the laser bucket and external hydraulic system for laser land levelling and specifications to meet the market demand. Custom designed buckets have now been manufactured in Cambodia to suit various size horsepowered tractors being used by the private sector.

Significant inroads have been made into developing a full commercial private sector laser land levelling industry. The Cambodian partners CARDI and TSC in collaboration with MAFF Department of Agricultural Engineering have worked to develop three private contractors in Cambodia with the necessary skills and expertise to undertake laser land levelling services in Cambodia. Within the project and with project partners over 450ha of area has now been laser levelled in Cambodia since the project began. This significant growth is likely to continue into the future as the private sector operators further establish a market for these services and farmers continue to see benefits from laser levelled fields which increase their returns.

Additionally, to support the further development of laser levelling activities a further 15 private contractors will be set up using this model and training and development material developed in the project will be used as part of the Climate-Resilient Rice Commercialization Sector Development Program (RRP CAM 44321) funded by the Asian

Development Bank. This project has $1.2M set aside which will be used for further supporting the development and setup of Precision land levelling contractors within Cambodia. Both MAFF Department of Agricultural Engineering and CARDI are partners in the programme. This should ensure that the laser land levelling activities and knowledge which has been developed in this project will be utilised and embed the practice of laser land levelling into the private sector and ensure its continued use, expansion and benefit over the coming years.

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

The initial field trials and assessment has shown that the potential for land levelling in Cambodia to increase yields is significant. Both demonstration trials on farmers fields by CARDI and surveys of farmers yields before and after laser levelling undertaken in the project have shown that increases in rice yields of 15-20% are realistic from the practice of introducing laser levelling into rice based farming systems in Cambodia. Field demonstrations using laser levelling fields and compared with traditional non-levelled rice fields also showed a 16% reduction in water use for irrigation. This has a significant economic benefit to farmers through reduced pumping costs. Additionally, any water savings in many cases may have the potential to be used to increase dry season paddy area further providing an economic benefit to farmers

It is clear from the survey data and modelling results that dry season rice yields should be able to be increased approximately 6 t/ha in the medium (5 years) term within Cambodia. Already from the survey results the best farmers are achieving these yield targets in some situations. Modelling suggests potential yields as high as 10t/ha under ideal conditions, however these levels may not be achievable in the field due to pest and disease or indeed be economically optimal when inputs are considered. However, it is clear that an increase of 2 t/ha (from a MAFF (2013) reported average of 4.35 t/ha for DSR) should be realistically achievable for many farmers. With approximately 500 000 ha of DSR grown annually in Cambodia and achieving 50% of farmers increasing yields to 6t/ha would see an extra half a million tonnes of rice produced annually in Cambodia at the national level. This would have a major economic impact.

8.3.2 Social impacts

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 in the development of rice industry. Project partners in Cambodia have formed strong links and this is particularly evident in the young career researchers in the partner organisations. There has also been linkages developed between the traditional water/irrigation service provider institutes and the agronomy agencies with a realisation that to increase irrigated agricultural productivity then agencies across the irrigation system design and agronomy/on-farm management areas need to be activity working together and collaborating to develop solutions that will see increase agricultural productivity.

Wider adoption and use laser land levelling complemented with mechanisation has been observed during the life of the project, with increases in off-farm labour opportunities for farmers and the potential to improve family income. Moving to laser levelled field and direct seeding reduces labour inputs and may allow farmers in some situations to seek off farm income or further increase their farming operation size.

Extension services using the field day and demonstration approach are now using participatory, discovery-based and experiential methods, following the new education paradigm of learning by doing and interacting with farmers through farm demonstration sites and also direct private sector industry engagement.

8.3.3 Environmental impacts

The projects focus on improved water management in rice farming systems has seen benchmarked water use and water use productivity figures established. It is believed that by expanding these results across provinces and identifying improved water management practices a reduction in off-site environmental impacts associated with rice farming will occur.

Based on knowledge gained from the project, exposed farmers have altered their decision-making on laser land levelling to observe and analyse field situations carefully for their investment in laser levelling for improved rice production.

Improving water management of paddy's has flow-on environmental impacts in improving efficiencies and potentially reducing the amount of water required for crop production if saved water is not put back into production. Improving efficiency increases sustainability of production systems and may reduce the extraction of water from river systems if correct policies are in place.

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 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 over a wide audience. This has ranged from individual farmers (i.e. field days and demonstrations) to policy makers (i.e Rice Policy Conference). Traditional scientific communication methods i.e. conference and journal papers which have been produced in the project are listed in section 10.2. These have covered a board range of conferences focusing on both policy makers and the scientific community.

