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A review on rice productivity in Cambodia and water use measurement using direct and indirect methods on a dry season rice crop

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November 2013

Sustainable Agriculture Flagship

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Citation

Smith DJ[1] and Hornbuckle JW[1] (Eds.), 2013. A review on rice productivity in Cambodia and water use measurement using direct and indirect methods on a dry season rice crop. Technical Report to ACIAR, Canberra, CSIRO Sustainable Agriculture Flagship, Australia.

Section 1: A literature review on rice productivity in Cambodia: constraints, challenges and options.

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Section 2: Water use measurement using direct and indirect methods on a dry season rice crop.

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[This work was funded by the Australian Centre for International Agricultural Research project LWR/2009/046 ‘Improved irrigation water management to increase rice productivity in Cambodia’ and CSIRO National Sustainable Agriculture Flagship. The authors are grateful for the review of this report and comments provided by CSIRO reviewer, Dr Mohammed Mainuddin.

Executive summary

Cambodia's economy is largely based on the agricultural sector which contributes 27% of national GDP and in which 65% of the labour force are engaged. Rice production is central to this sector, not only do the majority of Cambodia's farmers depend directly and indirectly on the success of the rice crop each year, as it is the main food staple, rice production is a big factor in the national effort to promote food security. Despite the importance of rice farming in the Cambodian landscape, it has traditionally been dependant on rainfall. Rice is predominately grown in the wet season which produces 80% of the total crop. Irrigation is mainly used for dry season rice and to complete wet season rice if necessary.

In recognising the importance of water management to increase Cambodia's rice production, the Cambodian government has made significant efforts to increase the area available to irrigation with the expectation that farmers can farm with more certainty, increasing their farm productivity and livelihoods. However, an increase in irrigation activity will place additional pressure on existing resources. Therefore, it is important that we can measure crop water requirements, particularly of rice, to ensure that we make the most efficient use of the available water resource.

In order to address these challenges, the focus of this report is twofold. Firstly, to conduct a literature review on rice productivity in Cambodia to ascertain what data is already available and to identify constraints, challenges and options to increase rice productivity. Secondly, to measure actual crop water use through direct and indirect approaches on a dry season rice crop in 2012 and to calculate water productivity indices.

The literature review highlights that from the very limited data for Cambodia (and indeed for the neighbouring countries), that it lags behind its Asian neighbours both in terms of physical productivity and water productivity by up to 50%. The major causes of low productivity of rice in Cambodia can be attributed to the low use of high yielding varieties, poor management practices, periodic drought and low application of fertilisers. There are several core constraints to rice productivity growth; however the inability to manage water flows is likely the most serious constraint on agricultural productivity in Cambodia due to the considerable variability in rainfall.

Water management in wet season rice in Cambodia is problematic as it is difficult to implement good water management practices when there is an oversupply of water through rainfall events over the majority of the season. From this perspective, there appears to be great opportunities to grow higher yielding rice in the dry season, supplemented with good water management practices, provided that the water is available from the supply network.

The review concludes that there is huge potential for Cambodia to increase its physical rice and water productivity. This can be accomplished by an improved understanding of crop water requirements, adoption of higher yielding varieties, increased use of fertilisers, improving water management practices and the expansion of dry season irrigated farming. An increase in irrigation activity will place additional pressure on existing water resources and it is imperative that we can measure the crop water requirements of rice, so that the water resource can be managed appropriately and to make the most efficient use of the available water resource.

Measuring the crop water requirement of rice using different approaches is the focus of the 2nd half of this report. Daily crop evapotranspiration (ET_c) was measured using direct (lysimeters) and indirect methods (Bowen ratio and ASCE short approach) on a dry season rice crop in 2012. There are advantages and disadvantages of each approach to measure crop water use and these are discussed in further detail in the report. For each method, two measures of water productivity (kg/m^3) were computed: input water productivity (WP_{IR}) – the ratio of grain yield to amount of irrigation water plus rainfall and: evapotranspiration water productivity (WP_{ET}) – the ratio of grain yield to crop evapotranspiration.

Both approaches recorded similar ET_c requirements and water productivity indices. ET_c measured from lysimeter 1 was 491 mm, whilst the ET_c from lysimeter 2 was very similar at 489 mm over the analysis period (1-Feb to 24th April 2012). These numbers are comparable to the Bowen ratio and ASCE approach (475 and 466 mm respectively). The input water productivity (WP_{IR}) was also very similar across approaches (0.50 – 0.56) as was the evapotranspiration water productivity (WP_{ET}) (0.66-0.69). The water productivity levels achieved at the Cambodian Agricultural Research and Development Institute (CARDI) are relatively good when benchmarked against neighbouring countries and practices. These results will aid in the development of best practice guidelines for water management in Cambodia.

Measuring irrigation water application is a basic prerequisite for determining water use productivity. In order to expand the ability to benchmark water use productivity across provinces and districts at a wider scale there is a need for low cost relatively accurate water measuring devices. Low cost devices made of PVC, known as circular flumes, are an appropriate device for measuring water application and water runoff.

Rice crop water use studies have continued to be undertaken at the CARDI experimental site with micro-meteorology and lysimetry equipment and have allowed researchers to develop a good understanding of dry season rice production and water use productivity at CARDI. The next step is to determine rice water use requirements across provinces and districts in Cambodia. To accomplish this, an automatic weather station (AWS) network setup within the project will provide wide scale crop evapotranspiration measurements and the circular flumes will allow irrigation application and runoff to be measured cost effectively across larger areas. Knowledge of the rice crop water requirements for dry-season and early dry-season rice crops are completely lacking in Cambodia and it is hoped that this methodology can be used to define water needs and water availability to maximise production.

Section 1 A literature review on rice productivity in Cambodia: constraints challenges and options

1 Introduction

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

Each of these drivers of demand (population growth, rising incomes and urbanisation) is 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), while simultaneously experiencing 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), although with economic growth and consumers becoming more affluent, meat and fish consumption are likely to increase with rice consumption decreasing (Delgado et al, 2007). However, total food production still needs to increase to feed a growing population and if this increase is to be satisfied by domestic production under increasing competition for water, greater pressure will be placed on agricultural water and resources.

Cambodia is bordered by Thailand, Laos and Vietnam and is situated in the Lower Mekong Basin (Figure 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 agricultural labour force is the poorest sector of the population earning less than US$2/day, which make up 30% of the national population (ADB 2010). Rice production is central to this sector, not only do the majority of Cambodia's farmers depend directly and indirectly on the success of the rice crop each year, as it is the main food staple, rice production is a big factor in the national effort to promote food security (Wokker et al, 2011).

Physical rice productivity in Cambodia lags behind surrounding countries (particularly Vietnam and Laos). The productivity of rice varies with the highest productivity 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 with dry season rice farming constituting only about 20 percent of this area, even though the yields per ha are higher. 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 farming being historically 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.

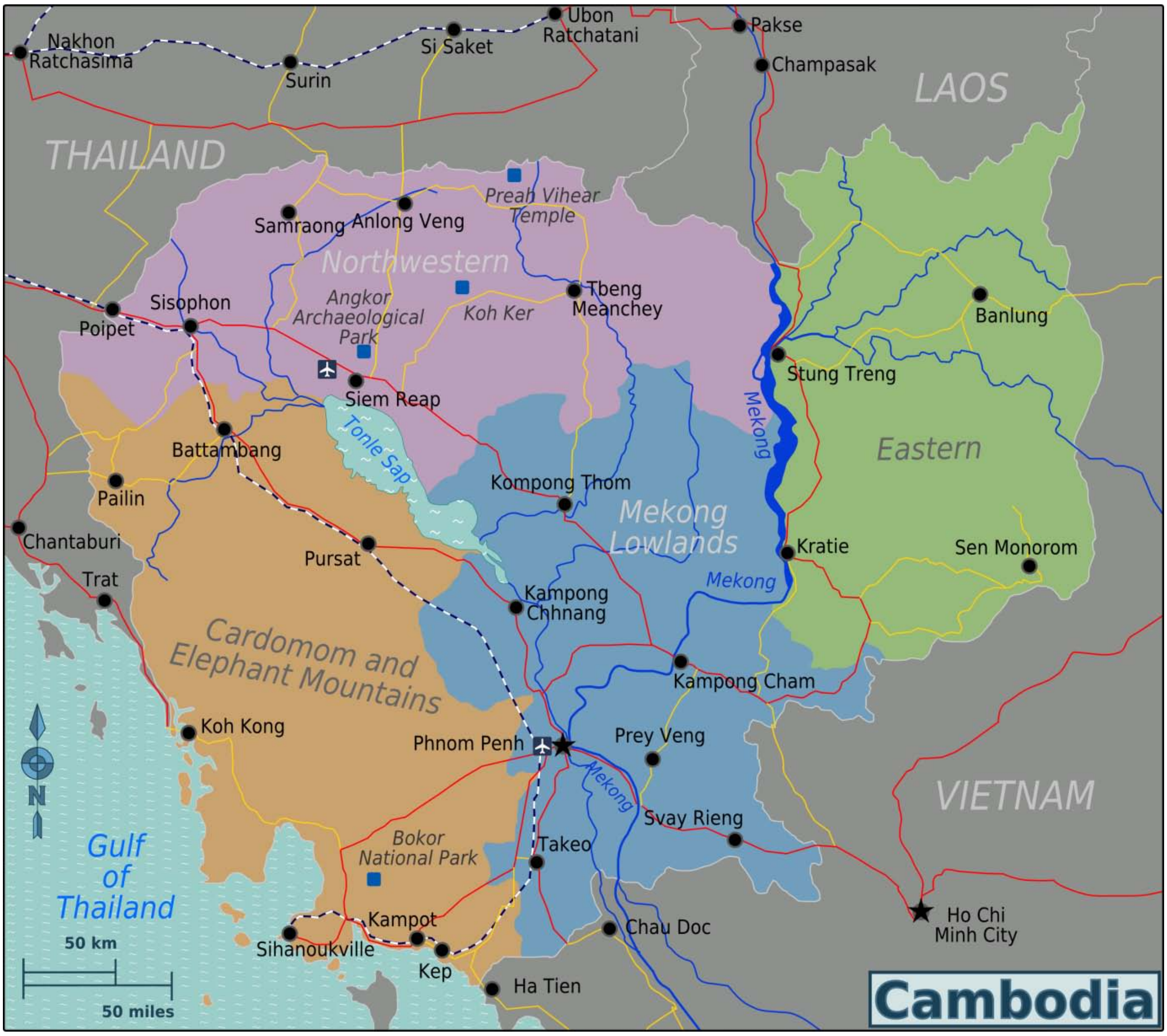

Figure 1: Map of Cambodia and surrounding countries

2 Rice water use

About 90% of the world's rice production is harvested from irrigated or rain-fed lowland rice fields (also called ''paddies''). Usually, lowland rice is raised in a seedbed and then transplanted into a main field. Rice can also be established by direct wet seeding (broadcasting pre-germinated seeds onto wet soil) or dry direct seeding (broadcasting dry seeds onto dry or moist soil) directly on the main field. After crop establishment, the main field is kept under continuous (irrigated) or intermittent (rain-fed) ponded water conditions. Keeping the fields continuously flooded helps control weeds and pests. Wet land preparation for transplanted and wet-seeded rice consists of soaking, ploughing, and puddling. Puddling is done for weed control and to reduce soil permeability and percolation losses. Due to the flooded nature of lowland rice, its water balance and water productivity are different from those of other cereals such as wheat.

