Analysis of landscape level environmental variation and on-farm technological adoption for sustainable rice production in three rice ecosystems with contrasting water environments in Cambodia

(カンボジアの水環境の対照的な３つの稲作生態系での持続可能な稲作のための景観レベルの環境変異と農家の技術受容の解析)

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Abstract

Rice yield is generally low (2.7 t ha^{-1} in 2008) in Cambodia. Increase of rice production remains the central focus of Cambodia's agricultural policy for potential export for economic development and for livelihood improvement for rural population. Paddy rice is grown over diverse water environments in Cambodia; (1) irrigation rehabilitation area of those constructed during Pol Pot time, (2) deepwater rice ecosystem in flood plains of Tonle Sap Lake, (3) rainfed lowland rice ecosystem sharing over 80% of Riceland in Cambodia . Rice yield should be increased in every rice ecosystem for food security and better livelihood for farmers. This study focused on (1) heterogeneous water environments within a village or within a landscape of human sight (i.e. defined as "micro-scale" in this thesis) within each of the rice ecosystems, (2) transfer and adoption of technologies available for farmers, and (3) positive externalities (i.e. multifunctional roles) of rice farming such as biodiversity conservation, landscape or cultural values, in order to improve rice yield in sustainable manner.

Analysis on the process of irrigation rehabilitation in Kamping Puoy in Battambang province, Northwest Cambodia, in the consecutive 4 cropping seasons from 2008 wet season rice to 2010 dry season rice revealed standing water depth (e.g. from September to November) much deeper in downstream fields than in upstream fields along the transect of the secondary drainage canals in wet season rice; farmers adapted to plant medium and late maturing varieties (maturity time in December and January) in the former while early and early medium maturing varieties (maturity time in November) in the latter. Water conditions were less different between upstream and downstream fields in dry season rice and with more uniform planting and harvesting time. As the area percentage of fields where dry season rice was introduced increased from 2008 (54%) to 2010 (100%), planting time in wet season rice shifted later (e.g., from May to July) with declining proportion of dry seeding method and mid-season tillage. On-farm grain yields in DSR were low (287 and 247 g m^{-2} in 2009 and 2010 on average, respectively), partly due to insufficient weed control and small amounts of fertilizers. Yields were lowest in fields which practiced dry season rice for the first time, and some improper management practices (such as variety mis-choice, wrong use of insecticides instead of fungicide) were observed, indicating insufficient agriculture extension support to farmers. Grain yield in WSR (286 and 291 g m^{-2} in 2008 and 2009 respectively) could be increased by transplanting, use of high yielding Raing Chey variety, and application of higher amount of N inorganic fertilizer.

Characterization of deepwater rice area in the flood plain of Tonle Sap Lake in Northwest Cambodia along a transect of water depth gradient (from the shallower rainfed lowlands side to the deeper floating rice side) during wet season rice production in 2008, 2009 and 2010 revealed (A) very gentle and almost flat slope (only 40 cm elevation differences in 1 km distance) and 3 groups of rice zones with (1) upper fields located closer to the National Road Number 5 where water depth was shallower and only lowland rice was grown; (2) middle fields where both lowland rice and floating rice were grown and where lowest grain yield was recorded in 2009 due to the flood; and (3) lower fields located near to the Lake where water depth was deeper (average maximum depth more than 150 cm) and only floating rice was grown. (B) Secondly it was also revealed large yearly differences in flood from Tonle Sap Lake; 2008 and 2009 when water came to the paddy fields from both the inundation from Tonle Sap Lake and rainfall and when the presence of continuous standing water started in September, reached maximum in October (> 1 m) and became non-flooded conditions in early December vs. 2010 when flood did not come from the Lake and all the 3 rice zones had less than 30 cm of maximum water depth and when rainfed lowland rice attained higher yield due to higher N fertilizer application rate. The overall average grain yield for both years of 2009 and 2010 was low with only 1.1 t ha^{-1} for floating rice and 1.8 t ha^{-1} for lowland rice. Late sowing and/or lack of basal N fertilizer application resulted in smaller plant stands when flood occurred, resulting in greater flood damage and more crop failure. Limited forecasting ability for water availability (e.g., flood occurrence) for the subsequent cropping season leave large risks for deep water rice production in flood plains of Tonle Sap Lake.

The study showed that grain yield was very low (1.5 t ha^{-1}) in the studied area in rainfed lowland rice in Kompong Chhnang province because farmers planted only local varieties on poor soil fertility with the low rate of inorganic fertilizer (14 kg ha^{-1}). Results of on-station experiments in wet season rice 2009 and 2010 showed that yield was improved by planting improved variety (e.g. Phka Rumdoul) and applying the recommended amount of fertilizer. Yield of Phka Rumduol with fertilizer application could be 60% higher than that of Thmar-Ror-meal (local variety) with fertilizer and more than triple that of Thmar-Ror-meal without fertilizer in 2009. However the efficient level of improved variety and fertilizer was less in wet season rice 2010 because of water deffct. Adoption level of improved variety and fertilizer depends on the availability and popularity of these resources among the farmers. Farmers preferred to grow Phka Rumduol in wet season rice 2010 but the adopted area was not high due to the seed shortage. On the other hand, fertilizer was not highly adopted by farmers in wet season rice 2010 due to unavailability of fertilizer (lack of money to purchase) and farmers' concerns on low benefit return in the drought situation.

Multifunctionalities of the 3 rice ecosystems (irrigated rice, deepwater rice and rainfed lowland rice) in Cambodia were recognized, such as those categorized as (1) livelihood and economic, (2) environment, and (3) social and cultural, at least in local scale among villagers, although the value of each function has not been quantitatively estimated. Bio-resources from paddy fields are important to farmers' livelihood, particularly poor people.

This study shows that (1) water environments are different not only between the rice ecosystems but also within each of the rice ecosystems at micro-scale i.e. between upstream and downstream fields along secondary canals in irrigated rice ecosystem, transect from rainfed lowland side towards the lake in deep water rice ecosystem in flood plains of Tonle Sap Lake, toposequential differences within a village in rainfed lowland ecosystem. The micro-scale variation in water conditions has large influences on farming practices and yield, so the characterization of field water environments is important for technology development and dissemination; (2) insufficient and ineffective usage of agricultural resources (e.g., inorganic N fertilizer, herbicides, fungicides, photoperiod

sensitive variety) caused lower farm level yield than possible attainable level in all the 3 rice ecosystems in Cambodia. In rainfed lowland ecosystem while an improved variety of Phkar Rumduol was rapidly and popularly adopted by farmers but in short of seeds multiplication, adoption of sufficient amount of inorganic fertilizer was hindered by water deficit and influenced by the cost-benefit balance; and (3) multifunctionlaities of rice production were recognized at village or landscape levels such as other biological resources for livelihood, should be up-scaled in order to draw attention of policy makers to attain sustainable rice farming in Cambodia.

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List of Abbreviations

AQIP	Agriculture improvement project
CARDI	Cambodian Agricultural and Rural Development Institute
CMS	Chmar Sar
DAP	Diammonium phosphate
DAT	Days after transplanting
DSR	Dry season rice
DWR	Deepwater rice
EIC	Economic Institute of Cambodia
FAO	Food and Agriculture Organization
FGD	Focus Group Discussion
FR	Floating rice
IR	Irrigated rice
JICA	Japanese International Cooperation Agency
KP	Kamping Pouy
KPIR	Kamping Pouy irrigation rehabilitation
LR	Lowland rice
NT	Noneam Torteung
PRD	Phka Rumduol
RGC	Royal Government of Cambodia
RLR	Rainfed lowland rice
RUR	Rainfed upland rice
TM	Thmar Ror-meal
TSL	Tonle Sap Lake
TY	Thlok Yol
WSR	Wet season rice

Chapter 1

Introduction

About 80 percent of Cambodia's population live in rural area and agriculture is the most important sector employing 71 percent of the country labor force (WB, 2006). Agriculture is more important for the rural poor as it is their most important income source (WB, 2009a). It was reported that the poorest 10 percent of the Cambodian population are rural households which mostly depend on agriculture for their livelihood (Knowles, 2006). Rice is dominant crop in Cambodian agriculture as it is cultivated on about 2.4 million ha occupying 80% of total cultivated area of the country (MAFF, 2006). However, rice yield in Cambodia is generally low (2.7 t ha^{-1} in 2008). It is important to enhance rice productivity in order to improve the farmers' livelihood, especially those rural poor. Moreover, Cambodian government shows its ambition to turn Cambodia into a major rice exporting country in the international market (RCG, 2010). Therefore, increase in rice production has been given the central focus of Cambodia's agricultural policy. A frequently stated aim is to improve Cambodia's average rice yield (2.7 t ha^{-1}) to the levels of its neighbors such as Laos (3.5 t ha^{-1}) and Vietnam (5.2 t ha^{-1}).