Additionally communication and dissemination activities not captured in section 10.2 have included:

<u>Farmer training workshops and demonstrations</u>

- Local demonstration days for laser levelling at the village level were undertaken by MOWRAM TSC in Kandal, Takeo, Kampong Thom and Pursat Provinces with 80 participants
- From MOWRAM TSC four communes, six villages and 92 farmers had laser land levelling undertaken on their fields in Kampong, Thom Province and Takeo Provinces.

- CARDI conducted three field days on laser levelling in three villages in Takeo with 120 participants
- Three seasonal length demonstration sites where established to compare lasered vs non-lasered fields by CARDI in Takeo Province
- 120 copies of Laser land levelling manuals were distribute to participants

Private sector engagement

- Four private sector levelling providers were engaged in the project and training provided on laser levelling

Farmer household surveys

- 180 household interactions as part of the socio-economic and infrastructure survey, which introduced irrigation farmers to the project and collected background data on their irrigation business and systems
- TSC conducted farming survey of farmland after laser land levelling in 6 communities and four provinces
- Interactions with local authorities (Village and Commune leaders) as part of the bio-physical land surveys and establishment of monitoring sites

Train the trainer workshops/ dissemination

- MOWRAM TSC conducted a “Sustainable Irrigation Systems” training course for 13 PDWRAMs in the Kandal, Takeo, Kampong Speu, Kampong Chhnang, Kampong Cham, Pursat, Battambang, Sihanuk, Kep, Siem Reap, Prey Veng, Kampong Thom, Svay Rieng and Banteay Meanchey provinces. The duration of this course was 4 days with three days focused on water management at district and farm scale and one day devoted to Laser land levelling.

- Training-workshop on Field Rice Water Use measurement and CROPWAT modelling, July 28th 2014 at the Institute of Technology of Cambodia (ITC), Phnom Penh, Cambodia

Undergraduate Curriculum expansion

- A series of seminars were presented to undergraduate students at ITC on results and findings from project and the importance of irrigation water management by Australian and Cambodian partners
- Irrigation water management has now been incorporated into the ITC undergraduate Hydrology curriculum
- Mr Som Bunna (CARDI) now guest lectures at the Royal University of Agriculture to final year undergraduate engineering students on the topic of laser land levelling
- An information package on Laser land levelling – manual + CD was distributed to all Provincial PDWRAM Directors

Rice Systems Research (RSR) Newsletters

Six rice system research newsletter article where written over the life of the project.

http://aciar.gov.au/files/node/14844/rsr_newlsetter_1_pdf_23005.pdf
http://aciar.gov.au/files/node/14844/rsr_enews_2_pdf_67284.pdf
http://aciar.gov.au/files/rsr_newsletter_3.pdf
http://aciar.gov.au/files/newsletter4_240913.pdf
http://aciar.gov.au/files/rsr_newsletter5.pdf
http://aciar.gov.au/files/rsr_enews_6_-_word.pdf

9 Conclusions and recommendations

9.1 Conclusions

- It is clear from the survey data and modelling results that dry season rice yields should be able to be increased to approximately 6 t/ha. Already from the survey results the best farmers are achieving these yield targets in some situations. Modelling suggests potential yields as high as 10t/ha under ideal conditions, however these levels may not be achievable in the field due to pest and disease.
- The project was able to demonstrate significant benefits from laser landing levelling across a number of demonstration sites on farmers' fields. These benefits included increased yields, easier management of irrigation water which led to reduced irrigation water demand and reduced pumping costs. Additionally, weed problems were reduced and a decrease in labour when combined with direct seeding of rice rather than transplanting.
- The project has developed a functional network of research partners in Cambodia across CARDI, ITC and MOWRAM TSC which is unique and unprecedented. Previous to this project there was no connection between field based agronomy research and development carried out by CARDI and irrigation infrastructure and regional irrigation development activities undertaken by MOWRAM. This project has developed a strong partnership between these two agencies and the undergraduate training centre ITC that will deliver improved irrigation systems to farmers in the future. MOWRAM now have a strong appreciation of the inter-connections of irrigation system design and the ability of farmers to successfully grow high yielding crops. Some of Cambodia's significant previous investments in irrigation infrastructure and refurbishment of irrigation systems has been constrained in success by poor ability on-farm to control irrigation water and this projected has now developed the links and expertise between these two agencies which now have the knowledge to overcome these issues.
- A significant increase in laser levelled land across Cambodia and the establishment of a private/commercial industry has been undertaken during the project which will have significant benefits across large scales in Cambodia into the future. Previous limitations such as external hydraulic pump issues and hydraulic oil coolers have been overcome in the project and systems developed to suit commercial providers. The commercial service providers now have the knowledge and skills to expand laser levelling throughout Cambodia. This capacity and interest did not exist prior to the project with no existing laser levelling activities in the country apart form a historical 10ha which was laser levelled by Joe Rickman in the early 2000's. Now over 450 ha has been laser levelled since the start of the project and this is continually growing.
- A major increase in the capacity of young Cambodian scientists has occurred during the project in research methodologies and research training. The project has been able to provide research training for 16 undergraduate students to complete their honours thesis on project research topics related to water and nutrient management and laser land levelling. Eight of these students have gone on to a Master's degree outside Cambodia and one is now completing her PhD. Three additional students finishing in the final year of the project have also gone on to