Water for lowland rice is needed for land preparation and to match the outflows by seepage, percolation, evaporation, and transpiration during crop growth. The amount of water used for wet land preparation can be as low as 100–150 mm when the time lag between soaking and transplanting is only a few days or when the crop is direct wet seeded (Bouman et al, 2007). Tabbal et al, (2002) estimates that water inputs for land preparation can be up to 940 mm and as long as 2 months in large scale irrigation systems that have poor water control. After crop establishment, the soil is usually kept ponded until shortly before harvest.

Seepage is the lateral subsurface flow of water and percolation is the down flow of water below the root zone. Seepage and percolation rates vary with soil type ranging from 1 to 5 mm day in heavy clay soils to 25–30 mm day in sandy and sandy loam soils (Bouman and Tuong, 2001). Water released into the air as vapour from a ponded water layer or from the surface of the soil is evaporation and water released as vapour by the plants is transpiration. Combined evapotranspiration rates of south asian rice fields are typically 4–5 mm/day in the wet season and 6–7 mm/day in the dry season. However, they can be as high as 10–11 mm/day in subtropical regions before the onset of the monsoon season (Tabbal et al, 2002). Approximately 30% of combined evapotranspiration is evaporation and 70% transpiration (Bouman et al, 2005), whereas in Australia where the fields are ponded for about 5 months from pre-sowing to the end of grain filling, approximately 40% of combined evapotranspiration is evaporation from the floodwater and 60% is transpiration (Simpson et al, 1992). Over-bund flow or surface runoff occurs when water depths rise above the paddy bunds. Seepage, percolation, over-bund flow, and evaporation are all non-productive water flows and can be considered losses at the field level (Bouman et al, 2007).

Total seasonal water input to rice fields (rainfall plus irrigation) can be as little as 400 mm in heavy clay soils with shallow groundwater tables that supply water for crop transpiration by capillary rise, to more than 2000 mm in coarse-textured (sandy or loamy) soils with deep groundwater tables (Bouman and Tuong, 2001; Cabangon et al, 2004). Approximately 1300–1500 mm is a typical value for irrigated rice in Asia (Bouman and Tuong, 2001). Phengphaengsy and Okudaira (2008) reported an irrigated rice water usage of 2050 mm in the Komping Pouy gravity scheme in Cambodia in the dry season period from October 2006 to March 2007 where percolation rates are high. Seepage and percolation can account for about 25–50% of all water inputs in heavy soils with shallow water tables of 20–50 cm depth (Cabangon et al, 2004; Dong et al, 2004), and 50–85% in coarse-textured soils with deep water tables of 1.5 m depth or more (Sharma et al, 2002; Singh et al, 2002).

3 Water Productivity

Water productivity (WP) simply refers to the ratio between yield and water use. WP can be measured in a number of ways depending on the availability of data and the questions to be answered. WP can be evaluated at different scales from plot to country and it is important to take this into consideration as firstly larger scales of assessment are generally associated with higher levels of water productivity and secondly, different outcomes are relevant to different stakeholders at different levels.

WP can be taken as transpiration, evapotranspiration, irrigation or irrigation plus rainfall. Modern rice varieties, when grown under flooded conditions have WP with respect to transpiration (WP_T) similar to that of other C_3 cereals such as wheat at approximately 2 kg grain m^3 (kg/m^3) (Bouman and Tuong, 2001; Tuong et al, 2005). Sparse available data indicate that WP with respect to evapotranspiration (WP_{ET}) is also similar to that of wheat ranging from 0.5 – 1.6 kg/m^3 (Zwart and Bastiaanssen, 2004). Tuong and Bouman (2003) give a very similar range of 0.4 - 1.6 kg/m^3 for lowland rice conditions. However, Mainuddin and Kirby (2009b) reported the WP_{ET} of rice for Cambodia (maximum of 0.33 kg/m^3) and Thailand (maximum of 0.30 kg/m^3) were even lower than the minimum reported by these authors. Mainuddin and Kirby (2009b) also report the WP_{ET} for Vietnam (maximum of 0.77 kg/m^3) and Laos (maximum 0.58 kg/m^3) falls within the range reported by Zwart and Bastiaanssen (2004) and Tuong and Bouman (2003). WP of rice with respect to total water input (irrigation plus rainfall, WP_{IR}) ranges from 0.2 to 1.2 kg/m^3, with 0.4 as the average value (Bouman et al, 2007). The major causes of low productivity of rice in Cambodia can be attributed to the low use of high yielding varieties, poor management practices, periodic drought and low application of fertilisers (Makara et al, 2004; Fukai and Kam, 2004).

Table 1 (modified from Wokker et al, 2011), attempts to provide a summary of the two studies (Mainuddin and Kirby 2009b; Phengphaengsy and Okudaira 2008) which have tried to quantify water productivity in the Lower Mekong Basin (LMB). A further five studies (Hafeez et al, 2007; Bouman et al, 2005; Belder et al, 2004; Cabangon et al, 2002; Tabbal et al, 2002) have been included to represent other South Asian countries. Mainuddin and Kirby (2009b) have assumed that there is no irrigation demand from the wet season in the LMB and given that there is no data available for supplementary irrigation in the LMB and that the application of supplementary irrigation in the wet season in Laos, Thailand and Cambodia is relatively small (Fukai, 2001), this is a reasonable assumption. Phengphaengsy and Okudaira (2008) report WP values for three schemes across the LMB for the dry season of 2006-2007 which obviously include irrigation (Table 1). The high WP values in Belder et al (2004) in Table 1 may be attributed to the shallow groundwater levels observed in this study.

Phengphaengsy and Okudaira (2008) also observed higher efficiency in schemes with active and strict water management, high degree of monitoring and evaluation of water allocation. This is essential to utilise water efficiently to meet agricultural demand and to have sufficient water to expand cultivation areas whilst avoiding shortages. Sites with low efficiency had poorly designed hydraulic structures allowing excessive water into command areas and then to drain out without being used. Higher water productivity is found in schemes practicing multiple agricultural activities, while lower water productivity is observed in schemes practicing single cropping (Phengphaengsy and Okudaira 2008).

Table 1: Water productivity in Cambodia and other South East Asian countries

Study	Country	Period	Irrigation	Scale	WP (kg/m^3)
Mainuddin and Kirby (2009)	Laos	1993-2004	Excluded	Province	0.20-0.49
(wet season rice)	Thailand	1995-2003	Excluded	Province	0.20-0.30

Study	Country	Period	Irrigation	Scale	WP (kg/m^3)
	Cambodia	1993-2003	Excluded	Province	0.11-0.24
	Vietnam	1995-2004	Excluded	Province	0.30-0.48
Phengphaengsy and Okudaira (2008)	Laos	2006-2007	Included	Scheme	0.40
(dry season rice)	Thailand	2006-2007	Included	Scheme	0.58
	Cambodia	2006-2007	Included	Scheme	0.18
Hafeez et al (2007	Philippines	2000-2001	Included	Scheme	0.18
(dry season rice)					
Bouman et al (2005)	Philippines	2000-2001	Included	Field	0.29
(dry season rice)		2001-2002	Included	Field	0.58
		2002-2003	Included	Field	0.46
Belder et al (2004)	Philippines	2000-2001	Included	Field	0.73-1.20
(dry season rice)					
Cabangon et al (2002)	Malaysia	1988-1994	Included	Field	0.26
(dry season rice)					
Tabbal et al (2002)	Philippines	1988-1989	Included	Field	0.23
(dry season rice)		1989-1990	Included	Field	0.35
		1990-1991	Included	Field	0.26
		1991-1992	Included	Field	0.14

From the very limited data for Cambodia (and indeed for the neighbouring countries), it is apparent that Cambodia lags behind its Asian neighbours both in terms of physical productivity and water productivity by up to 50%. Wokker et al (2011) suggests that irrigation of wet season rice is of marginal benefit and perhaps can be better considered as an 'insurance' type of approach against crop failure due to drought years. This type of approach can lead to problems in management and maintenance as the irrigation system for wet season rice is not considered critical by farmers, sometimes they use it and sometimes not. The returns from wet season rice are low typified by a low input: low output approach. Therefore, farmers will not be willing to contribute for wet season irrigation if they do not perceive a clear benefit.

4 Constraints in water management in Cambodia

The core constraints to rice production growth are: (i) underfunding of agricultural crop extension programmes; (ii) inadequate funding for scientific agricultural research; (iii) low production and availability of improved rice seed; (iv) lack of commercial farm credit system; (v) stagnating rice crop yield growth rates; (vi) stagnating irrigation expansion (USDA, 2010). The inability to manage water flows is likely the most serious constraint on agricultural productivity in Cambodia due to the considerable variability in rainfall (RGC, 2001).

The Ministry of Water resources and Meteorology (MOWRAM) and the Ministry of Agriculture, Forestry and Fisheries (MAFF) are working to increase investment in irrigation and research to promote agricultural production for poverty reduction. MOWRAM has shown a strong commitment to increase the irrigated area in Cambodia by 20 000 ha/year. Increasing investment in irrigation to increase rice production and encourage agricultural diversification for food security and higher value-added crops is essential, but these are not the only goals of water resources management. Integrated water resources management involves agriculture, fish production, biodiversity, water supply and sanitation, and transport and hydropower (FAO Aquastat, 2010). Thus it is crucial that basin-wide management issues are considered when planning irrigation development (CDRI, 2008).

Cambodia is experiencing difficulty in that many irrigation schemes developed since independence generally are in physical disrepair and operating much below potential. Even when rehabilitation does occur there is a policy that farmers incur the responsibility of maintenance, which they are unable to do as exemplified by only 9% of water fees actually being collected (Wokker et al, 2011). 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 water wastage.