Rice is grown over diverse water environments in Cambodia which are grouped into four rice ecosystems: irrigated rice, deepwater rice, rainfed lowland rice and upland rice. Rice yield should be increased in every rice ecosystem for food security and better livelihood for farmers. Among these, the three former are mainly located in the central plain around the Tonle Sap Lake and towards the southeast, while the latter, rainfed upland rice, is grown in the mountainous area with only small proportion of the total rice cultivated area (2.2%) in 2005 (MAFF, 2006). Of the three former, rainfed lowland rice (RLR) occupies the largest proportion of rice cultivation land (80.7%). Those who are living in RLR area are often poor-resource farmers. Small increase in rice yield will contribute to food security and possibly small income for farmers from local market. Irrigated rice (IR) area recently has been expanded by rehabilitating the impaired-old irrigation schemes or constructing new ones. High yield achievement in this rice ecosystem is expected for increasing rice export amount in Cambodia, given that the current trends of relatively high international rice price maintained and good demand for rice from international market continued (IRRI, 2008), and that Cambodian government could establish control system for rice quality and marketing. Deepwater rice (DWR) used to be common in Cambodia as it occupied up to 16% of rice cultivated area (Javier, 1997; Seng et al., 1988). The area decreased due to the discouragement of growing deepwater rice during Pol Pot regime; however, some of the provinces or districts (e.g. Kompong Thom, Banteay Meachey and Battambang) still share large percentage of deepwater rice at present in the flood plain of Tonle Sap Lake. DWR production is unique with its flooding pattern and floating rice varieties and is important source of livelihood to many poor villages that do not have access to better agricultural land.

A number of international organizations such as FAO, JICA, and particularly CARDI and IRRI-Australian groups have done a lot of efforts for rice yield improvement in Cambodia through agricultural development projects. Germplasm collection (mainly rice), soil map making, rice cultivar development, nutrient and pest management, improvement of drought or submergence resistance, increasing crop intensity, crop diversification and farm mechanization are the major approaches for reconstruction and development of rice production systems in the country (Nesbitt, 2001; Fukai, 2006). Cambodia used to face annual rice shortage during 1980's. It became self sufficient rice in 1995 and surplus for rice export contributing to economic growth at present. These achievements are partly contributed by the efforts of the international communities. However, there are still some research areas which have not been fully covered yet, for instance, the heterogeneity of farming environments in each rice ecosystem, technology dissemination, or assessment of multifunctional roles of agriculture for more sustainable development.

There is variation in water availability among paddy fields within a landscape or a village. The size of those area may be 10 ha (ca. 1 km x 100 m) toward one direction, or 100 ha (ca. 1 km x 1 km) forward with the angles of 90 degrees if viewed on the ground level. From a top of a small hill more than 1000 ha of area can be viewed. A typical Cambodian village in RLR may contain 100 ha of rice fields, but often with toposequential variation and landscape is in mosaic of upper rice and lower rice and trees and houses. In flat plains such as large irrigation area or flood plains, one village can contain 500 ha or 1000 ha of rice fields. Real farming environments within those areas would be heterogeneous, but this aspect is not well studied. For example, IR area in developing countries are often without higher branches of canals and without good drainage system, and distribution of water may be different between upstream and downstream of the canals, affecting farm management and rice productivity. In case of DWR, flood patterns around Tonle Sap Lake are known to be different from year to year but without quantitative evidences and without studies on its impact on deep water rice production; the maximum water conditions of a certain rice field in the flood plain of the Tonle Sap Lake could be more than 1 m (regarded as deepwater rice ecosystem) in one year but less than 50 cm (medium to deep rainfed lowland ecosystem) in another year, and large spatial variation in water conditions is expected between shallower points far from Tole Sap Lake and deeper points closer to the Lake. In case of rainfed lowlands, toposequence variation is well-known as a reason to cause for heterogeneity of water availability (Boiling et al., 2008; Tsubo et al., 2009). It is important to characterize water environments within a landscape or within a village, which are important boundary for the farming activities and livelihood for the farmers. We call this as "micro-scale" in this thesis. By doing so improved technologies suitable for each water environment can be selected and introduce to farmers in order to enhance rice productivity more efficiently. The transect survey approach (surveying along line; e.g. Ardales et al. 1996; Van Groenigen et al. 2003; Neumann et al. 2009) can be used to capture the variation in environment conditions (i.e. water, soil, management practices) along the transect.

Technology development and extension are 2 wheels and both are important for enhancing rice production. But it has been long discussed that technology developed in research stations has not been well adopted by farmers (Pandey, 1999; Balasubramanian, 1999; Villano and Pandey, 2000). Example is rainfed agriculture where green revolution benefit was little or smaller. Where environments are heterogeneous, central system (technology developed in research stations to be disseminated to local regions and farmers) is less effective and channels to communicate between researchers and local farmers (i.e. including extension staff) become more important. In Cambodia, agricultural system (both research and extension) was once damaged due to the war and hence capacity of extension service is weak; and that can be a factor for low on-farm yield.

Apart from food and fiber, there are multiple outputs from agriculture which most of them have non-market values. These multiple outputs are referred as multifunctionality of agriculture which include food security, formulation of the landscape, environmental protection, and contribute to the socio-economic viability of rural community (OECD, 2001). Among OECD countries, multifunctionality of agriculture has been discussed in order to balance enhancement of productivity with conservation of environment and promotion (or empowerment) of rural communities to cope with worldwide trends of globalization (Groenfeldt, 2006). In case of Japan, flood prevention, biodiversity conservation (e.g. conservation of ecosystem and living creature, conservation of genetic resources, and protection of wild creature), and landscape promotion are examples of positive role of multifunctionality for rice production (Yamaoka, 2005; Matsuno, 2006) which can be maintained, enhanced or impeded depending largely on management practices applied to the field. Multifunctionality for rice production has been studied in Japan and elsewhere but rarely studied in Southeast Asian countries. Since extreme intensification of rice production has caused environmental and health problems in developing countries (Dung and Spoor, 2007), it is worthwhile to assess multifunctionality in Cambodian rice production, in order to establish sustainable rice farming in the country.

This study aimed at identifying strategies for sustainable rice production in 3 rice ecosystems of irrigated, deepwater and rainfed lowlands. The specific objectives of the study are:

(1) to improve understanding of spatial and temporal variations in water condition and farmers' management practices among paddy fields at micro-scale, and their effects on rice yield in each rice ecosystem in Cambodia;

(2) to assess the effectiveness of using improved varieties and fertilizer on yield enhancement and identify factor limiting farmer's adoption of these technologies in rainfed lowland rice; and

(3) to assess the multifunctionalities or externalities of each rice ecosystem.

There are 3 hypotheses given in this study as below:

(1) There are spatial and temporal variations in water environment at micro-scale within each of the rice ecosystems which affected rice production and caused different technological needs within the same ecosystem.

(2) On-farm grain yield could be low which would be substantially related with insufficient technological options and limited information (i.e. low level of agricultural extension).

(3) Numbers of multifunctionalities will be listed in Cambodia as well, but with much more local importance on biodiversity aspects for livelihood, which would be different from Japan and developed countries.

The thesis structure is presented in Fig. 1. 1. This thesis consists of an introduction (Chapter 1), an overview of rice production at national scale in Cambodia (Chapter 2), micro-scale survey on rice production at 3 key study sites under 3 rice ecosystems; in an irrigation rehabilitation area (Chapter 3), in deep water rice area in flood plain of Tonle Sap Lake (Chapter 4) and in rainfed lowland area (Chapter 5). Farmers' management practices and grain yield of rice in response to different water environments are studied. In Chapter 5, the efficiency of using an improved variety and inorganic fertilizers for yield improvement is also studied including farmer participatory trials and examination of adoption by farmers. Chapter 6 assesses the importance of external roles, services produced from rice farming other than rice grains in the 3 rice ecosystems in Cambodia, which are referred as multifunctionalities. In Chapter 7, the micro-scale water variation within each of the 3 rice ecosystems, the importance of technology transfer for yield improvement and prospects for sustainable rice farming for the 3 rice ecosystems in Cambodia are discussed.