apply for master scholarships aboard. Additionally, knowledge generated in the project is now being used in the teaching curriculum at both ITC and RUA universities.

- Research scientists in Cambodia have been introduced to new technologies and approaches and now have the ability to undertake waterbalance studies across a range of cropping systems using a variety of techniques. Additionally, a number of early career Australian scientists associated with project now have significant knowledge of the Cambodia agricultural landscape and major issues in land and water management within Cambodia. 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.

- Ground water quality is favourable for crop production in the project sites. Their impact on soil quality and crop yields seems not detectable at this stage given some indications of high salt concentration in GW in some sites. There is a recognition that the groundwater resource has not been properly assessed nationally and considered at higher strategic levels. However, in the meantime, to improve productivity and reduce production constraints, there may be opportunity for farmers to increase groundwater use efficiency by building small on farm storage ponds or channels. Using fairly simple interventions, groundwater may be diluted with rainfall and surface water allowing improved water quality and timely access. This may be particularly useful in the production of high value vegetables and in the establishment of rice in the early wet season.

9.2 Recommendations

- At present around one million young Cambodians are leaving farming for garment factory employment inside and outside the country. This is and will exacerbate in future and cause significant labour shortages in the agriculture sector. This shortage of labour for transplanting and harvesting will see a drive for labour saving technologies in Cambodia. There is a significant opportunity for ACIAR to help farmers adjust to these changes through mechanisation R&D research.

- There is Australian commercial interest in Cambodian agriculture. Australian companies are looking at purchasing or co-investing in rice mills in-country. There is an opportunity for ACIAR to link with these activities to value add to their existing research. For instance these millers are looking at developing price premiums for high quality rice and having a farmer network of supply similar to a co-op and providing training to farmers on techniques and technologies to improve rice yields and quality. This is a recent development and may offer ACIAR a unique opportunity to value add to R&D investment and also potentially underpin investment in R&D capacity in-country.

- Promoting laser levelling activities should be expanded beyond rice cropping. Many Cambodian farmers are moving to double cropping and non-rice cropping activities which offer higher value returns. The benefits of laser land levelling within double or triple cropping rotations and on non-rice crops should be investigated.

- Knowledge at the district scale on irrigation water management could still be further improved. While at a catchment and basin scale many studies have been undertaken there is still limited knowledge of the district scale interactions of water management. This project has filled a gap at the farm scale level but district and commune water management does appear to be an area with significant knowledge gaps. It also is an area with poor policy implementation that often see's models created which don't allow for sustainable district water management practices to occur.

- Diversification into other crops in rotation with rice should also be seen as a priority. There are a number of options for dry season cropping which could offer significant returns above dry season rice. However, there are a number of constraints which would need to be investigated particularly in relation to soil constraints and irrigation system layouts that would need further investigation and systems developed to successfully grow these crops.

- New research partners in Cambodia have been identified and developed in Cambodia within this project that offer capacity outside traditional skill sets. ACIAR should look to continue the support of these agencies into the future.

- On-farm water management research skills by Cambodian scientists need further support for addressing the countries future needs in irrigated agriculture. This support should include future training linking agronomic and on-farm and off farm irrigation infrastructure to reduce risks with irrigation cropping or allow diversification. A real limitation of previous research has been either a sole agronomic focus on agronomy or a water supply/infrastructure focus with little recognition of how closely these two areas affect overall yield performance of farmers.