Irrigation is a mechanism for increasing agricultural production and hence increasing incomes of the rural poor and developing the national economy, as described by the Royal Government of Cambodia (RGC) in the planning and development document the Rectangular Strategy (RGC 2004; RGC, 2009). The RGC Rectangular Strategy (2004) emphasises growth in irrigated rice and in response investment in irrigation infrastructure by RGC has been US$60 million per year between 2007 and 2010 (Sophal et al, 2010). It is estimated that only 30% of the suitable land for irrigation has been developed (Pech and Sunada 2008) and hence the potential for ongoing investment in irrigation schemes in Cambodia is very large indeed. Many of these schemes are being refurbished and new ones built. These schemes are usually built with a policy that RGC develops the headworks and main canals and the farmers must develop the secondary and tertiary systems themselves and must pay for ongoing maintenance. However, as stated earlier the majority of maintenance fees are not collected. As such, this approach rarely works, many schemes fail to irrigate the area for which the headwork's and main canals were designed, the farmers not having the resources (financial, technical, social etc) to undertake the works and the schemes rapidly fall into disrepair. Other issues such as disputes about water sharing also arise.

International literature indicates that the success of irrigation schemes in a development context is affected by physical design factors, social factors such as human capital and economic factors such as markets and labour availability. Irrigation development that does not pay close attention to the local biophysical, social and economic patterns, and does not seek to adjust design and management to suit these local patterns are at grave risk of failing to meet their development objectives. A one size fits all approach based on textbook engineering has the most risk of failure. As can be seen from the above, the performance of current irrigation systems needs to be improved and there is the opportunity for influencing the large RGC investment in future irrigation systems.

The results from irrigation development in Cambodia have a large degree of variability. Some parts of Cambodia that have reliable irrigation supply can develop their rice cropping to two or three crops per year and also diversify into other crops and improve their livestock production. For example, in an irrigation project in the south of Takeo province, rice yields from two dry season crops total 10-12 t/ha. This successful example of irrigation increasing productivity in southern Takeo has only been possible due to a coming together of key factors such as: a reliable irrigation water source, functioning main canal system, private sector water delivery to secondary and tertiary delivery systems, adequate revenue raising for management and maintenance of the system by the Farmer Water User Committee (FWUC) and adoption of 'intensive' rice farming and the farming community is willing to adopt a high input: high output approach (Vathana et al, 2009).

It can be argued that irrigation is playing its role in developing Cambodia as total rice production has increased from 2.2 million tonnes in 1992 to 4.2 million tonnes in 2004 and then to 8.2 million tonnes in 2010 (FAOSTAT, 2012). Investigating the national level data however shows that the increase in rice production between 1992 and 2004 is due to a doubling of wet season yield from 1.0 to 2.3 t/ha and an increase in wet season planted area of 0.54 million ha. Wet season rice was responsible for 80% of production in 2004. In 2004 it was estimated that only 11.5% of the wet season rice was irrigated and as discussed above it appears that wet season irrigation may have little benefit, unless there is a drought. As such there may be an argument that irrigation as currently executed has little effect on 80% of Cambodian rice production. Dry season rice yields in the same period increased from 3.1 to 3.9 t/ha and the planted area increased by 0.16 million ha. The increase in production from 2004 to 2010 appears to be a combination of an increase in irrigation facilities, an expansion of cultivated areas and good rainfall in this period (Vathana et al, 2009). To further increase crop yields in the future, irrigation will play a very critical role. Without a good irrigation system, two main problems will be encountered, firstly abundant water in the wet season resulting in the flooding of farmlands and secondly, little available water in the dry season for late wet season and dry season rice farming (Vathana et al, 2009).

4.1 Irrigation systems and social factors in Cambodia

Improving irrigation systems in Asian countries has been a high priority for the allocation of international aid. These expensive investments have infrequently led to long-term improvement in the operation of irrigation systems in Asia. Lam and Ostrom (2009) examined in a longitudinal survey the process and impact of an innovative irrigation assistance project that was initially undertaken in Nepal in the mid-1980s. Using Qualitative Comparative Analysis they found that investments in system infrastructure were only one factor that helped to generate short-term improvement. Unless farmers encourage local entrepreneurs and organize themselves, create their own rules or use sanctions, and augment their rules through collective action, infrastructure investment alone is not sufficient to achieve sustainable higher performance.

This leads us to consider the human element and it's interaction with the irrigation scheme. The farmer-managed irrigation systems of Nepal are examples of schemes that rely on strong local rules and social norms. Because the rules and norms that make an irrigation system operate well are not visible to external observers, efforts governments and donors that seek to replace primitive, farmer-constructed systems with newly constructed, government owned systems can sometimes even reduce rather than improve irrigation scheme performance (Lam and Ostrom, 2009).

The success of farmer community management and development depends largely on people's participation, however participation in Cambodia is often limited (Kim and Ojendal, 2007). CDRI (2008a) describes people's participation in development in Cambodia as follows … A large body of research literature has been dedicated to understanding why Cambodians do not want to take part in development planning for their community. Participation is a new concept for Cambodians. People in Cambodia also tend to see participation differently to those in the West. In western liberal democracies, "participation" means "involvement in decision making". However, Cambodian citizens have a rather passive definition of participation. According to their study of the progress of decentralization and deconcentration, Rusten et al (2004) observe that local Cambodians interpret "participation" as "to be there and listen". Cambodian people are also more used to "directive from top" (Rusten et al, 2004) – that is, being led rather than participating. Contact with state representatives, except those who are friends, is often perceived as threatening by Cambodians, and therefore should be avoided (Hughes, 2003).

This appears to be a very strong stereotyping of Cambodians, with little empirical evidence. However, accepting that there may be greater difficulties in community co-operation and participation in Cambodia than in some other countries then the relative investment into physical capital and social capital in Cambodia probably needs to be more weighted towards social capital than in other countries.

4.2 Interaction between physical elements of irrigation and sustainable management

The physical elements of an irrigation scheme are important in that they provide technical efficiency, however, how the physical elements are designed and constructed have important implications for subsequent management and the schemes economic and social sustainability.

The FAO Aquastat (2010) Cambodia overview reports that there are around 946 full/partial control irrigation schemes in 2006, covering a total area of 353 600 ha. However, only 176 of these schemes were reported to be fully operational. 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 headworks on some of the schemes. This 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 during the onset of the dry season.

Irrigation area has never been estimated for the physical area that could be irrigated considering land and water resources. However, it could be at least 1 million ha (FAO Aquastat, 2010). The operating schemes can be divided into five main categories as described by the FAO Aquastat (2010) Cambodian country overview report as follows:

1. River lake or stream diversion by gravity. These systems are used for wet season supplementary irrigation and only some dry season 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 system that maybe either above or below ground. These areas also benefit from natural flooding for land preparation; 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. These 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 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 use on a small scale for vegetable production during the dry season. Groundwater abstraction is from shallow tubewells. Groundwater availability is highly variable and depends upon local aquifer properties, monsoon recharge and connectivity to rivers.

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. The Cambodian farming systems have developed in response to varying local biophysical, social and economic conditions. A question that needs to be addressed is whether the unique physical characteristics of potential irrigation sites in Cambodia are taken into account when engineering infrastructure is constructed. Engineering infrastructure which does not fit into the local physical environment is likely to reduce rather than enhance farmers' capability to manage irrigation.

In irrigation physical attributes such as the size of an irrigation system or the characteristics of physical infrastructure have always been treated as important factors affecting irrigation technical performance. Largely as a result of this emphasis constructing or upgrading irrigation engineering infrastructure is perceived as an essential policy tool to improve irrigation performance as exemplified by the RGC Rectangular Strategy. Although large amounts of money have been spent in many instances it has not led to the high levels of irrigation performance expected (Sophal et al, 2010). To understand this apparent anomaly a need exists to understand how engineering infrastructure affects irrigation performance in different socio-economic and biophysical environments across Cambodia (CRDI, 2008a).

For example, do storage based irrigation systems perform better than river diversions? Storage provides a degree of control and stability that is important for agricultural productivity. However, local storage where the local irrigation community can assess the water available for themselves leads to more informed decision making, control more likely for the local community and avoidance of manipulation by government authorities. Thus systems with storage, compared to those with river diversions give local communities more leverage to control water flow so that the implementation of management decisions such as rice areas and rotation of water flows is more viable.

In Cambodia there are many options for water supply for irrigation with often several water sources occurring in the same area, e.g. river diversion, pond/lake storage and groundwater. Should irrigation schemes be designed upon one source or the use of multiple sources be included or encouraged to supplement the irrigation scheme? Whether alternative water sources exist or not affects the degree of dependence of farmers on irrigation systems. The existence of alternative sources of water may make farmers less dependent on the irrigation system, which in turn may lessen their incentive to work to maintain the irrigation scheme. However, if the alternative irrigation source makes the use of water from the irrigation scheme more effective then it may increase their incentive to maintain the irrigation scheme.

5 Challenges ahead for Cambodia

5.1 Food production

One of the main challenges facing many Asian countries is to keep providing sufficient and affordable food for their growing and urbanizing populations. Asia is rapidly urbanizing and more people will shift from being net rice producers to net rice consumers (Pingali et al, 1997). The total number of urban poor is expected to increase. Therefore, a major challenge is not only to produce more rice, but to keep its price low to contribute to livelihood improvement of the urban and rural poor who are net rice purchasers. Since a low rice price depresses the profitability of rice farming, the simultaneous challenge is to decrease the cost of rice production (per kilogram) so that the profitability of rice farming can increase (Bouman et al, 2007). This increase in rice production has to be accomplished under increasing pressure on land and water resources that threatens the sustainability of the rice production base.

The challenge to produce more food under increasing water scarcity has lead to the notion that crop WP needs to increase (Kinje et al, 2002). The debate on how to increase WP is confounded by different definitions and scale levels of analysis. Merely increasing WP may not solve the dual challenge of increasing food production and saving water (Bouman, 2007). Bouman (2007) has developed a conceptual framework for the improvement of crop WP at different spatial scales. It is a systematic framework built on generic principles for the analysis of WP to identify interventions that can contribute to the dual goal of increasing food production and saving water. These principles can be applied to the improvement of genetic resources and to the improvement of natural resource management.

5.2 Water Scarcity

While Cambodia may be abundant with fresh water during the wet season, it is a vastly different story in the dry season. In principle, water is always scarce in the dry season when the lack of sufficient rainfall makes cropping difficult without supplementary irrigation. Overall, increasing water scarcity can lead to crop diversification and less flooded conditions in rice fields where water is becoming scarce (Bouman et al, 2007). Around the world, water for agriculture is becoming increasingly scarce as competition from other sectors such as urban and industrial users increases and Cambodia will be not be exempt from this.