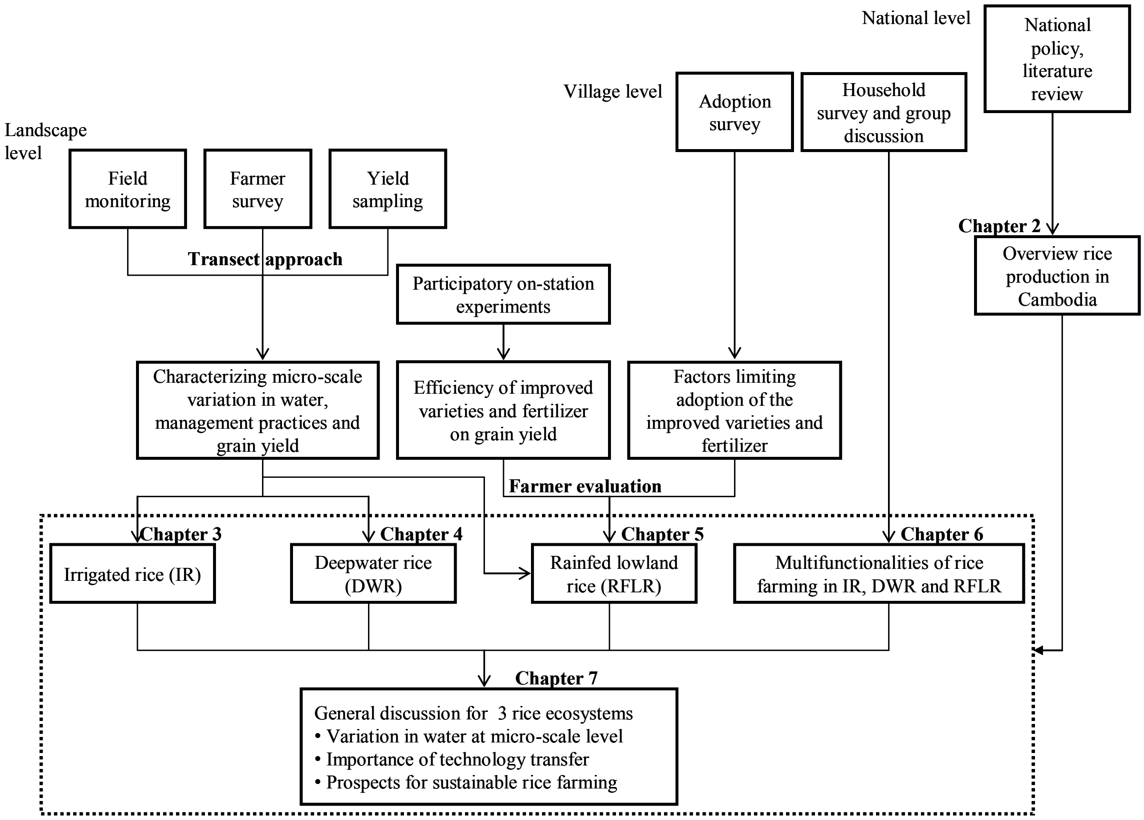

Fig. 1. 1. Methodological framework and thesis outline

Chapter 2

Overview of rice production in Cambodia

2.1 Geography and climate

Located in Southeast Asia on the coast of the Gulf of Thailand, Cambodia has a total area of 181,040 km^2 and neighboring countries of Thailand in the west, Lao PDR in the north and Vietnam in the east. Besides these countries, Cambodia shares the Mekong River basin with China and Myanmar. Water surfaces, including Tonle Sap Lake constitute of about 2.2% of the total area of the country. The country comprises 24 provinces with a total population of 14,562,000 inhabitants in 2008, of which about 79% live in rural area. There are four geophysical zones including the Plains Region, the Tonle Sap Region, the Plateau and Mountainous Region, and the Coastal Region.

Cambodia is dominated by the tropical monsoon climate with two distinct seasons (1) the dry season from November to April associated with the northeast monsoon giving drier and cooler air; and (2) the wet season from May to October with the southwest monsoon, and with rainfall patterns of two peaks. The first peak is between April and July and the second is between August and October (Vance et al., 2004). Though average annual rainfall of the country is estimated at 1,400 mm, it ranges from nearly 1,000 mm in Svay Chek in the western province of Banteay Mean Chey to approximately 4,700 mm in Bokor in the southern province of Kampot. Precipitation also differs largely from year to year. A dry spell may occur from July. The warmest month of the year is April with a maximum temperature of 36^{o}C, while coldest month is January with the minimum temperature of 21^{o}C (FAO, 2010).

2.2 Reconstruction from civil strife and development

Cambodia experienced long period of turmoil and civil strife, which began in 1970 with the overthrow of the government of Prince Sihanouk. That strife and instability, lasted 28 years (the real political stability came with new national elections and the death of Khmer Rouge leader Pol Pot in 1998), and severely and adversely affected the Cambodian economy, its human resource base, and its physical infrastructure. As a result of the civil war, Cambodia is one of the poorest countries in Asia, and ranked 136th out of 174 countries in the world in terms of the UN Human Development Index, according to the Second Five Year Socioeconomic Development Plan (ACI, 2002). The human development progress of Cambodia is also one of the lowest in Asia, ranked 130th out of 177 in the UNDP Human Development Report (UNDP, 2004). However, there have been dramatic political, economic and social changes since 1993, the year of the first post-conflict national elections leading to the first coalition government. The country has been a member of World Trade Organization since October 2004 and has carried out crucial institutional and economic reforms. As an outcome, the GDP increased by 10% annually between 2000 and 2008, higher than Thailand and Vietnam, the country's neighbors (WB, 2009a). The economic development of Cambodia is based on three pillars which are agriculture with 35% of GDP, industry with 23% of GDP, and services with 36% of GDP in 2009. The share of GDP of agriculture has reduced by 8% since 1999 (WB 2009b). Nevertheless, Cambodia's economy is still highly dependent on agriculture (largely on rice cultivation), which employs 71% of labor force in 2008 (USDA, 2010). Disparity between rich and poor in Cambodia has now become the highest in Asia and the inequality amplified both between rural and urban areas, and within rural areas (UNDP 2009).

2.3 The importance of rice production and agricultural policies

Rice is the predominant staple crop in Cambodia and it has been believed to be cultivated in the country for more than 2000 year (Nesbitt, 1997). Total cultivated rice area in 2006 was around 2.4 million ha (80% of total cultivated area), of which 2.1 million ha grown in wet season and 0.3 million ha in dry season (MAFF, 2006). Rice is one of main drivers in agricultural growth, contributing nearly half of total crop growth in the 1994-2006.

Recently Cambodia has re-entered the world market as a rice exporting nation, following a 30-year hiatus caused by war, political isolation, and a decimated agricultural sector. A resurgence of rice cultivation is occurring all across the nation's vast lowlands, as the rural population expands and as previously abandoned or mined farmland is brought back into production. Rice cultivated area increased from 2.3 million ha in 2000 to 2.8 million ha in 2010 (MAFF, 2011). Public statements by government ministers in the last year indicate that Cambodia wants to double rice production by 2015 to approximately 15 million tons (9.5 million tons milled rice) and export 8 million tons (5 million tons milled rice) (USDA, 2010). Rice gave more than 10% of the country's total export value in 2007 (IMF 2009).

Despite being an exportable surplus country, the rice-based farming systems in Cambodia are characterized by low income and food insecurity remains a major concern in some parts of the country, especially at administratively disaggregated levels, such as province, district, commune and household, where droughts and floods occur frequently (WFP, 2010).

Being aware of important role of the rice sector in economic development, poverty reduction and food security, the Royal Government of Cambodia (RGC) has specially focused on this sector through the *National Strategic Development Plan* (NSDP) for 2006-2010 (MAFF and MOWRAM, 2007). Intensification (i.e. irrigation and fertilizer use) for improving rice yield has been highlighted as the top priority for promotion of agricultural growth, rather than further expansion of the farmed land area. The NSDP required a Strategy for Agriculture and Water with the goal *"to contribute to poverty reduction, food security and economic growth through (a) enhancing agricultural productivity and diversification and (b) improving water resources development and management"*. According to the policy, major measures to obtain the goal are (1) enhancing efficient use and management of water and land, (2) increasing agricultural productivity, (3) enhancing agri-business processes, (4) institutional capacity building, and (5) improving the access to knowledge and technology.

As a result from the support of the government, average rice yield rose from 2.1 t ha^{-1} in 2000 to 2.7 t ha^{-1} in 2007. The rapid growth in rice production has turned Cambodia from a net rice importer to an exporter. For instance, Cambodia could export up to 1.5 million tons in 2007 (Yu and Diao, 2011). The RGC has recently showed the ambition to transform Cambodia in to a “rice basket” and a major rice exporting country in the world. In order to achieve this goal, the RGC has launched a *Policy on the promotion of paddy production and rice export* (RGC, 2010). To support for the export ambition, some of quick-win and medium and long term measures related to rice production have been given in the policy. The quick-win measures are (1) to use high yield seed and modern farming techniques (fertilizer and other agricultural inputs, and machinery) through importing, local production and agricultural extension to increase rice productivity, (2) to continue to expand irrigation, (3) to continue build and maintain rural roads, and (4) to promote micro-credit for agriculture. On the other hand, the medium and longer term measures are (1) to improve productivity and crop intensification through enhancing water management, increasing investment in agricultural research and technology transfer, and expanding agricultural extension services at commune level, (2) to promote implementation of “the National Policy on Rural Electrification”, (3) to promote and establish farmer organization, and (4) to promote and encourage the implementation of policy on sustainable use of agriculture land.

2.4 Rice ecosystems

Brought by the country’s rainfall distribution, flooding pattern and topography, rice in Cambodia is grown over diverse water environments from upland to flooding with water depth as much as 5 meters (Ouk, 2011). These environments are grouped into 4 major rice ecosystems: IR, DWR, RLR and rainfed upland (RUR). Among these, the three formers are mainly located in the central plain around the Tonle Sap Lake and towards the southeast (Fig. 2.1) while the last, rainfed upland rice, is grown in the mountainous area located mainly in north and northeast of Cambodia. Followings are the overview of the 4 rice ecosystems.