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11 Appendixes

11.1 Appendix 1:

Laser Land levelled Areas

laser land leveling in Takeo province							
ID	Name	Easting (m)	Northing (m)	Village	Commune	District	Area (m^2)
1	Chea Nget	447971.633	1224706.402	Stueng	Ou Saray	Tram Kok	1,204.95
2	Khom Han	448072.837	1224697.67	Stueng	Ou Saray	Tram Kok	1,256.35
3	Dok Ngol	448071.646	1224652.03	Stueng	Ou Saray	Tram Kok	2,165.68
4	Eth Sang	448025.212	1224591.308	Stueng	Ou Saray	Tram Kok	2,001.38
5	Reoun Thear	448128.399	1224603.214	Stueng	Ou Saray	Tram Kok	889.22
6	Nim Leng	448198.249	1224662.745	Stueng	Ou Saray	Tram Kok	3,641.94
7	Khy Nouch	448229.206	1224664.333	Stueng	Ou Saray	Tram Kok	2,369.74
8	Nay Theam	448291.912	1224677.43	Stueng	Ou Saray	Tram Kok	2,511.68
9	Bil Neang	448266.115	1224618.295	Stueng	Ou Saray	Tram Kok	4,990.84
10	Noy Ven	448314.534	1224597.261	Stueng	Ou Saray	Tram Kok	3,905.10
11	Thy Touch	448292.309	1224519.473	Stueng	Ou Saray	Tram Kok	2,843.92
12	Than Vong	448461.51	1224456.899	Stueng	Ou Saray	Tram Kok	4,658.01
13	Reoun Thear	448140.306	1224658.38	Stueng	Ou Saray	Tram Kok	1,054.62
14	Manh	448120.065	1224525.029	Stueng	Ou Saray	Tram Kok	1,615.52
15	Than Vong	448171.262	1224521.061	Stueng	Ou Saray	Tram Kok	2,436.78
16	Eth Sang	448118.874	1224503.995	Stueng	Ou Saray	Tram Kok	1,441.61
17	Vanna Nget	448140.702	1224474.626	Stueng	Ou Saray	Tram Kok	2,840.36
18	Ny Sdaeng	448064.502	1224459.545	Stueng	Ou Saray	Tram Kok	3,670.80
19	Yey Heoun	448028.783	1224429.382	Stueng	Ou Saray	Tram Kok	2,725.89
20	Khin Keo	447995.843	1224351.198	Stueng	Ou Saray	Tram Kok	3,827.69
21	Oun Mao	448029.974	1224666.317	Stueng	Ou Saray	Tram Kok	4,041.09
22	Thy Nut	448069.662	1224598.848	Stueng	Ou Saray	Tram Kok	2,719.15
23	Chay Run	448168.087	1224641.711	Stueng	Ou Saray	Tram Kok	3,487.20
24	Thol Meth	448098.237	1224423.032	Stueng	Ou Saray	Tram Kok	2,736.66
	Total						**65,036.20**

laser land leveling in Kampong Thom province							
ID	Name	Easting (m)	Northing (m)	Village	Commune	District	Area (m^2)
1	Vorng Vorn	468698.655	1423178.315	SANG KUM	DAMREI SLAB	KAMPONG SVAY	3,454
2	Trop Vorn	468704.608	1423148.708	SANG KUM	DAMREI SLAB	KAMPONG SVAY	847
3	Kheav Phy	468751.836	1423207.049	SANG KUM	DAMREI SLAB	KAMPONG SVAY	4,000
4	Khem Sourt	468804.224	1423232.052	SANG KUM	DAMREI SLAB	KAMPONG SVAY	3,537
5	Eam Pream	468860.712	1423090.5	SANG KUM	DAMREI SLAB	KAMPONG SVAY	10,753
6	Eam Rourt	469094.605	1423195.275	SANG KUM	DAMREI SLAB	KAMPONG SVAY	5,808
7	Yom Touch	469094.605	1423258.775	SANG KUM	DAMREI SLAB	KAMPONG SVAY	5,863
8	Seng Soy	469072.38	1423359.317	SANG KUM	DAMREI SLAB	KAMPONG SVAY	6,477
9	Leoung Lam	469529.58	1423318.042	SANG KUM	DAMREI SLAB	KAMPONG SVAY	6,512
10	Eam Phan	469569.797	1423366.725	SANG KUM	DAMREI SLAB	KAMPONG SVAY	2,289
11	Kourk Eav	469505.239	1423351.909	SANG KUM	DAMREI SLAB	KAMPONG SVAY	1,599
12	Thet Ol	469523.23	1423273.592	SANG KUM	DAMREI SLAB	KAMPONG SVAY	2,910
13	Thet Ol	469505.239	1423376.25	SANG KUM	DAMREI SLAB	KAMPONG SVAY	2,711
14	Chheang Touc	469265.79	1423243.032	SANG KUM	DAMREI SLAB	KAMPONG SVAY	1,744
15	Pov Bros	469498.492	1420537.133	Thmey	SAN KOR	KAMPONG SVAY	4,621
16	Hong Non	470227.156	1420476.808	Thmey	SAN KOR	KAMPONG SVAY	2,803
17	Sy Na	470292.243	1420594.283	Thmey	SAN KOR	KAMPONG SVAY	11,995
18	Vanny	470257.318	1420229.158	Thmey	SAN KOR	KAMPONG SVAY	1,689
19	Srey Pich	470216.043	1420267.258	Thmey	SAN KOR	KAMPONG SVAY	5,117
20	Hong Non	470179.531	1420284.72	Thmey	SAN KOR	KAMPONG SVAY	7,203
	Total						**91,932**