6 Responses needed to address challenges

Tilman et al, (2002) suggests a key response option to achieve food security and alleviate poverty is to increase yields and productivity on existing crop land. This has to be completed in a way that avoids environmental degradation, destruction of natural ecosystems, and loss of biodiversity that are associated with an expansion of any cropped area. Hossain and Fischer, (1995) recognise that for many poor farming households, increasing rice productivity is often the first step out of poverty as it provides food security and frees up land and labour resources. If more rice can be produced on less land, some of the farm land can be taken out of rice production and converted into more profitable cash crops. Increased income can be used to invest in the education of children, which is a potential pathway out of farming and poverty. Bouman et al, (2007) highlights that with increased yield and increased total production and current management practices, more water will be needed to meet the increased transpiration requirements. Therefore the productivity of rice needs to increase. To increase the productivity of rice, various options exist for varietal improvement and for better management practices of which water saving technologies are an integral part of (Bouman et al, 2007).

6.1 Varietal improvement

Significant yield improvement (up to 30% higher yields than other types of inbred rice) has recently come only from the development of hybrid rice varieties and is a key technology that meets the increasing global demand for rice (IRRI, 2012). Traditional breeding programs around the world for irrigated environments have typically been selected under conditions of continuously ponded water. With increasing water scarcity projected in future years, breeding programs should include selection under conditions of water saving technologies such as alternate wetting and drying (AWD) (Bouman et al, 2007).

6.2 Improved management practices

An example of technology that aims to close the gap between actual yield and potential yield using a holistic approach is the system of rice intensification (SRI) (Stoop et al, 2002) and site specific nutrient management (Doberman, et al, 2002). The components or elements that constitute SRI practice are: (1) transplanting an 8–15- day-old rice plant within 15–30 min of uprooting at wider spacing than usual; (2) reducing the use of inorganic fertilizer and increasing the use of organic matter; (3) using a mechanical weeder instead of herbicide; and (4) avoiding the usual practice of flooding of rice fields and reducing the amount of water used in the paddy cultivation process (Namara et al, 2007). However, SRI has relatively high labour requirements and this could be discouraging for producers to adopt the SRI system (Bouman et al, 2007).

Some proponents claim that SRI will revolutionise the method of rice production, while others see it as a fad (Namara et al, 2007). For instance, in Thailand and Laos, the SRI effect has not been seen as dramatically as in other countries such as Cambodia and Philippines (Namara et al, 2007). Namara et al (2007) report studies in Cambodia that increase rice yields up to 40 % and an increase in net benefit of 74% by adopting the SRI approach.

6.3 Water saving technologies

There are various water saving technologies that exist or are currently being developed to assist producers to cope with water scarcity in irrigated agriculture (Humphreys et al, 2005) (Yadav et al, 2011). The aim of these water saving technologies is to increase the productivity of total water inputs (primarily irrigation and rainfall) by reducing seepage and percolation losses and to a lesser extent by reducing evaporation (Belder et al, 2004; Bouman et al, 2005). Water saving technologies include: soil amelioration (puddling and compaction techniques), reducing the time between wet land preparation and transplanting, saturated soil culture and alternate wetting and drying water management. Saturated soil culture (SSC) and alternate wetting and drying (AWD) will be discussed in more detail below as these two water management approaches are gaining wide acceptance in Southern Asia.

As the name suggests, in SSC the soil is kept as close to saturation where possible. This approach has the effect of reducing the hydraulic head of the ponded water, which in turn decreases seepage and percolation losses. SSC when practiced aims to provide a shallow irrigation to obtain approximately 1cm ponded water depth a day or so after the disappearance of ponded water. Bouman and Tuong (2001) compiled a database on SSC and AWD from IRRI experiments and those reported in the literature. They found that water input decreased on average by 23% from the continuously flooded treatments with a non significant yield reduction of 6%. A study conducted in southern New South Wales, Australia by Thompson (1999) reported that SSC reduced both irrigation water input and yield by 10%, thus maintaining the irrigation water productivity. The main disadvantage of implementing SSC is that it requires good water control at the field level and frequent shallow irrigations that are labour intensive (Bouman, 2001).

In AWD, irrigation water is applied to obtain flooded conditions (typically 2-5cm) after a certain number of days after the disappearance of ponded floodwater. The large irrigation water savings in all AWD irrigation can be significant (15-40%) and is reported in numerous studies (Humphreys et al, 2010; Yadav et al, 2011). However, this is often at the expense of decreased yield. Whilst some studies report a yield increase under AWD (Zhang and Song, 1989), this appears to be the exception with the majority of studies reporting yield losses (Belder et al, 2004; Cabangon et al, 2004; Bouman and Tuong et al, 2001). In these studies, yield losses were predominately smaller than the reductions in water input and therefore water productivities actually increased. Tuong (2005) suggested that irrigation should be based on a threshold soil water potential at 10 cm depth of 20 kPa, instead of the number of days without ponded water. A recent study conducted by Yadav et al (2011) reported that dry seeded rice with the 20 kPa threshold outperformed puddled transplanted rice with the 20 kPa threshold in terms of maintaining yield (in comparison with continuously flooded rice) whilst reducing irrigation input by 30-50%. AWD is a mature technology that can have considerable benefits in lowland rice production in Cambodia.

7 Discussion

It is apparent that Cambodia lags behind its Asian neighbours both in terms of physical productivity and water productivity by up to 50%. Studies suggest that irrigation of wet season rice is of marginal benefit and perhaps can be better considered as an 'insurance' type of approach against crop failure in drier years or a dry finish. The returns from wet season rice are low, typified by a low input: low output approach. Therefore, farmers will not be willing to contribute for wet season irrigation if they do not perceive a clear benefit. Unfortunately, this type of approach can lead to problems in management and maintenance as the irrigation system for wet season rice is not considered critical by farmers.

Water management in wet season rice in Cambodia is problematic as it is difficult to implement good water management practices when there is an oversupply of water through rainfall events over the majority of the season. From this perspective, there appears to be great opportunities to grow higher yielding rice in the dry season, supplemented with good water management practices, provided that the water is available from the supply network. An increase in irrigation activity will place additional pressure on existing water resources and it is imperative that we can measure the crop water requirements of rice, so that the water resource can be managed appropriately and to make the most efficient use of the available water resource. Measuring the crop water requirement of rice using different approaches will be the focus of the 2nd half of this report.

The major causes of low productivity of rice in Cambodia can be attributed to the low use of high yielding varieties, poor management practices, periodic drought and low application of fertilisers. The inability to manage water flows is likely the most serious constraint on agricultural productivity in Cambodia due to the considerable variability in rainfall. Irrigation is a mechanism for increasing agricultural production and hence increasing incomes of the rural poor and developing the national economy. In Cambodia, dry season rice farming constitutes only about 20 percent of total rice cultivation even though the yields per ha are higher. Average rice yield in 2010 was 2.76 tonnes per ha in the wet season, compared to 4.2 tonnes per ha in the dry season. As farming in Cambodia is historically dependent on rainfall, the majority of lowland farmers grow just one crop a year.

The results from irrigation development in Cambodia have a large degree of variability. Some parts of Cambodia that have reliable irrigation supply can develop their rice cropping to two or three crops per year and also diversify into other crops and improve their livestock production. Studies have demonstrated higher efficiency in schemes with active and strict water management, combined with a high degree of monitoring and evaluation of water allocation. This is essential to utilise water efficiently to meet agricultural demand and to have sufficient water to expand cultivation areas whilst avoiding shortages.

There is huge potential for Cambodia to increase its physical rice and water productivity. Increased productivity can be achieved by adoption of higher yielding varieties, increased use of fertilisers, improving management practices (such as AWD) and expansion of dry season irrigated farming. Obviously the last point will depend on the infrastructure available and the ability to capture and store water from the wet season. MOWRAM and MAFF are working to increase investment in irrigation and research to promote agricultural production for poverty reduction. MOWRAM has shown a strong commitment to increase the irrigated area in Cambodia by 20 000 ha/year. Increasing investment in irrigation to increase rice production and encourage agricultural diversification for food security and higher value-added crops is essential for Cambodia's future prospects.

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Section 2: Water use measurement using direct and indirect methods on a dry season rice crop

9 Introduction

Irrigation in Cambodia is mainly used for dry season rice, where yields are typically higher and is supported by the strong commitment of the Cambodian government to increase the irrigated area by 20,000 ha/year. Increased irrigation activity will place additional pressure on existing water resources. Therefore, it is important that we can measure crop water requirements, particularly of rice, to ensure we make the most efficient use of the available water resource and that it is managed appropriately. Measuring the crop water requirement of rice using different approaches will be the focus of the 2^{nd} half of this report.

Daily crop evapotranspiration (ET_c) was measured using direct (lysimeters) and indirect methods (Bowen ratio and ASCE short approach) on a dry season rice crop in 2012 at the Cambodian Agricultural Research and Development Institute (CARDI). Using lysimeters, the water balance can be broken down into the individual components. A Bowen ratio approach can be automated and provides a more representative measurement of the whole field through non destructive sampling. The ASCE short approach (ASCE-EWRI, 2005), also known as the FAO 56 Penman-Monteith method (Allen et al, 1998), is the most widely used and recommended method for indirect calculation of ET_c derived from commonly available weather data and crop coefficients.

For each method, two measures of water productivity (kg/m^3) were computed: input water productivity (WP_{IR}) – the ratio of grain yield to amount of irrigation water plus rainfall and: evapotranspiration water productivity (WP_{ET}) – the ratio of grain yield to crop evapotranspiration. Measuring irrigation water application is also a basic prerequisite for determining water use productivity. In order to expand the ability to benchmark water use productivity across provinces and districts at a wider scale there is a need for low cost relatively accurate water measuring devices, such as low cost PVC circular flumes.

One of the objectives of this project is to determine rice water use requirements across provinces and districts in Cambodia. To accomplish this, an automatic weather station (AWS) network setup within the project will provide wide scale crop evapotranspiration measurements and the circular flumes will allow irrigation application and runoff to be measured cost effectively across larger areas. It is envisaged that this methodology can be used to define water needs and water availability to maximise production.

10 Materials and methods

10.1 Experimental site

The study was undertaken in a paddy field at CARDI (11.4764^o, 104.8114^o) located approximately 20 km SW from Phnom Penh. Phnom Penh has a tropical wet and dry climate. Average annual rainfall is approximately 1400 mm. The field has an area of 2650 m^2 at an altitude of 10m. The soil type was classified as a limoneux sable (loamy sand) with general soil data described in Table 2. The rice variety Chulsa was initially developed for rainfed lowland conditions. It is an early maturing variety (100 days) and has been used by CARDI since 1999. In this study, it was used as a dry season variety and was sown on the 20th January 2012 using a drum seeder.

Table 2: Soil data at the CARDI experimental field.