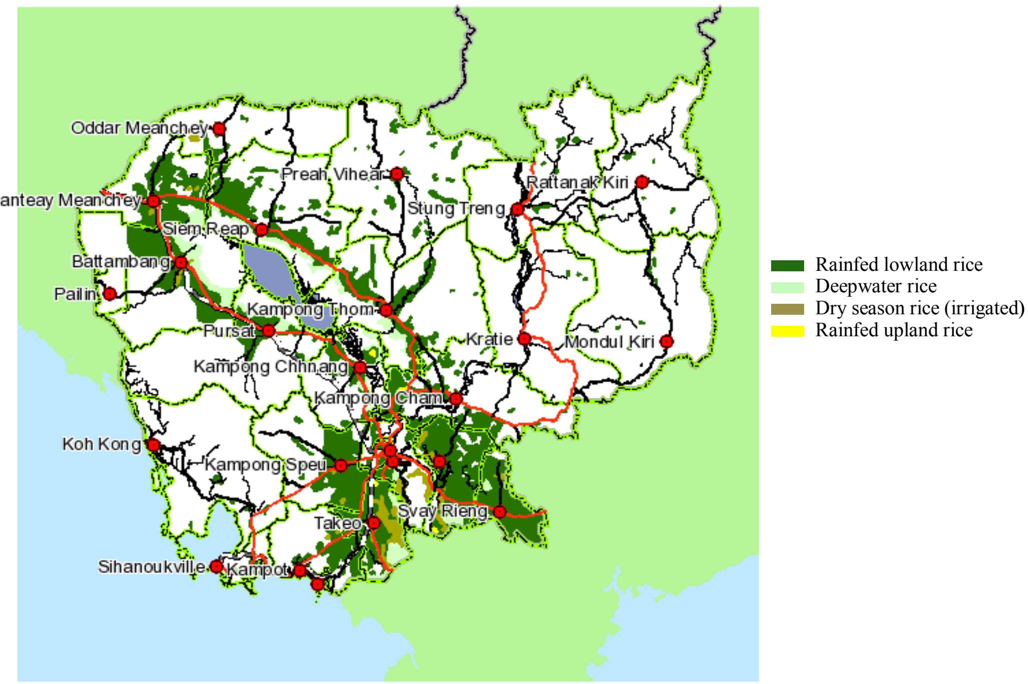

Fig. 2.1. Map of rice ecosystems in Cambodia (DANIDA, 2007)

2.4.1 Irrigated rice

Irrigation in Cambodia has developed since Angkor period between 10th and 13th century. In recent time, the development can be divided into four periods which include French period (1930 – 1950), Prince Sihanouk period (1950 – 1970), Pol Pot (Khmer Rouge) period (1975 – 1979), the domestic irrigation management (1980 – early 1990s) and from early 1990s to present with the support from international organizations (i.e. ADB, FAO, JICA) for developing water law and irrigation rehabilitation/construction (Perera, 2006). Irrigation schemes in Cambodia can be divided into 3 groups based on their scale: small (less than 200 ha), medium (200-5,000 ha) and large (greater than 5,000 ha). Kamping Puoy irrigation rehabilitation area in Battambang province described later in Chapter 3 belongs to the last group. Most medium and large-scale irrigation systems and some small-scale irrigation systems have water reservoirs and irrigation distribution canal systems. It is estimated that there are 2,403 irrigation schemes (1,415 small, 955 medium, and 33 large), and they can potentially irrigate more than one million hectares (Thun et al., 2009).

However, most of these schemes were constructed during the Sihanouk period and particularly the Khmer Rouge period and they were mostly impaired due to poor design and serious deterioration (Thun, 2008).

Recognizing the importance of irrigation development in increasing agriculture productivity, poverty alleviation and economic growth, the government has encouraged people's participation as well as investments of donors from foreign countries (i.e. ADB, Japan, Korea and China) in rehabilitating the existing ineffective irrigation schemes. As a consequence, the irrigated area has risen rapidly from 7 % of the total cultivated area during 1998 – 2002 (Yu and Fan, 2011) to 13 % in 2006 (Table 2.1) and 19 % of the total cultivated in 2008 (Yu and Daio, 2010).

Most of the irrigated areas in Cambodia were previously used to be mainly recession dry season rice (i.e. rice planted as flood waters recede and partially irrigated from the flood water storage; only one crop per year, usually planting in November and harvesting in February or March). For instance, Up to 200,000 of 255,000 ha of dry season rice in Cambodia was recession rice in 2000 (Nesbitt et al., 2004). Dry season rice area has recently increased to 485,000 ha (19% of total cultivated area) in 2009 mainly through irrigation rehabilitation as mentioned above. This means that the area with double cropping system must increase but the ratio between the double cropping area (with fully irrigated dry season rice) and recession dry season rice area is not clear.

2.4.2 Deepwater rice

DWR is defined as rice growing area where water depth is more than 50 cm for a month or longer during the growing season (Catling et al., 1988). Though the definition covers all water depth above 50 cm, DWR and floating rice are often distinguished from each other. DWR is the traditional tall rice (140-180 cm) even without flooding grown in deepwater environments with range of water depth from 50 to 100 cm. It is usually photoperiod-sensitive; has long leaves and long internodes but only weak to moderate or no elongation ability. Floating rice include cultivars which are tall (150-220 cm) even without flooding and has strong elongation ability. These cultivars are grown in water depth above 100 cm (Catling, 1992; Catling et al., 1988). There are about 11 million ha of DWR which is located mainly in South and Southeast Asia and some in West Africa (Bouman et al., 2007).

In Cambodia, “there is no clear demarcation of DWR areas in Kampuchia, although floating rices are said to be those growing in more than 1 m of water” according to Seng et al (1988). Many varieties tolerating water up to 1.25 m but not true floating rice are grown in Cambodia. Scientists would classify them as DWR varieties while Cambodian farmers would classify them as late maturing rainfed lowland rice. This is because these DWR is not only grown in DWR area but also in rainfed lowland area (Lando and Mak, 1994). DWR areas in Cambodia are located in the provinces near to the Tonle Sap Lake, the Mekong River, and Tonle-Bassac River. The main areas are located in Kampong Thom, Banteay Meachey, and Battambang. Maximum water of DWR areas ranges from 50 cm to more than 3 m. DWR area around the Tonle Sap Lake is unique because of its flooding patterns depending on the water flows from the Mekong River to Tonle Sap Lake during May/ June and the reversed flows to the River in September/October. In 1960s, the DWR area occupied up to 16% of Cambodia’s rice land (about 400,000 ha) (Javier, 1997; Seng et al, 1988). However, as the discouragement of growing DWR during Pol Pot regime, DWR area decreased sharply and it was only 120,000 ha in 1988. Many floating rice varieties were also lost during this time (Seng et al. 1988). The area has been further decreased due to the conversion of DWR into recession dry season rice (see the explanation in the previous section: irrigated rice) which can give higher yield. According to MAFF (2006), DWR presented only 3.9 % of the cultivated area in 2006 (Table 2.1). There have been concerns that the increase in using of agricultural chemicals such as fertilizer and pesticides, related to the introduction of high yielding varieties for recession rice cultivation may pose potential problems for fish production in the DWR area (Hand, 2002).

2.4.3 Rainfed lowland rice

RLR which is defined as rice growing in leveled and bunded fields without accessing to irrigation water (Mackill et al. 1996), covers about 46 million hectares in South and Southeast Asia, or almost 35% of the total world rice area (Maclean et al. 2002). RLR rice occupies the largest proportion of rice cultivated area 80.7% among the 4 rice ecosystems in Cambodia (Table 2.1). Only small enhancement of rice productivity in this area would improve livelihood of many Cambodian farmers for food security and small income generation.

Within the RLR, five subecosystems are recognized, based on the maximum water depth of water accumulating in the fields. The subecosystems include (1) rainfed shallow, favourable; (2) rainfed shallow, drought-prone; (3) rainfed shallow, drought-and submergence-prone; (4) rainfed shallow, submergence-prone; and (5) rainfed medium deep, waterlogged. In Cambodia, the drought and drought/submergence prone area occupied even nearly 95% of the total rainfed lowland rice of the country (Bell et al., 2001). About half of the rice area under rainfed lowland conditions in Cambodia belongs to Prey Khmer and Prateah Lang soil type which have very sandy surface horizons, low organic matter, low exchangeable cations (White et al., 1997). Field trials have shown that soils of most rainfed lowland rice areas in Cambodia are characterized by limited availability of N, P and K (Seng et al., 2001).

2.4.4 Upland rice

The area under RUR cultivation accounts for 2.2% of Cambodia's total annual rice cropping areas in 2006 (Table 2.1). RUR areas are unbunded fields that depend entirely on local rainfall and are generally scattered in the mountainous and rolling hill areas of Cambodia mainly in the provinces of Mondulkiri, Rattanakiri, Kratie, Koh Kong, Kampong Cham and Kampong Thom. Among these, Mondulkiri and Rattanakiri are the two only provinces where upland rice area is the major rice ecosystem (Javier, 1997).

Table 2. 1. Cultivated area percentage, yield, production percentage of the 4 rice ecosystems in Cambodia

Rice ecosystems	Area %	Yield (t ha^{-1})	Production %	Interests
Irrigated rice (IR)	13.2	3.9	20.9	irrigation development and rice export
Deep water rice (DWR)	3.9	2.1	3.3	Tonle Sap floodplain, farmers' livehood, less research
Rainfed lowland rice (RLR)	80.7	2.3	74.6	farmers' livelihood, less benefit from Green Revolution
Rainfed upland rice (RUR)	2.2	1.5	1.2	Not studied in this thesis

Source: calculated from rice production statistics of MAFF (2006)

From the next chapters, detailed studies for each of the three important rice ecosystems (irrigated rice deepwater rice and rainfed lowland rice) at landscape and village levels are presented.

Chapter 3

Farmers' Management Practices and Grain Yield of Rice in Response to Different Water Environments in Kamping Puoy Irrigation Rehabilitation Area in Northwest Cambodia

3.1 Introduction

Rice grain yield is low (2.7 t ha^{-1} in 2008; FAOSTAT, 2011) and irrigation development is limited in Cambodia. Dry season rice which is produced under complete irrigated conditions shared 0.34 million ha, only 14% of total rice cultivated area in 2008 (JICA, 2010c, USDA, 2010). Development of irrigated rice production with higher yield level in sustainable manner is important for Cambodia.