Laser land levelling in 2014 in Pursat

ID	Name	Area (m2)	Easting (x)	Northing (y	Village	Commune	District	Remarks
1	Thav Eng	8022.50	353060	1402266	Kampang	Svaydokeo	Bakan	5 plot-2pl.
2	Chrek Sothy	8628.10	353101	1402023	Kampang	Svaydokeo	Bakan	5 plot-2pl.
3	Sdaeng Bo	6540.40	352819	1403780	Kampang	Svaydokeo	Bakan	2 plot-1pl.
4	Pok Hourt	2575.26	353122	1402092	Kampang	Svaydokeo	Bakan	2 plot-1pl.
5	Pok Hourt	1928.64	353554	1401758	Kampang	Svaydokeo	Bakan	2 plot-1pl.
6	Pay Sareoun	3162.79	353148	1402020	Kampang	Svaydokeo	Bakan	2 plot-1pl.
7	Pay Sareoun	2499.51	353553	1401731	Kampang	Svaydokeo	Bakan	2 plot-1pl.
8	Pay Sarourn	6172.20	352790	1402865	Kampang	Svaydokeo	Bakan	2 plot-1pl.
9	Nam Sang	3036.96	352795	1402918	Kampang	Svaydokeo	Bakan	3plot-1pl.
10	Nam Sang	2504.44	353151	1402594	Kampang	Svaydokeo	Bakan	3plot-1pl.
11	Houy Veang	5657.70	352885	1403302	Kampang	Svaydokeo	Bakan	4plot-3pl.
12	Khorn Sao	5063.50	352765	1403086	Kampang	Svaydokeo	Bakan	2 plot-2pl.
13	Pay Samit	3007.50	352678	1402935	Kampang	Svaydokeo	Bakan	1 plot-1pl.
14	Eth Souy	10532.20	354407	1402094	Psa Andet	Ou Tapaung	Bakan	5 plot-5pl.
15	Eour Heng	10269.80	355674	1401592	Psa Andet	Ou Tapaung	Bakan	3plot-1pl.
16	Sem Phourn	7036.80	356166	1401564	Psa Andet	Ou Tapaung	Bakan	2 plot-2pl.
17	Ouk Chamro	11303.50	355845	1401553	Psa Andet	Ou Tapaung	Bakan	2 plot-2pl.
18	Srey Chhat	3300.70	356579	1401528	Psa Andet	Ou Tapaung	Bakan	1 plot-1pl.
19	Eour Hong	3752.30	354980	1401891	Psa Andet	Ou Tapaung	Bakan	1 plot-1pl.
	Total	**104,994.80**						