Loamy sand			
General soil data		**Additional soil data for rice calculations**	
Total available soil moisture (FC-WP) (mm/m)	70	Drainable porosity (SAT-FC) (%)	30
Maximum infiltration rate (mm/day)	77	Critical depletion for puddling cracking (fraction)	0.4
Maximum rooting depth (cm)	900	Maximum water depth (mm)	200
Initial soil moisture depletion (%)	0	Percolation rate (below 2m) (mm/day)	1

10.2 Experimental layout and treatments

Two replicates of small, non-weighing lysimeters were installed within a paddy field at CARDI on the 23rd January 2012 (one at the western end and one at the eastern end of the field). A lysimeter is a device which can be used to measure the amount of evapotranspiration by a crop. By observing the amount of rainfall and the amount of water lost through the soil, the amount of evapotranspiration and percolation can be calculated. Each replicate consisted of an evapotranspiration (ET), evaporation (E) and a percolation (P) pan. The dimensions of each pan are as follows, ET pan: 80 cm (W) * 80 cm (L) * 80 cm (D), E pan: 50 cm (W) * 50 cm (L) * 20 cm (D) and P pan: 30 cm (W) * 20 cm (L) * 10 cm (D). The experimental layout is shown in Figure 2. Bowen ratio instrumentation was also installed on the same day in the paddy field. The installation of the lysimeters and Bowen ratio will allow rice water use to be calculated both directly and indirectly.

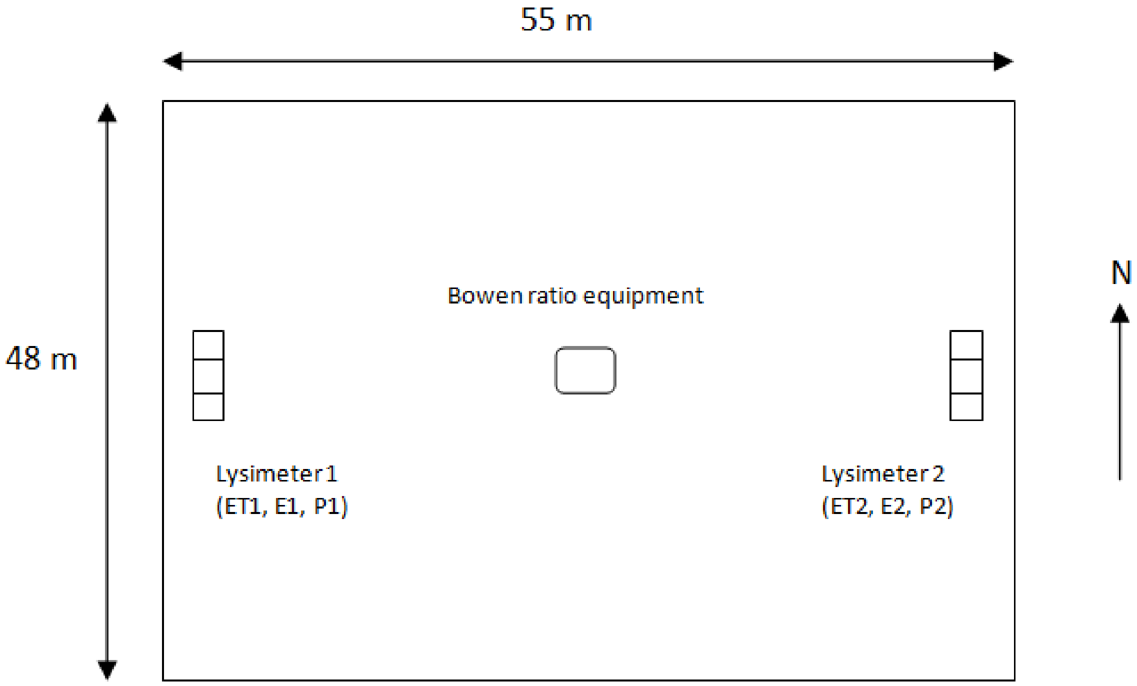

Figure 2: Experimental layout at CARDI field

10.3 Calculating crop water requirement

10.3.1 INDIRECT METHOD – BOWEN RATIO AND ASCE METHOD

The Bowen ratio approach is a practical and generally reliable micrometeorological method for calculating crop water requirement. The Bowen ratio system produces 30 minute estimates of the vertical fluxes of sensible and latent heat in the surface layer above the evaporating surface. Flux estimates are calculated from observations of net radiation, soil surface heat flux and the vertical gradients of temperature and relative humidity. This approach works very well when soil water is not limiting evapotranspiration (Angus and Watts, 1984). Figure 3 shows the installation of the Bowen ratio instrumentation in the paddy field.

Figure 3: Installation of the Bowen ratio instrumentation on the 23rd January 2012.

The ASCE method is one form of the standardized reference evapotranspiration equation for calculating reference evapotranspiration, and in turn using appropriate crop factors, crop evapotranspiration. It is represented by the following formulae.

$$ET_{sz} = \frac{0.408\,\Delta\,(R_n - G) + \gamma \frac{C_n}{T + 273} u_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + C_d\,u_2)}$$

The calculation of ET_{sz} requires measurements or estimates for air temperature, humidity, solar radiation and wind speed, and are the minimum requirements to estimate ET_{sz}. However, the accuracy of any evapotranspiration calculation depends on the quality of the weather data, which typically requires good quality control and quality assurance procedures. We have used the ASCE short approach to calculate ET_c.

10.3.2 DIRECT METHOD – LYSIMETER

At the two chosen locations, an evapotranspiration, evaporation and percolation pan were installed to directly measure crop water use. The evapotranspiration pan (bottom sealed) was buried to a depth of 60 cm and subsequently refilled with soil (60 cm) to allow for crop growth with rice seed sown inside this pan. The percolation pan (bottom unsealed) was simply pushed into the paddy soil 5 cm and sown with rice seed. The evaporation pan (bottom sealed) was buried to a depth of 5 cm and subsequently refilled with soil (5 cm). In each pan there was a water level sensor recording at 30 minute intervals. Manual measurements were also taken 2-3 times per week. The water balance components are defined by the subtraction of the water level change in each pan as described in Table 3. Lateral seepage was assumed to be minimal as the surrounding bays were also irrigated. The installed pans are shown in Figure 4.

Table 3: Water balance components as defined by measuring apparatus.

	Measuring apparatus	Water balance component	Unit
A	Percolation pan	E+T+R+P	mm
B	Evapotranspiration pan	E+T+R	mm
C	Evaporation pan	E+R	mm
D	Rainfall	R	mm
E	Irrigation	I	mm

Where Evaporation (E) = C-D
Transpiration (T) = B-C
Percolation (P) = A-B
Rainfall (R) = D
Irrigation (I) = I

Figure 4: Installation of the percolation, evapotranspiration and evaporation pan.

10.4 Crop management

The field was pre-irrigated and puddled to a depth of 30 cm prior to planting. Rice (Chulsa) was sown in the field on the 20th January 2012 using a drum seeder at a rate of 80 kg/ha. Rice was also sown inside the evapotranspiration and percolation pan on a pro rata area calculation on this same day. As a result of trampling from installing the lysimeter pans and Bowen ratio equipment, rice was transplanted around this equipment approximately 3 weeks after initial sowing.

Basal fertilizer was applied 3 days after sowing, followed by three top dressings on the 10th Feb, 1st Mar and 19th Mar. The last topdressing was a special application not normally done to counter the effect of pest attack. Broadleaf weeds were controlled by an application of the herbicide 2,4-D and pests (brown plant hopper) were controlled by two applications of pesticides. A summary of the crop management is provided in Table 4. The paddy field was uneven after puddling and this resulted in the weed problem and poor germination of seed in a raised area where water was not available. Planking or leveling of the field would help alleviate this problem. The field and lysimeters were harvested on the 30th April 2012.

Table 4: Crop management summary

ACTIVITY	WHEN	WHO
Collected pre broadcasting soil samples	16 Jan 12	CARDI team
1st Land preparation(Plot size: 48m x 55m)	16 Jan 12	CARDI team
2nd Land preparation and broadcasting using drum seeder	20 Jan 12	CARDI team
Set up tools for measuring water data	23 Jan 12	ITC
Applied basal fertilizer (Urea=6.2kg/plot, DAP=12.4kg/plot, KCl=12.4kg/plot)	23 Jan 12	CARDI team
Golden snail attack	24 Jan 12	CARDI team
Spayed herbicide 2,4 D	06 Feb 12	CARDI team
Applied 1st top dress fertilizer (Urea=6.7kg/plot)	10 Feb 12	CARDI team
Re-planting the missing hills	19-24 Feb 12	CARDI team
Applied 2nd top dress fertilizer (Urea=6.7kg/plot)	01 Mar 12	CARDI team
Sprayed pesticide to control BPH by using Hopsan	06 Mar 12	CARDI team
Sprayed pesticide to control BPH by using Cyperian	15 Mar 12	CARDI team
Applied 3rd top dress fertilizer (Urea=6.7kg/plot)	19 Mar 12	CARDI team
Observed 50% Flowering	30 Mar 12	CARDI team
Counted panicles number (no./0.25m^2)	05 Apr 12	CARDI team
Received heavy rain	03 Apr 12	CARDI team
Measured plant height	16 Apr 12	CARDI team
Harvested the whole area	18 May 12	CARDI team
Collected post harvesting soil samples	19 May 12	CARDI team

10.5 Irrigation management

Irrigation water supply to the paddy field was pumped from an irrigation canal at CARDI through an underground pipe network. Water discharges from the outlet pipe were measured using a "bucket" approach in order to estimate the irrigation amount applied each time. The irrigation interval was determined by the remaining water depth in the field and was generally between 5 and 7 days. When there was sufficient rainfall (12 events over the growing season), irrigation water was not applied. Water was also applied to the pans every 5 – 7 days depending on the weather conditions. When adding water to the pans, the measurement before and after filling was noted as a backup to the water level sensors located in each pan.

10.6 Crop growth and yield

The measurement of crop height in the lysimeters and field was conducted weekly. Photographs of the lysimeters and field were also taken weekly to observe rice development stages.

10.7 Water productivity

Two measures of water productivity (kg/m^3) were computed: input water productivity (WP_{IR}) – the ratio of grain yield to amount of irrigation water plus rainfall and: evapotranspiration water productivity (WP_{ET}) – the ratio of grain yield to crop evapotranspiration.

10.8 Weather

Meteorological data were collected from the Bowen ratio equipment and were used to calculate the crop evapotranspiration over the paddy field. It was also used to calculate potential evapotranspiration (ET_o) using the ASCE short approach. Rainfall was also measured at the CARDI experimental field.

11 Results

11.1 Weather

The CARDI experimental station experiences a tropical wet and dry climate. The climate is warm to hot all year round with only minor variation (Table 5). It has two distinct seasons. The rainy season, which runs from May to October due to southwest monsoons blowing inland moisture-laden winds from the Gulf of Thailand and Indian Ocean, can see temperatures rise up to 40^{o} C and is generally accompanied with high humidity. The northeast monsoon ushers in the dry season from November to April when temperatures can drop to 22^{o} C. The area generally experiences the heaviest precipitation from September to October with the driest period occurring January to February.