Rice production in Cambodia covers cultivated area of about 2.3 million ha (almost 85 % of agricultural land) (USDA, 2010), holds about 70 % of total national workforce (Asthana, 2010), and provides the most important export commodity (JICA 2010a). In the latest policy paper on the promotion of paddy production and rice export reported by Royal Government of Cambodia (RGC, 2010), the Government showed the ambition to turn Cambodia into a major rice exporting country in the international market. Cambodian government recognized the importance of irrigation development as one of the quick-win measures in increasing agriculture productivity, poverty alleviation and economic growth, and has recently encouraged agricultural and water management sectors as well as investments of donors from foreign countries (i.e. ADB, Japan, Korea and China) to develop irrigation systems for rice production.

In Cambodia, major existing irrigation systems were built during the Pol Pot regime (69% of 841 schemes) (Perera, 2006), which is estimated as 0.72 million ha with canal system of 14,000 km (JICA, 2010a), but most of these systems were reported to have been defunct due to poor planning and design and construction (Perera, 2006; Thun, 2008; JICA, 2010a). Cambodian Government encouraged rehabilitating those existing ineffective irrigation schemes, as it may be less costly than the new development. As a consequence, the fully irrigated area during dry season is reported to have risen rapidly during the last decade, compared with only 7 % of the total cultivated area during 1998 – 2002 (Yu and Fan, 2010). The percentage of irrigated area including those in wet season is estimated to be 25% in 2008, with 0.59 million ha (JICA, 2010a). Rapid expansion of the areas including partially irrigated systems is also advocated by Cambodian government (Hun, 2010; CRDB and CDC, 2010). Such a progress in irrigation rehabilitation is considered to have to some extent contributed to rice yield increase from 2000 (i.e. only 2.1 t ha^{-1}) (FAOSTAT, 2011). However, it is not known to what extent the systems once defunct but now after/under rehabilitation are able to evenly distribute irrigation water. Micro-scale variation in water condition may be large. Besides the current national rice yield (i.e. 2.7 t ha^{-1}) was still relatively low compared to neighboring countries with similar weather and soil condition such as Thailand, Laos and Vietnam where grain yields were 2.9, 3.5 and 5.2 t ha^{-1} in 2008 respectively (FAOSTAT, 2011). Assessment of rice yield and farm management would be needed in those irrigation rehabilitation areas.

Several socio-economic surveys are available which reported via interviews rice productivity in irrigation rehabilitation area in Cambodia (WB, 2006; Try, 2008; Thun et al., 2009). For instance, WB (2006) compared the reported rice grain yields before and after the conduction of irrigation projects and evaluated some projects as unsuccessful and others as successful. However, little has been analyzed how farmers adapt to the new cropping system as the introduction of irrigated system proceeds, while not much is known about spatial variation in rice field management in the irrigation rehabilitation areas. In order to introduce suitable and more productive technologies to irrigation rehabilitation areas through agricultural extension activities, farmer management and yield level must be assessed including the area-wide spatial distribution and the yearly changes in response to the progress of introduction of double cropping. This information may provide insights into the problem-solving approaches of farmers to cope with seasonal and spatial variability as well as suggest feasible strategies for policy makers to improve productivity of the system.

We conducted a study to quantify the difference in water environments at micro-scale in an irrigation rehabilitation area in Northwest Cambodia, and to examine the farmers' management practices in response to the different water environments and to the introduction of double cropping system. We also attempted to assess grain yield and determine yield limiting factors in the studied area. In this paper we have 3 hypotheses; (1) field water environment in the irrigation rehabilitation area is spatially varied along drainage canals (i.e. micro-scale water variation) due to the weakness of water distribution system; (2) the expansion of dry season rice (DSR) area (and double cropping system) will force modification of whole cropping sequence including management practices for wet season rice (WSR), in which technical advices and information will be desired; and (3) rice yield of both DSR and WSR will not instantly boost up only as a result of rehabilitation of irrigation infrastructure but will be better improved by agronomic management information by agricultural extension support.

3.2 Materials and Methods

3.2.1 Study site

The study was carried out at Kamping Pouy irrigation rehabilitation (KPIR) area (13°02' N, 103° 04' E) which is located approximately 25 km west from Battambang City, Battambang province, Northwest Cambodia (Fig. 3.1). KPIR area was at first developed during Pol Pot regime from 1975 to1979 by forced labor including those forced to move from urban areas. Due to poor planning, design and construction, the irrigation system was not well-functional. Since 1999, Japanese and Italian government started rehabilitating the area with a capacity of about 5,000 ha of beneficiary area (JICA 2010b). KPIR area is divided into 3 zones: the most up-stream zone close to Kamping Puoy (KP) Water Reservoir (700 ha), midstream zone (consisting of 2 areas of 1,200 and 2,200 ha), and downstream zone (950 ha). The area of 2,200 ha in the midstream zone has just been operated irrigating for DSR 2010 (Fig. 3.1). The downstream zone, rehabilitated by JICA from 2001-2003, was used for this study. This 950 ha zone consisted of 6 irrigation canals (N2-1, N2-3 to N2-11) which vertically branched from the canal N2 (with N2-1 upstream and N2-11 downstream along N2) and 6 drainage canals (D2-1, D2-3 to D2-11) between the 2 adjacent irrigation canals. In this paper, we refer N2 as a main irrigation canal, N2-1 to N2-11 as secondary irrigation canals, and D2-1 to D2-11 as secondary drainage canals. Tertiary irrigation canals are incomplete, and hence most of the paddy fields except for those along the irrigation canals are supplied with irrigation water by plot to plot irrigation.

The two secondary drainage canals D2-1 (9.8 km from KP Water Reservoir) and D2-7 (13.2 km from KP Water Reservoir) within the 950 ha area were chosen for the transect study during rainy season rice in 2008 and 2009, and dry season rice in 2009 and 2010. D2-1 is located at more upstream direction along N2 than D2-7. The transect study (e.g. Ardales et al. 1996; Van Groenigen et al. 2003; Neumann et al. 2009) is conducted based on the logical assumption that environmental and management conditions may be different along the transect; in our study it was intended to clarify spatial variation along the secondary irrigation and drainage canals in the 950 ha area in KPIR area. There are 98 fields located in both sides along D2-1 and 42 fields located in both sides along D2-7. D2-1 was longer (2.8 km) than D2-7 (1.7 km) and its single field size was slightly smaller (Table 3.1), which lead to much more numbers of fields along D2-1 than D2-7. In total 140 fields were grouped as (1) upstream D2-1 (1U); (2) mid-stream D2-1 (1M); (3) downstream D2-1 (1D); (4) upstream D2-7 (7U); (5) midstream D2-7 (7M); and (6) downstream D2-7 (7D). Upstream fields are closer to N2 than downstream fields (Fig. 3.1 and Table 3.1).

Monthly rainfall and temperature from May 2008 to July 2010 measured at Kamping Puoy Agricultural Development Center, which is located about 7 km northwest of study area, are shown in Table 3.2. Rainfall in 2009 was lower than in 2008, particularly in the beginning (July, August) and the end (November) of rainy season. Maximum and minimum temperatures in 2010 were higher than in 2009, especially in April and May.

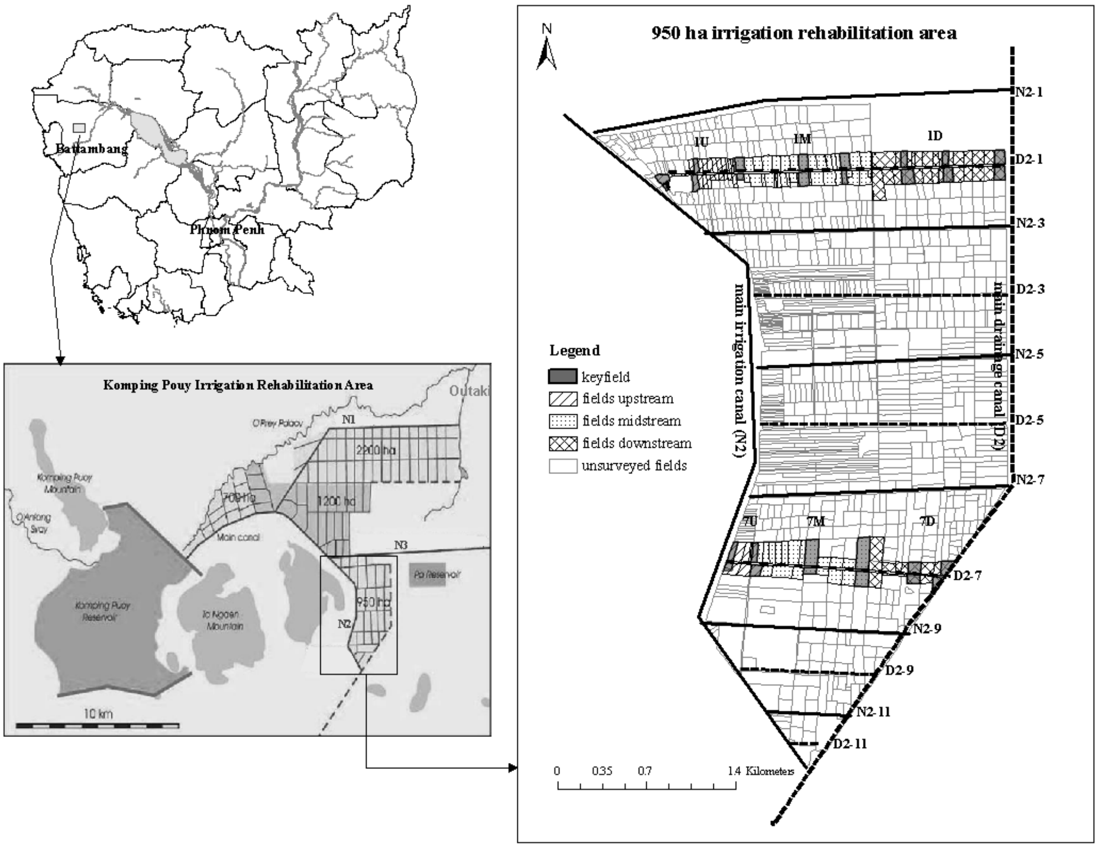

Fig. 3.1. Location of the study site; N2-1, N2-3 to N1-11 are secondary irrigation canals; D2-1, D2-3 to D2-11 are secondary drainage canals; A part of map was modified from Fig. 3 in MRC (2007)