ID	Name	Area (m2)	Easting (x)	Northing (y)	Village	Commune	District
1	Teng Am	3,225.40	469195	1429451	Vor yav	Damreyslab	Kampong Svay
2	Teng Am	3,591.90	469185	1429465	Vor yav	Damreyslab	Kampong Svay
3	Teng Am	16,752.00	469090	1429459	Vor yav	Damreyslab	Kampong Svay
4	Yem Huort	2,174.50	469212	1429334	Vor yav	Damreyslab	Kampong Svay
5	Kreong Chean	4,425.60	469238	1429246	Vor yav	Damreyslab	Kampong Svay
6	Cheang Pho	5,830.40	469190	1429212	Vor yav	Damreyslab	Kampong Svay
7	Toch Ty	6,355.50	469150	1428983	Vor yav	Damreyslab	Kampong Svay
8	Chhum yet	3,118.70	469185	1429026	Vor yav	Damreyslab	Kampong Svay
9	Ly Im	5,619.00	468986	1429544	Vor yav	Damreyslab	Kampong Svay
10	Nhe Teang	2,816.90	468907	1429426	Vor yav	Damreyslab	Kampong Svay
11	Seang Sean	3,944.10	468849	1429700	Vor yav	Damreyslab	Kampong Svay
12	Meoy Onn	2,706.60	468989	1429507	Vor yav	Damreyslab	Kampong Svay
13	Theong Teang	2,875.70	469205	1428697	Vor yav	Damreyslab	Kampong Svay
14	Toch Tean	4,201.20	469166	1429884	Vor yav	Damreyslab	Kampong Svay
15	Huort Hov	3,416.60	468802	1429720	Vor yav	Damreyslab	Kampong Svay
16	Veong Rean	2,627.50	469097	1429251	Vor yav	Damreyslab	Kampong Svay
17	Veong Rean	5,499.60	469087	1429287	Vor yav	Damreyslab	Kampong Svay
18	Loch sear	4,123.80	469524	1421173	Sang Kum	San Kor	Kampong Svay
19	Phorn Hool	3,925.10	479217	1421848	Sang Kum	San Kor	Kampong Svay
20	Srey Mar	3,652.20	469510	140668	Sang Kum	San Kor	Kampong Svay
21	Taing Vorn	3,752.20	469172	1418235	Sang Kum	San Kor	Kampong Svay
22	Un Rech	1,771.20	469230	1418223	Sang Kum	San Kor	Kampong Svay
23	Un Rech	3,116.80	469262	1418269	Sang Kum	San Kor	Kampong Svay
24	Tha Chantheng	8,263.00	469293	1417476	Sang Kum	San Kor	Kampong Svay
25	Pich Menh	15,955.00	470711	1420260	dey Angkrorr	San Kor	Kampong Svay
26	Khem Rumcheb	11,887.00	473170	1421809	Tlok Krasang	San Kor	Kampong Svay
27	Vuth	15,325.00	473130	1420793	Tlok Krasang	San Kor	Kampong Svay
Total		**150,952.50**					

	Table for farming research			Location		Ousaray Commune, Tram Kok District, Takeo province						
Before land leveling 2012						After land leveling 2013			After land leveling 2014			
N°	Farmer Name	Area (m$^{2)}$	Time/year	Dir. See/T.pla	Yield (t/ha)	Time/year	Dir. See/T.p	Yield(t/ha)	Time/year	Dir. See/T.pla	Yield(t/ha)	Remark
1	Chea Nget	1,205	2	Transpanting	2.800	2	Dir. Seeding	3.400	2	Dir. Seeding	3.500	early rainy sea.
2	Khom Han	1,256	2	Transpanting	3.000	2	Dir. Seeding	3.600	2	Dir. Seeding	3.600	and rainy sea.
3	Dok Ngol	2,166	2	Transpanting	2.900	2	Dir. Seeding	3.700	2	Dir. Seeding	3.900	
4	Eth Sang	2,001	2	Transpanting	2.900	2	Dir. Seeding	3.500	2	Dir. Seeding	3.500	
5	Reoun Thear	889	2	Transpanting	3.000	2	Dir. Seeding	3.400	2	Dir. Seeding	3.650	
6	Nim Leng	3,642	2	braodcasting	3.000	2	Dir. Seeding	3.500	2	Dir. Seeding	3.300	
7	Khy Nouch	2,370	2	braodcasting	2.600	2	Dir. Seeding	3.200	2	Dir. Seeding	3.750	
8	Nay Theam	2,512	2	Transpanting	2.700	2	Dir. Seeding	3.000	2	Dir. Seeding	3.400	
9	Bil Neang	4,991	2	Transpanting	2.800	2	Dir. Seeding	3.200	2	Dir. Seeding	2.900	
10	Noy Ven	3,905	2	Transpanting	2.900	2	Dir. Seeding	3.400	2	Dir. Seeding	3.400	
11	Thy Touch	2,844	2	Transpanting	2.800	2	Dir. Seeding	3.300	2	Dir. Seeding	3.600	
12	Than Vong	4,658	2	Transpanting	3.000	2	Dir. Seeding	3.600	2	Dir. Seeding	3.500	
13	Reoun Thear	1,055	2	Transpanting	2.600	2	Dir. Seeding	3.100	2	Dir. Seeding	2.800	
14	Manh	1,616	2	Transpanting	2.800	2	Dir. Seeding	3.300	2	Dir. Seeding	3.800	
15	Than Vong	2,437	2	Transpanting	2.700	2	Dir. Seeding	3.200	2	Dir. Seeding	3.750	
16	Eth Sang	1,442	2	Transpanting	2.800	2	Dir. Seeding	3.700	2	Dir. Seeding	3.900	
17	Vanna Nget	2,840	2	Transpanting	2.700	2	Dir. Seeding	3.000	2	Dir. Seeding	3.200	
18	Ny Sdaeng	3,671	2	Transpanting	2.800	2	Dir. Seeding	2.800	2	Dir. Seeding	3.400	
19	Yey Heoun	2,726	2	Transpanting	2.600	2	Dir. Seeding	3.000	2	Dir. Seeding	3.100	
20	Khin Keo	3,828	2	braodcasting	2.900	2	Dir. Seeding	2.900	2	Dir. Seeding	3.400	
21	Oun Mao	4,041	2	braodcasting	2.800	2	Dir. Seeding	3.200	2	Dir. Seeding	3.000	
22	Thy Nut	2,719	2	Transpanting	2.700	2	Dir. Seeding	3.500	2	Dir. Seeding	3.400	
23	Chay Run	3,487	2	Transpanting	2.900	2	Dir. Seeding	3.100	2	Dir. Seeding	3.200	
24	Thol Meth	2,737	2	Transpanting	3.200	2	Dir. Seeding	3.200	2	Dir. Seeding	3.500	
25	Pat Saveoun	5,044	2	Transpanting	3.400	2	Dir. Seeding	3.700	2	Dir. Seeding	3.300	
		65,036		AVERGAG	2.852		AVERGAG	3.300		AVERGAG	3.430	