Table 5: Climatic data from Pochentong station (May 2011 - April 2012)

Month	Min Temp °C	Max Temp °C	Humidity %	Wind m/s	Sun hours	ETo mm/day
January	23.5	31.5	73	2.5	6.4	4.25
February	24.1	32.6	74	2.3	8.2	4.86
March	25	34.4	72	2.7	8.3	5.60
April	25.6	35.3	74	2.9	7.9	5.74
May	25.6	34.6	77	2.7	6.9	5.12
June	25.5	33.8	78	2.9	6.3	4.90
July	24.9	33.4	80	2.9	6.2	4.70
August	24.9	32.7	82	2.6	5.9	4.44
September	24.8	31.8	83	2.8	4.4	3.91
October	25	31.6	84	2.6	6	4.01
November	24.7	31.7	78	3.5	8.3	4.67
December	22.5	30.5	73	3.8	7.5	4.58
Average	24.7	32.8	77	2.9	6.9	4.73

11.2 Establishment and growth

Generally, establishment was quite good. However, there were issues with the field not being level which resulted in a weed burden (due to poor water control) and patches of poor or no germination in a high area of the paddy field where water was not available. In the early vegetative stage, there was an outbreak of golden snail which was controlled by removing them from the paddy field. Crop height data from the lysimeters and paddy field are presented in Table 6. Photos depicting initial, crop development, mid and late season growth stages are presented in Figures 5-8.

Table 6: Crop height measurements in the lysimeters and paddy field. (P = percolation pan and ET = evapotranspiration pan at either lysimeter 1 or 2).

Date	Location	Crop height (cm)					MEAN
		1	2	3	4	5	
20/2/2012 (developing stage)	P1	21	21	_	_	_	21
	ET1	24	24	25	26	23	24.4
	P2	24	24	_	_	_	24
	ET2	26	25	29	28	25	26.6
	FIELD	23	23	28	23	25	24.4
6/3/2012 (developing stage)	P1	35	41	_	_	_	38
	ET1	35	40	37	41	39	38.4
	P2	35	41	_	_	_	38
	ET2	43	36	46	49	42	43.2
	FIELD	39	30	40	40	37	37.2
22/3/2012 (mid-season stage)	P1	48	50	_	_	_	49
	ET1	48	52	50	53	50	50.6
	P2	48	50	_	_	_	49
	ET2	53	53	53	54	53	53.2
	FIELD	52	42	50	52	52	49.6
6/4/2012 (mid-season stage)	P1	72	68	_	_	_	70
	ET1	64	68	67	63	65	65.4
	P2	70	70	_	_	_	70
	ET2	73	70	70	72	70	71
	FIELD	70	63	70	68	73	68.8

Figure 5: Rice in initial growth stage.