Table 3.1. Numbers and area of the surveyed fields, distance from main irrigation canal, and planting dry season rice in the 3 field groups with different distance from Kamping Puoy (KP) lake and main irrigation canal (upstream, midstream and downstream) in the two drainage canals D2-1 and D2-7 in Kamping Puoy irrigation rehabilitation (KPIR) area.

Drainage ID	Field group by water	N[1]	n[2]	Field size (ha)[3]		Distance from main irrigation canal (km)	
				Single field	Total	Min	Max
D2-1	Upstream (1U)	31	4	0.3 ± 0.2	8.0	0.1	0.7
	Midstream (1M)	38	6	0.6 ± 0.3	23.9	0.8	1.7
	Downstream (1D)	29	6	0.8 ± 0.4	24.5	1.8	2.8
D2-7	Upstream (7U)	8	4	0.7 ± 0.2	5.7	0.0	0.2
	Midstream (7M)	20	4	1.0 ± 0.6	20.6	0.6	1.0
	Downstream (7D)	14	4	0.8 ± 0.7	10.8	1.4	1.7
Total		140	28	0.7 ± 0.5	93.5		

[1] N indicates number of fields where water score, planting time, harvesting time, varieties, and planting method have been periodically monitored.

[2] n indicates number of key fields where rice has been sampled for yield evaluation, yield component analysis, weed amount at maturity and farmers' management practices of the fields have been interviewed.

[3] Area was calculated based on N samples

Table 3.2. Monthly rainfall (mm) and monthly mean daily minimum and maximum air temperature (^{0}C) from May 2008 to July 2010 at Kamping Puoy Agricultural Development Center.

	Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall	2008						177	172	148	181	189	247	192	1.3	1530
	2009		0	0	75	163	196	128	73.3	166	275	282	32	0	1391
	2010		8	12	25	70	77	121	242						
Temperature	2008	max.					33.3	33.2	33.1	33.0	32.0	31.5	29.4	29.5	32.4
		min.	18.6	19.6	21.9	23.9	24.4	24.4	24.3	24.4	24.0	24.3	22.1	20.2	22.7
	2009	max.	29.7	34.2	34.3	34.9	32.3	33.8	32.8	34.0	32.0	31.0	30.9	32.0	32.7
		min.	18.4	22.9	24.5	25.8	25.5	25.9	25.5	25.5	25.0	25.0	23.1	22.0	24.1
	2010	max.	32.2	35.3	36.1	37.1	36.6	34.6	33.4						
		min.	22.4	24.9	25.2	27.0	27.2	26.3	25.6						

3.2.2 Measurements

All the 140 fields in the 6 groups along D2-1 and D2-7 were monitored about once in every 4 weeks except in rainy season 2008 (every 8 weeks) for examining differences in water availability, cropping schedule and rice management practices (i.e. planting method, varieties, mid-season tillage practice). Water availability were assessed based on the method of Kamoshita et al. (2010) in which field water conditions were recorded as water scores, simple indices of visual wetness of soil surface or standing water depth in paddy fields: -1 (dry), -0.5 (moist but not saturated), 0 (saturated without standing water) and x/10 (flooded with x cm standing water).

Planting dates were estimated based on leaf number of seedlings in combination with field observation and farmer interview during field surveys in July and August for WSR and in February and March for DSR while harvesting dates were determined based on the estimation of physiological maturity time of the each rice field during field surveys in November, December and January for WSR and in May and June for DSR. Planting methods were divided into direct seeding and transplanting of seedlings. Direct seeding methods were divided further into wet seeding and dry seeding (Fig. 3.2). In wet seeding method, pre-germinated seeds are broadcasted into puddled and leveled fields while in dry seeding method, dry seeds are broadcasted on dry or moist soil in ploughed fields and then incorporated into surface soils by harrow. Planting methods were determined from the appearance of rice seedlings during establishment stage and by clarification through interviewing farmers if needed.

Mid-season tillage is a practice of weed management by plowing when rice seedlings are at more than 30 days or sometimes up to 80 days after emergence depending on water accumulation in the field (Fig. 3.2). This practice, used only in direct seeded fields for medium and late varieties, is intended to control weeds and redistribute seedling density. Mid-season tillage practice in KPIR area was described in details in Kamoshita et al. (2009, 2010). We clarified whether mid-season tillage was conducted or not in each field based on field surveys from August to November. Rice varieties were identified with a help of a knowledgeable local farmer during field surveys in November and December.

For yield assessment, 16 and 12 key fields along D2-1 and D2-7 respectively were selected (Table 3.1 and Fig. 3.1), and the farmers of those fields were identified to interview their estimated yield and management practices. Each field group contains 4 to 6 key fields. One field in 7M in WSR 2009 and 4 fields in 7D in DSR 2009 were uncultivated while 1 field in 7U and 1 field in 7M were missed for sampling in DSR 2009. Therefore, total key fields with yield data were 28, 27, 22 and 28 for WSR 2008, WSR 2009, DSR 2009 and DSR 2010, respectively. Three 1m x 1m samples for WSR 2008 and DSR 2009 and one 1 m x 1 m sample for WSR 2009 and DSR 2010 were harvested from the ground level in each key field. Sample positions for each key field were located in the areas with average growth/yield based on visual observation for the whole field. For each rice sample, number of panicles with fertile grains was counted, and dry weights (after putting into oven for 2 days at 70 ^{0}C) of straw, ripened grains (those sinking in the tap water), un-ripened grains (those floating in the tap water), and 100 counted both ripened and un-ripened grains were determined. Fraction of ripened grain, 1000-grain weight, number of spikelets per panicle, and harvest index were calculated. Grain yield, calculated from dry weight of ripened grain, and 1000-grain weight were presented at 14% moisture content. Yield components were not measured in WSR 2008.

For the 28 key fields, weed infestation at maturity was also evaluated by collecting all the weeds with their plant height greater than approximately 3 cm in a quarter of every quadrate of the 1m x 1m for the rice sampling mentioned above, to determine weed dry weights. Amounts of organic and chemical fertilizers and amounts of active ingredients of herbicides and insecticides were determined by interviews at ending time for each rice season.

Analysis of variance using Waller-Duncan (Waller and Duncan, 1969) was conducted to examine the differences in yield and yield components among the 4 combinations of crop seasons and years (WSR 2008, WSR 2009, DSR 2009 and DSR 2010), and the differences in yield among the 6 field groups (1U, 1M, 1D, 7U, 7M and 7D), both regarding field numbers as replications. The effects of planting method (transplanting vs direct seeding) and variety (Raing Chey vs other varieties) were tested by independent-samples t-test. The simple correlation coefficient between grain yield and environmental and management factors were calculated. All of the statistical analysis was conducted using SPSS software.

Fig. 3.2. Photos of planting method (dry seeding, wet seeding and transplanting) and midseason tillage practice in KPRI area.

3.3 Results

3.3.1 Field water environments

All fields were under non-flooded (negative values of water score) or saturated (water score = 0) at the beginning of WSR (i.e., August), but field water depth became deeper (larger positive water score) with the progress of rainy season from September to November and started decreasing in late November (Fig. 3.3). In WSR 2009 water depth increased sharply from August to September; especially in downstream fields the average depth reached 27 cm (while the depth of the deepest field in 7D 58 cm) in early September 2009. Water depth was much deeper in downstream fields than in upstream fields in the both canals, and deeper in fields in D2-7 than those in D2-1. For example, average water score in early November 2009 were -0.1 (with the maximum score in the deepest field 0.3) in 1U and 4.2 (with the maximum score 7.6) in 7D, respectively. At the end of season, the disappearance of standing water in upstream fields was generally earlier than that in mid and downstream (e.g. early November vs. mid December to January), and earlier in 2009 than 2008.

In contrast to WSR, there was smaller variation in field water condition in both between field locations and during the crop season in DSR (Fig. 3.3). Water depth in DSR was also shallower in comparison to that in WSR. Irrigation water was fully provided during growing season in both 2009 and 2010. However, irrigation started 7 days earlier in 2010 (1st February) than in 2009 (7th February). All fields were under shallow flooded condition with the average water score ranged from 0.5 to 1.7 in March and April except for fields in 7D which were fallowed with non-flooded dry condition (water score = -0.9 in March and -0.8 in April) in 2009 and which were planted but with non-flooded dry condition in March (water score = -0.2) in 2010.