	Table for farming research				Kampong Svay District, Domrey Slab and San Kor communes, Sang Kum and Thmey Villages							
Before land leveling 2012						After land leveling 2013			After land leveling 2014			
N°	Farmer Name	Area(m^2)	Time/year	Dir. See/T.pla	Yield (t/ha)	Time/year	Dir. See/T.pla	Yield(t/ha)	Time/year	Dir. See/T.pla	Yield(t/ha)	Remark
1	Vorng Vorn	3,454.00	2	Dir. Seeding	2.800	2	Dir. Seeding	3.400	2	Dir. Seeding	3.250	IR dry season
2	Trop Vorn	847.00	2	Dir. Seeding	2.500	2	Dir. Seeding	3.000	2	Dir. Seeding	3.350	Paka Rumdol
3	Kheav Phy	4,000.00	2	Dir. Seeding	3.000	2	Dir. Seeding	4.000	2	Dir. Seeding	4.200	rainy season
4	Khem Sourt	3,537.00	2	Dir. Seeding	2.700	2	Dir. Seeding	3.200	2	Dir. Seeding	3.550	
5	Eam Pream	10,753.00	1	Dir. Seeding	3.200	2	Dir. Seeding	3.200	2	Dir. Seeding	3.150	
6	Eam Rourt	5,808.00	2	Dir. Seeding	3.200	2	Dir. Seeding	3.200	2	Dir. Seeding	3.450	
7	Yom Touch	5,863.00	2	Dir. Seeding	3.100	2	Dir. Seeding	3.400	2	Dir. Seeding	3.400	
8	Seng Soy	6,477.00	2	Dir. Seeding	2.900	2	Dir. Seeding	3.500	2	Dir. Seeding	3.600	
9	Leoung Lam	6,512.00	2	Dir. Seeding	2.500	2	Dir. Seeding	3.400	2	Dir. Seeding	3.950	
10	Eam Phan	2,289.00	2	Dir. Seeding	2.900	2	Dir. Seeding	3.500	2	Dir. Seeding	3.250	
11	Kourk Eav	1,599.00	2	Dir. Seeding	3.000	2	Dir. Seeding	3.000	2	Dir. Seeding	3.450	
12	Thet Ol	2,910.00	2	Dir. Seeding	2.800	2	Dir. Seeding	2.800	2	Dir. Seeding	3.350	
13	Thet Ol	2,711.00	2	Dir. Seeding	3.100	2	Dir. Seeding	3.700	2	Dir. Seeding	4.010	
14	Chheang Touch	1,744.00	2	Dir. Seeding	3.200	2	Dir. Seeding	3.900	2	Dir. Seeding	3.850	
15	Pov Bros	4,621.00	1	Dir. Seeding	2.900	1	Dir. Seeding	3.400	1	Dir. Seeding	3.500	
16	Hong Non	2,803.00	1	Dir. Seeding	3.200	2	Dir. Seeding	3.200	2	Dir. Seeding	3.200	
17	Sy Na	11,995.00	1	Dir. Seeding	3.000	2	Dir. Seeding	3.500	2	Dir. Seeding	3.320	
18	Vanny	1,689.00	1	Dir. Seeding	2.900	1	Dir. Seeding	3.800	1	Dir. Seeding	3.650	
19	Srey Pich	5,117.00	1	Dir. Seeding	3.000	2	Dir. Seeding	3.400	2	Dir. Seeding	3.500	
20	Hong Non	7,203.00	1	Dir. Seeding	3.100	1	Dir. Seeding	3.100	1	Dir. Seeding	3.350	
		91,932		AVERAGE	2.950		AVERAGE	3.380		AVERAGE	3.517	