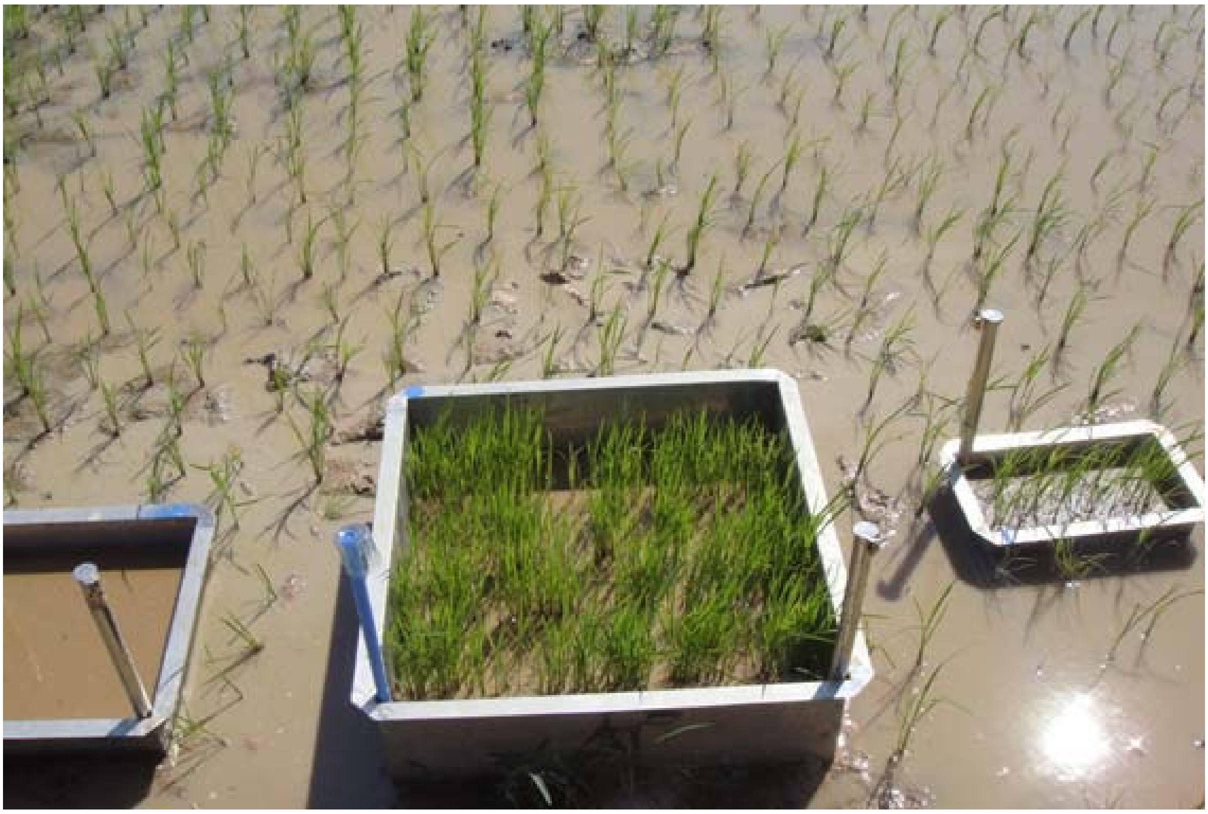

Figure 6: Rice in crop development growth stage

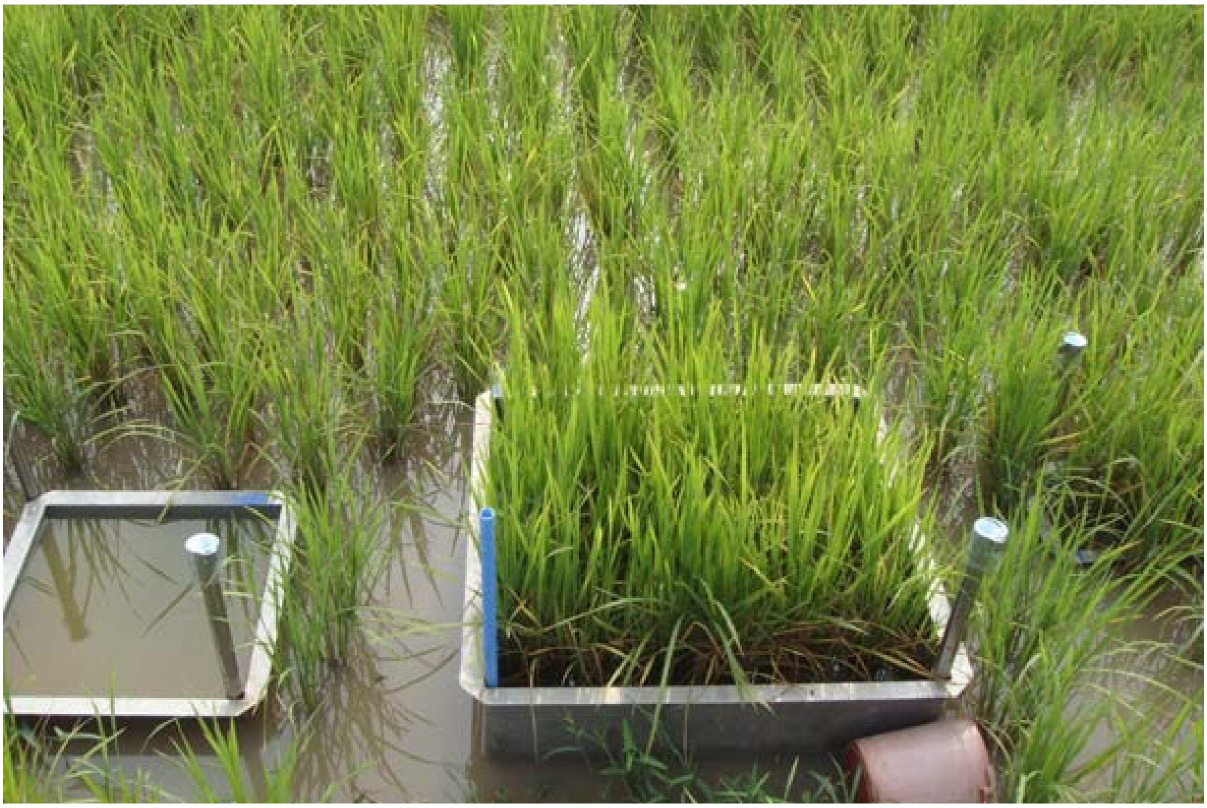

Figure 7: Rice in mid season growth stage

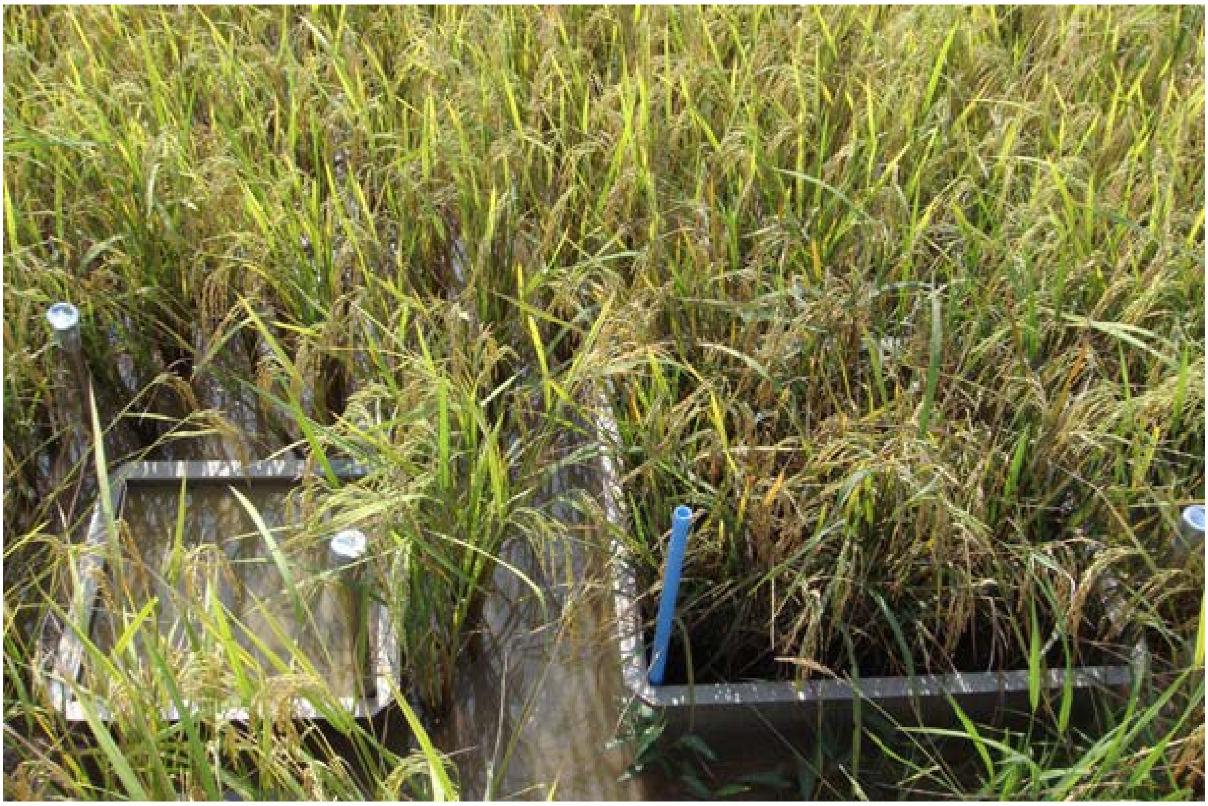

Figure 8: Rice in late season growth stage

11.3 Yield components and yield

The rice in the experimental paddy field was harvested on 30th April 2012 at 5 locations of 9 m^2 at the four corners and the middle of the paddy field. The yield breakdown is presented in Table 7.

Table 7: Dry straw, dry grain yield and harvest index (HI) from paddy field.

Sample	Straw (t/ha)	Yield (t/ha)	HI
1	4.44	2.86	0.39
2	4.78	3.51	0.43
3	4.22	2.76	0.40
4	5.00	3.58	0.42
5	5.33	3.46	0.39
Average	4.75	3.23	0.40

11.4 Crop water requirement

Even though the crop was sown on the 20th January 2012 and harvested on the 30th April, the Bowen ratio equipment was only operational between the 1st February 2012 and the 24th April 2012 and this is the period that will be used for all upcoming analysis.

11.4.1 INDIRECT METHOD – BOWEN RATIO AND ASCE METHOD

Figure 9 represents data of daily crop evapotranspiration (ET_c) using the ASCE short formulae and the ET_c directly measured from the Bowen ratio instrumentation. The ET_c estimated from the ASCE short methodology (using various crop coefficient (K_c) values for each development stage) was 466 mm, whilst the ET_c from the Bowen ratio was very similar at 475 mm. The average K_c value, when applied throughout the growing season, was calculated to be 1.12.

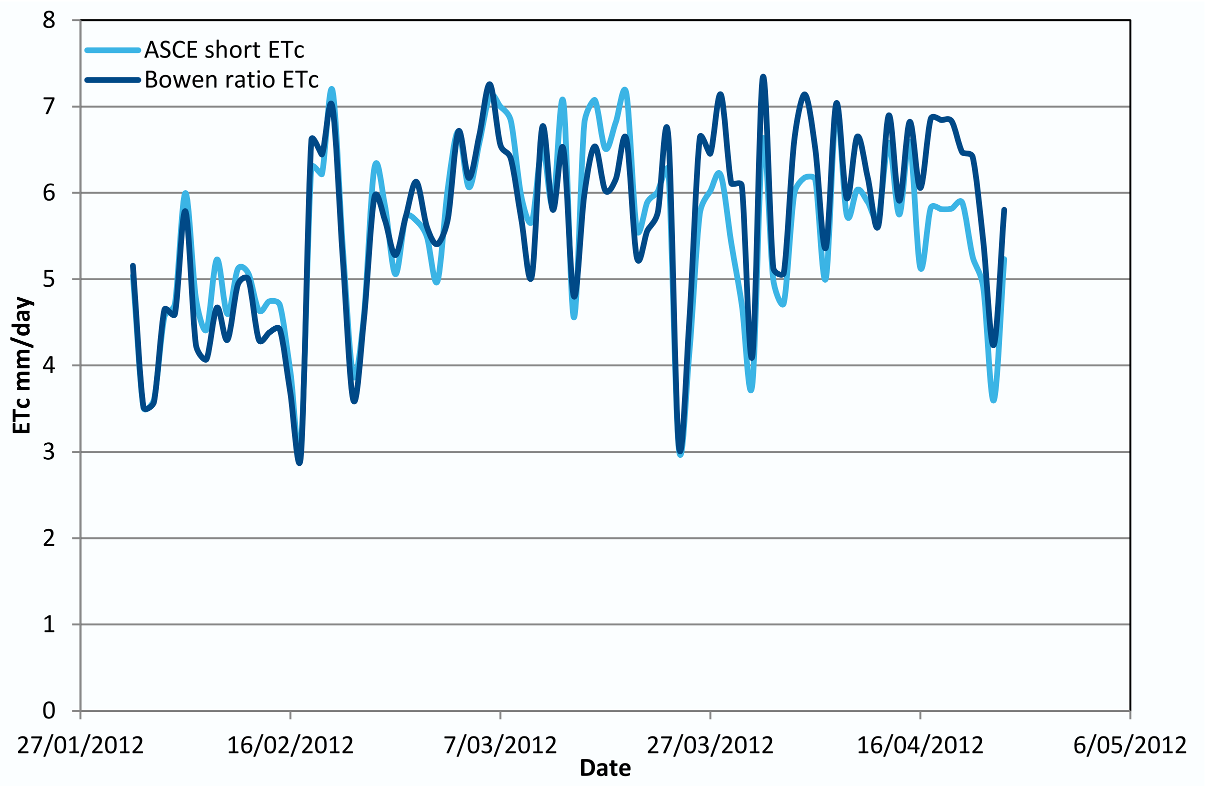

Figure 9: Daily crop evapotranspiration (ET_c) using Bowen ratio and ASCE short approach for the period 1-Feb to 24 April 2012.

11.4.2 DIRECT METHOD – LYSIMETER

In lysimeter one, 16 irrigations were added to the evapotranspiration pan (ET1), 13 irrigations to the evaporation pan (E1) and 15 irrigations to the percolation pan (P1). In lysimeter 2, 16 irrigations were added to the evapotranspiration pan (ET2), 14 irrigations to the evaporation pan (E2) and 14 irrigations to the percolation pan (P2). Rainfall was recorded 12 times over the growing season totaling 166 mm. Total irrigation and rainfall to lysimeter 1 and 2 were 640 and 573 mm respectively. Total percolation losses were estimated at 113 mm and 102 mm for lysimeter 1 and 2 respectively. A total of eight irrigations (432 mm) were applied to the paddy field of which the first two (91 and 131 mm) were applied for land preparation purposes. Total water applied (irrigation plus rainfall) to the paddy field was 598 mm. Figures 10 and 11 depict the ET_c measured from the two evapotranspiration pans after conversion and correction from the 30 minute readings of the water level sensor to a daily basis.

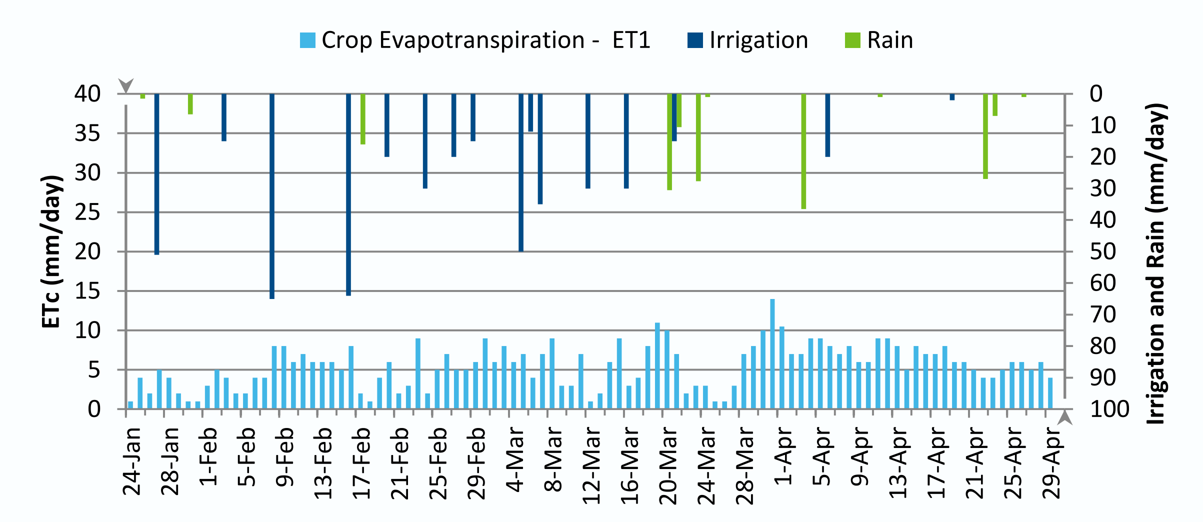

Figure 10: Daily values of ET_c, irrigation and rain from lysimeter 1.