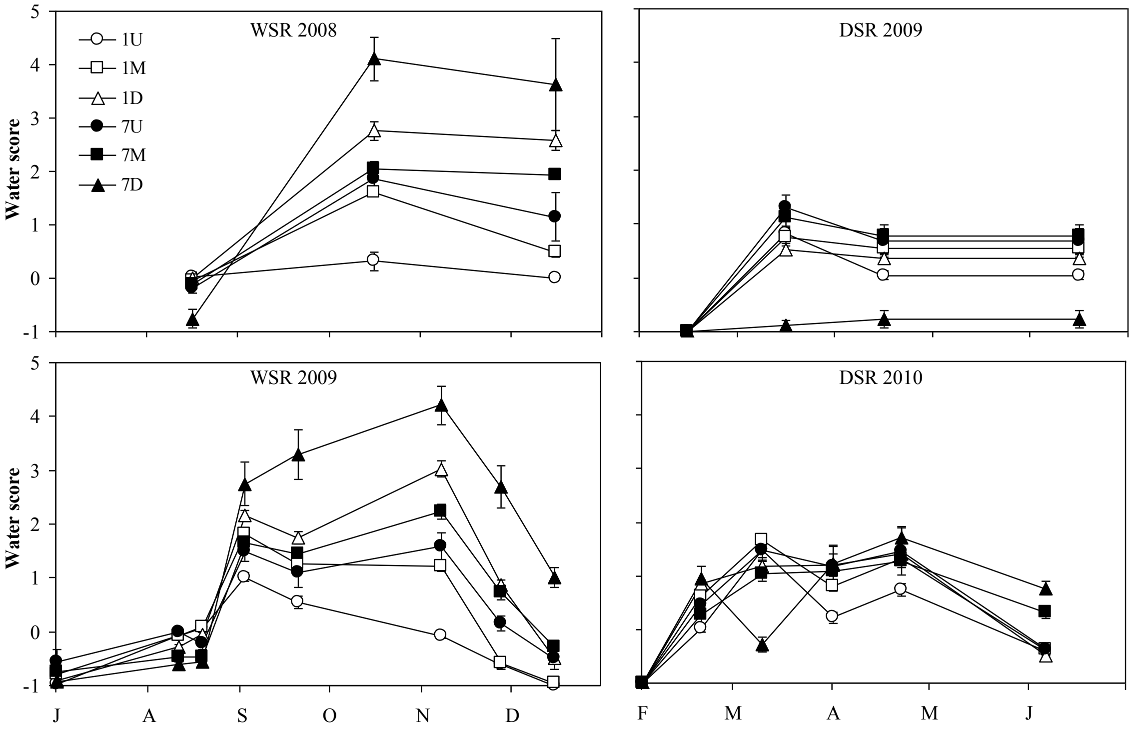

Fig. 3.3. Water score, a quick index for soil and paddy water availability, in WSR 2008, WSR 2009, DSR 2009, and DSR 2010 in different field groups along two drainage canals. Bars indicate standard error of mean (N = 140, 125 135 and 140 for WSR 2008, DSR 2009, WSR 2009 and DSR 2010, respectively).

3.3.2 Dry season rice area

DSR was planted in all the 3 field groups (1U, 1M and 7U) and only partly in 1D (54% of the area) but not in 7M and 7D in 2008 (Fig. 3.4 and Table 3.3). In 2009, DSR was planted in all the field groups except 7D, and in 2010 DSR was planted in all the fields groups. DSR area percentage within the two transects D2-1 and D2-7 was 54% in 2008 and gradually increased to 100% in 2010. These percentages were similar to the values for the whole 950 ha area (increasing from 567 ha (60%) in 2008 to 950 ha (100%) in 2010) (personal communication with the chief of WUG for KPIR area).

Table 3.3. Changes in proportion of dry season rice (DSR) for each field group along drainage canal D2-1 and D2-7 from 2008 to 2010.

Field location	% of DSR area		
	2008	2009	2010
1U	100	100	100
1M	100	100	100
1D	54	100	100
7U	100	100	100
7M	0	100	100
7D	0	0	100
Total	54	88	100

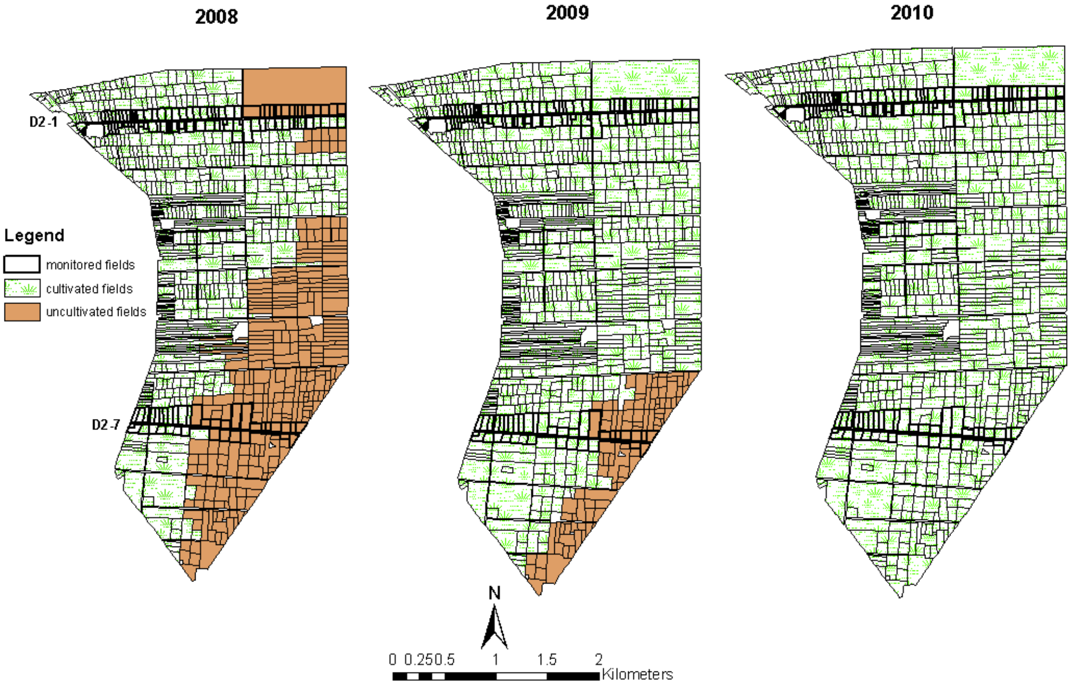

Fig. 3.4. Progress of introduction of DSR into the KPIR area from 2008 to 2010

3.3.3 Management practices

WSR seeding started firstly in downstream fields (e.g., late May 2008 for 7D), then in midstream fields (e.g., early June 2008 for 7M), and finally in upstream fields (e.g., late July 2008 for 1U) (Fig. 3.5). On the other hand, rice harvest started from upstream fields (e.g., mid November 2008 for 1U) and moved to downstream fields (e.g., late December 2008 for 7D). Direct seeding time started earlier (i.e. late May to mid August) than transplanting time (i.e. late July to late August). For the direct-seeded fields, sowing time in 2009 was generally later than that in 2008 (e.g., around early July in 2009 and around early June in 2008 for 1D and 7M). Sowing time became less varied within each field group and less different among field groups except 1U and 7D in WSR 2009 compared with WSR 2008. In DSR planting time and harvesting time were much more similar among and within the field groups in the both years of 2009 and 2010 (Fig. 3.5). In general, rice was planted in mid to late February in 2009 and early to mid February in 2010, respectively, while harvested in early to mid June in 2009 and late May to early June in 2010, respectively. Most of the fields were harvested by machine, especially in DSR 2010.

San CraOrb, a photoperiod insensitive variety with growth duration of 110 – 120 days, was the only variety grown in DSR 2009 and 2010 in the 950 ha area. There was a problem of misusing a photoperiod sensitive variety Phkar Rumduol (PRD) in the studied fields in DSR 2009, which accounted for approximately 10% of the area of the studied fields. In WSR 5 photoperiod sensitive varieties and San CraOrb (for producing seeds for DSR) were used (Table 3.4). PRD and Raing Chey are improved varieties which were developed by Cambodian Agricultural Research and Development Institute (CARDI) while the three others are traditional local varieties. In general, early and early medium varieties such as San CraOrb or PRD were planted in upstream fields while medium and late varieties such as Raing Chey or Neang Khon were planted in midstream and downstream fields. San CraOrb variety was most dominantly planted in 1U (100% and 96% of the surveyed area in 2008 and 2009, respectively). Raing Chey, the most widely planted variety in the whole area, with its area percentage increasing from 36% in 2008 to 58% in 2009, was consistently most popular in 1M and 1D. Neang Khon, the second popular variety, with its area percentage declining from 28% in 2008 to 20% in 2009, was most popularly grown in 7D (95% and 83% of the surveyed area). Kong Sach, grown in 1M and 1D in WSR 2008, was no longer grown in WSR 2009.