	Table for farming research		Location		Svaydonkeo and Otapaong Communes, Bakan District, Pursat province							
			Before land leveling 2013				After land leveling 2014					
N°	Farmer Name	Area (m^{2})	Water con	grass con	Time/yea	Dir. See/T.pla	Yield (t/ha)	Water con	grass con.	Time/yea	Dir. See/T.pl	Yield(t/ha)	Remark
1	Thav Eng	8,022.50	Water sho	difficult	1	Transpanting	2.150	Better	Better	2	Dir. seeding	3.750	early rainy sea.
2	Chrek Sothy	8,628.10	difficul	difficult	1	Transpanting	3.500	Water sho.	Better	2	Dir. seeding	2.100	and rainy sea.
3	Sdaeng Bo	6,540.40	difficul	difficult	1	Transpanting	3.400	Water sho.	Better	2	Dir. seeding	3.076	
4	Pok Hourt	2,575.26	Water sho	difficult	1	Transpanting	2.900	Better	Better	2	Dir. seeding	3.210	
5	Pok Hourt	1,928.64	Water sho	difficult	1	Transpanting	2.100	Better	Better	2	Dir. seeding	3.300	
6	Pay Sareoun	3,162.79	Water sho	difficult	1	braodcasting	2.200	Better	Better	2	Dir. seeding	3.500	
7	Pay Sareoun	2,499.51	Water sho	difficult	2	braodcasting	2.400	Better	Better	2	Dir. seeding	2.100	
8	Pay Sarourn	6,172.20	difficul	difficult	2	Transpanting	3.270	Better	Better	2	Dir. seeding	4.426	
9	Nam Sang	3,036.96	difficul	difficult	2	Transpanting	3.000	Water sho.	Better	2	Dir. seeding	3.000	
10	Nam Sang	2,504.44	difficul	difficult	2	Transpanting	3.000	Water sho.	Better	2	Dir. seeding	3.000	
11	Houy Veang	5,657.70	difficul	difficult	2	Transpanting	3.200	Better	Better	2	Dir. seeding	4.700	
12	Khorn Sao	5,063.50	difficul	difficult	1	Transpanting	3.500	Better	Better	2	Dir. seeding	4.800	
13	Pay Samit	3,007.50	difficul	difficult	2	Transpanting	3.800	Better	Better	2	Dir. seeding	5.500	
14	Eth Souy	10,532.20	difficul	difficult	2	Transpanting	3.900	Water sho.	Better	2	Dir. seeding	2.700	
15	Eour Heng	10,269.80	difficul	difficult	2	Transpanting	3.450	Better	Better	2	Dir. seeding	3.450	
16	Sem Phourn	7,036.80	difficul	difficult	2	Transpanting	4.500	Better	Better	2	Dir. seeding	4.000	
17	Ouk Chamror	11,303.50	difficul	difficult	2	Transpanting	4.100	Water sho.	Better	2	Dir. seeding	2.000	
18	Srey Chhat	3,300.70	difficul	difficult	2	Transpanting	4.000	Water sho.	Better	2	Dir. seeding	2.800	
19	Eour Hong	3,752.30	difficul	difficult	2	Transpanting	3.800	Water sho.	Better	2	Dir. seeding	2.200	
		104,994.80				**AVERGAG**	**3.272**				**AVERGAG**	**3.348**	