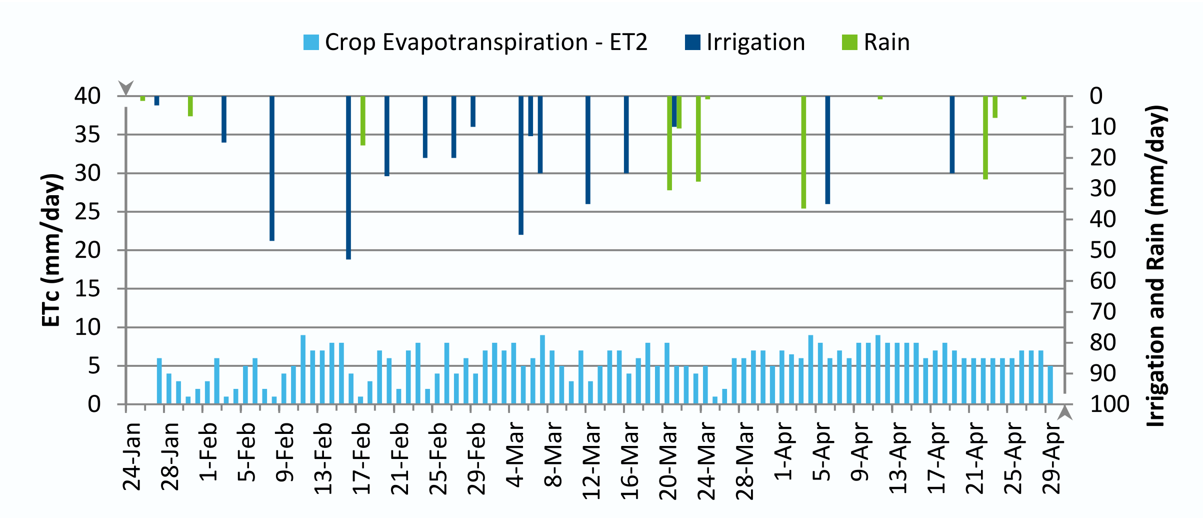

Figure 11: Daily values of ET_c, irrigation and rain from lysimeter 2

The ET_c measured from lysimeter 1 was 491 mm, whilst the ET_c from lysimeter 2 was very similar at 489 mm (average 490 mm) over the analysis period (1-Feb to 24th April 2012). These numbers are comparable to the Bowen ratio and ASCE approach (475 and 466 mm respectively). Cumulative values of for each month and each approach are presented in Table 8:

Table 8: Cumulative values of ET_c for both indirect and direct approaches over the period 1-Feb to 24th April 2012.

Month	ACSE (indirect)	Bowen ratio (indirect)	Lysimeter 1 (direct)	Lysimeter 2 (direct)
	ET_c (mm/month)	ET_c (mm/month)	ET_c (mm/month)	ET_c (mm/month)
February	145	142	141	140
March	184	184	182	178
April	137	149	168	171
Total	466	475	491	488

It is interesting to note that for the first two months (February and March), both the indirect and direct approaches are tracking very closely and then they slightly diverge in April. One possible explanation is that the evaporation pan and percolation pan were not installed at the same height as the evapotranspiration pan (Figure 4). The maximum level of water in the field was recorded as approximately 240 mm of water depth. It was noted that the evaporation pan and percolation pan were submerged once the water level reached 150 mm water depth due to two large rain events in late March and early April 2012. This has facilitated some evacuation pumping of the paddy field to bring the water level down to the evaporation pan level. This has had important ramifications for the evaporation pan (which is used to calculate ET_c) and has been possibly overestimated during these events. This has lead to a possible overestimation of the ET_c for each lysimeter ranging from 20 – 40mm across the growing season.

11.4.3 WATER PRODUCTIVITY

Water productivity for both direct and indirect approaches is summarized in Table 9. The average yield of 3.23 t/ha from the experimental paddy field has been used in all water productivity calculations.

Table 9: Water productivity of Chulsa using different approaches.

Equipment	Method	Irrigation (mm)	Rain (mm)	ET_c (mm)	WP_{IR} (kg/m^3)	WP_{ET} (kg/m^3)
Lysimeter 1	Direct	474	166	491	0.50	0.66
Lysimeter 2	Direct	407	166	488	0.56	0.66
Bowen ratio	Indirect	432	166	475	0.54	0.68
ASCE	Indirect	432	166	466	0.54	0.69

The input water productivity (WP_{IR}) was very similar across approaches as was the evapotranspiration water productivity (WP_{ET}). Bouman et al, (2007) reports water productivity of rice with respect to total water input, ranges from 0.2 to 1.2 kg/m^3, with 0.4 as the average value. The values reported here fall into this reported range and would be considered above average. In contrast, from the literature review section, Phengphaengsy and Okudaira (2008) report a WP_{IR} of 0.18 in the Cambodian province of Komping Pouy for a dry season rice crop. The primary reason for the much lower water productivity value is that the irrigation requirement was much higher than at the CARDI experimental field, due to the extremely high percolation losses prevalent at the Komping Pouy location.

Crop water use studies continue to be undertaken at the CARDI experimental site with micro-meteorological and lysimetry equipment. This information, along with measured yields will continue to be used to determine rice water use productivity figures for Cambodia. The associated literature review of studies in neighbouring countries (in Section 1 of this report) has also been undertaken and this data used to benchmark CARDI irrigation and nitrogen management practices as shown in Figure 12. Figure 12 indicates that the CARDI recommended practices, when benchmarked against neighbouring countries and practices are relatively good. These results will aid in the development of best practice guidelines for water management in Cambodia.

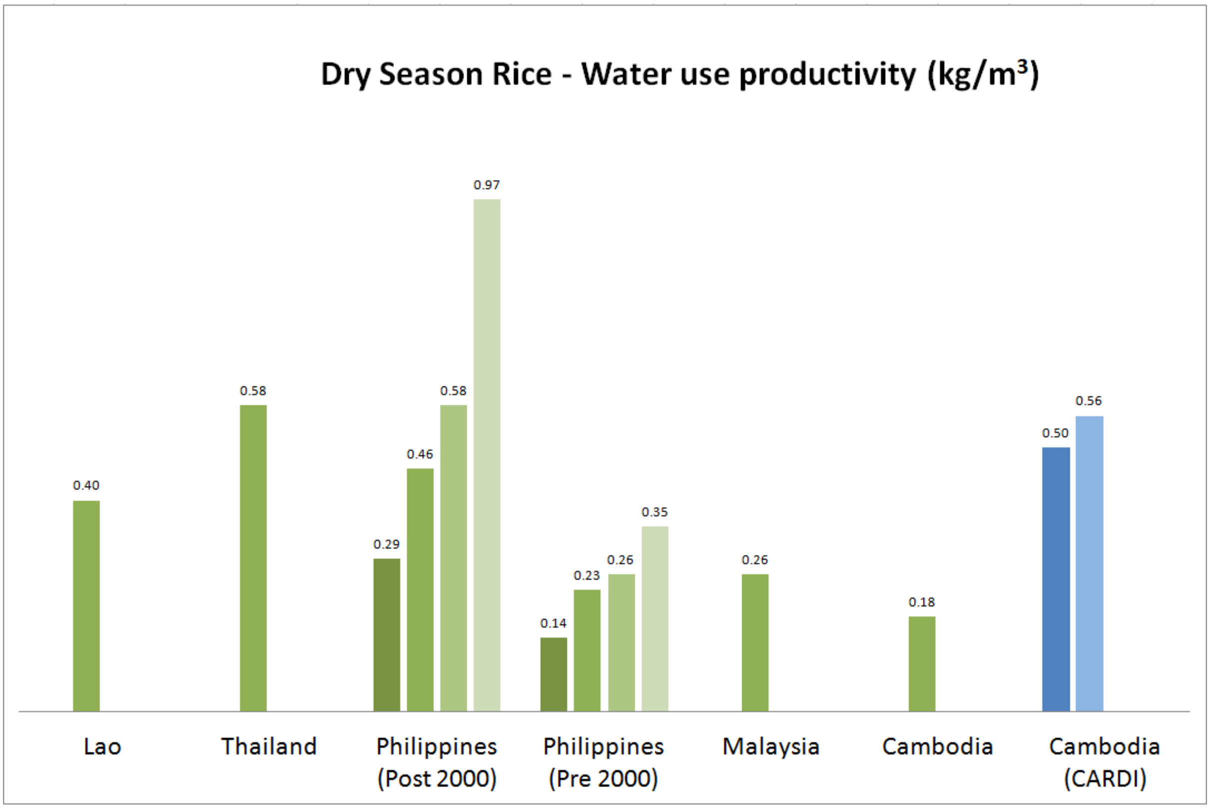

Figure 12: Dry-season water use productivity (WP_{IR}) in Cambodia and surrounding countries

12 Discussion and Conclusions

Crop water use was measured using direct and indirect methods on a dry season rice crop in 2012. Both approaches recorded similar ET_c requirements and water productivity indices. It is postulated that rain events in late March and early April had ramifications on the evaporation pan (which in turn is used in the calculating of ET_c) in that evacuation pumping to remove excess water from the field due to submergence of the pan may have led to an overestimation of pan evaporation, and therefore an overestimation of ET_c.

There are advantages and disadvantages of each approach to measure crop water use. The main advantages of the direct approach through lysimetry are that the equipment is relatively inexpensive and the water balance can be broken down into the individual components. The main disadvantages are that the area under measurement may be quite small and represents a closed environment. Another disadvantage is that the lysimeter itself may heat up resulting in a modified energy balance within the lysimeter, affecting ET_c. The main advantages of the Bowen ratio approach is that it can be automated and provides a more representative measurement of the whole field through non destructive sampling. The main disadvantages are the costs associated with the equipment and the strict monitoring to ensure quality data. Owing to the difficultly experienced sometimes in obtaining accurate field measurements, one of the main advantages of the ASCE short approach in calculating ET_c is that it can be derived from commonly available weather data and crop coefficients. The main disadvantage of this approach is poor quality weather data and incorrect crop coefficient choice. A recommendation for any future experiments using lysimeters is that all the pans have the same surface area to avoid any recording anomalies and that they are all set at the same height in the field.
Measuring irrigation water application is a basic prerequisite for determining water use productivity.
In order to expand the ability to benchmark water use productivity across provinces and districts at a wider scale there is a need for low cost relatively accurate water measuring devices. Low cost devices made of PVC, known as circular flumes, are an appropriate device for measuring water application and water runoff. The flumes are constructed from low cost PVC and allow a simple height measurement to be made which can be directly used to obtain flow rates. The flow rate can then simply be converted to an irrigation water application. One of the main difficulties in determining the components of a water balance is that deep drainage, more often than not, has to be estimated. However, by knowing how much water is applied to a field in an irrigation event and how much water was measured as runoff by using the circular flumes, the difference is the volume that has infiltrated the field. Therefore, deep drainage can be calculated/estimated by the difference between ET_c and the infiltrated volume.

Rice crop water use studies have continued to be undertaken at the CARDI experimental site with micro-meteorology and lysimetry equipment and have allowed researchers to develop a good understanding of dry season rice production and water use productivity at CARDI. The next step is to determine rice water use requirements across provinces and districts in Cambodia. To accomplish this, an AWS network setup within the project will provide wide scale crop evapotranspiration measurements and the circular flumes will allow irrigation application and runoff to be measured cost effectively across larger areas. This data when combined with measured yield data will allow crop water use productivity and deep drainage benchmarks to be established for different hydro-climatic regions and soil types, therefore leading to improved planning capabilities on the use of water resources across the Cambodian provinces. Knowledge of the rice crop water requirements for dry-season and early dry-season rice crops are completely lacking in Cambodia and it is hoped that this methodology can be used to define water needs and water availability to maximise production.

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