While wet seeding was only farmers' choice in DSR, dry seeding, wet seeding and transplanting methods were observed to be practiced in WSR. Transplanted fields were observed only in upstream and midstream fields and the proportion of transplanted area to the total surveyed area rose from 11% in 2008 to 20% in 2009 (Table 3.5). Dry seeding was only practiced in fields where rice was not cultivated in the preceding dry season such as 1D, 7M and 7D in 2008 and 7D in 2009. There was large decrease in area with dry seeding from 35% in 2008 to 12% in 2009 while small increase in area with wet seeding from 54% to 68%.

Mid-season tillage was only practiced in midstream and downstream fields in the both years except 7U in WSR 2009 (Table 3.5). The practice area percentage was high in 2008 (62%) but decreased sharply in 2009 (only 18%). The largest decrease was observed in 1D (100% down to 6%), followed by 7M (75% to 20%).

Farmers often used farmyard manure as organic fertilizer to apply for their rice fields. The average amount of organic fertilizer ranged from 191 kg ha^{-1} in DSR 2009 to 784 kg ha^{-1} in WSR 2008 (Table 3.6). The standard deviations were large as many fields did not receive organic fertilizer. Popular inorganic fertilizers used in KPIR area were urea (46-0-0), diammonium phosphate (DAP; 18-46-0), 16-20-0, and 15-15-15. Average amount of element N from the inorganic fertilizers in WSR 2008 (28 kg ha^{-1}) was significantly lower than that in WSR 2009, DSR 2009 and DSR 2010 (38, 45 and 44 kg ha^{-1}, respectively) (Table 3.6). The average amount of element P ranged from 13 kg ha^{-1} in WSR 2008 to 23 kg ha^{-1} in DRS 2010 (not significantly different at P=5%). Farmers only applied element K from the chemical fertilizers in DSR but its average amount was quite small.

Average amount of herbicide applied in DSR 2010 (628 g a.i. ha^{-1}) was significantly higher than the other cropping seasons which ranged from 367 g a.i. ha^{-1} in DSR 2009 to 443 g a.i. ha^{-1} in WSR 2009 (Table 3.6). Herbicide types which farmers often used in the KPIR area were only for killing broadleaf weeds such as 2,4-D dimethyl amin from Vietnam (e.g. Zico 720 EC and Anco 720 EC) and 2,4-D sodium salt 80% WP from Thailand. Amounts of 2,4-D in direct seeded fields in WSR tended to be higher without conducting mid-season tillage practice than with conducting mid-season tillage practice (479 vs 383 g a.i. ha^{-1}; data not shown). Average amount of insecticide (e.g., Videci 2.5 ND (Deltamethrin) and Visher 25 ND (Cypermethrin) from Vietnam, and Folitec 025EC (Beta-cyfluthin) from Thailand) used in DSR was significantly higher than that in WSR (Table 6), with almost twice higher in DSR 2010 than in DSR 2009 (73.2 g a.i. ha^{-1} vs. 38.4 g a.i. ha^{-1}).

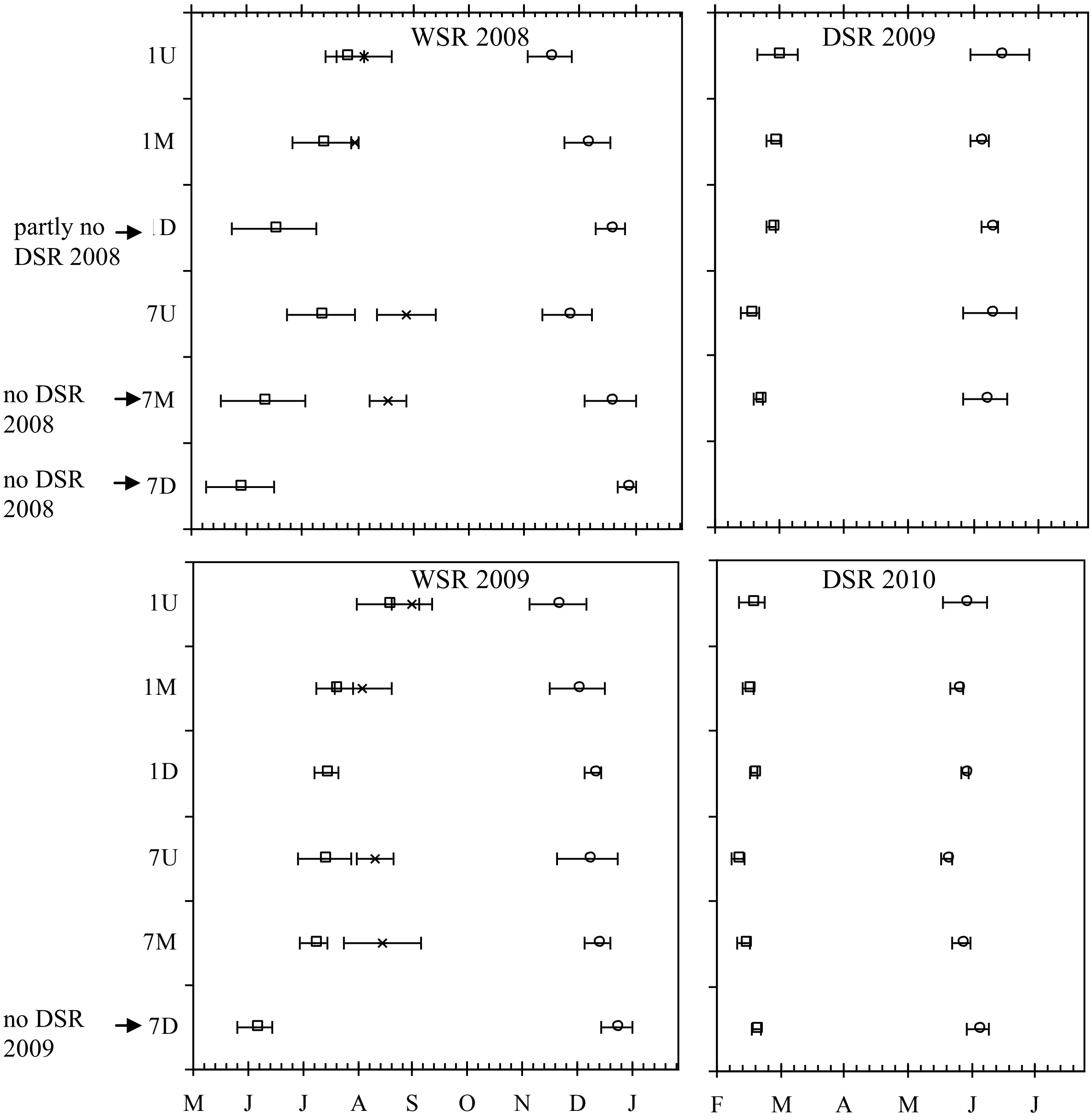

Fig. 3.5. Crop calendar for WSR 2008, DSR 2009, WSR 2009 and DSR 2010 for different field groups along drainage canal D2-1 and D2-7. The squares, cross-lines and circles indicate mean dates of direct seeding, transplanting and harvesting respectively. The error bars indicate standard deviation of the mean dates (N = 140, 125, 135 and 140 for WSR 2008, DSR 2009, WSR 2009 and DSR 2010, respectively).

Table 3.4. Area (ha) and area percentage of early, medium, late and extremely late maturing varieties in different field groups along drainage canal D2-1 and D2-7 in wet season rice (WSR) 2008 and 2009.

Year	Field location	Early variety	Early medium variety	Medium variety		Late variety	
		San CraOrb	Phka Rumdoul	Phka Knei	Raing Chey	Kong Sach	Neang Khon
2008	1U	8.0 (100%)	0.0 (0%)	0.0 (0%)	0.0 (0%)	0.0 (0%)	0.0 (0%)
	1M	4.9 (20%)	0.0 (0%)	5.9 (24%)	11.3 (48%)	1.9 (8%)	0.0 (0%)
	1D	0.0 (0%)	0.0 (0%)	1.0 (4%)	13.8 (56%)	5.3 (22%)	4.4 (18%)
	7U	3.2 (57%)	1.1 (19%)	0.0 (0%)	1.4 (24%)	0.0 (0%)	0.0 (0%)
	7M	0.0 (0%)	0.0 (0%)	2.2 (10%)	6.7 (33%)	0.0 (0%)	11.7 (57%)
	7D	0.0 (0%)	0.0 (0%)	0.0 (0%)	0.5 (5%)	0.0 (0%)	10.3 (95%)
	Total	16.1 (17%)	1.1 (1%)	9.1 (10%)	33.7 (36%)	7.2 (8%)	26.3 (28%)
2009	1U	7.7 (96%)	0.3 (4%)	0.0 (0%)	0.0 (0%)	0.0 (0%)	0.0 (0%)
	1M	4.4 (19%)	0.6 (2%)	3.2 (13%)	14.7 (61%)	0.0 (0%)	1.1 (5%)
	1D	0.0 (0%)	0.0 (0%)	0.0 (0%)	22.7 (93%)	0.0 (0%)	1.8 (7%)
	7U	0.7 (13%)	0.0 (0%)	1.5 (27%)	2.3 (41%)	0.0 (0%)	1.1 (19%)
	7M	0.0 (0%)	0.0 (0%)	0.8 (5%)	9.7 (65%)	0.0 (0%)	4.5 (30%)
	7D	0.0 (0%)	0.0 (0%)	0.0 (0%)	1.8 (17%)	0.0 (0%)	9.0 (83%)
	Total	12.9 (15%)	0.9 (1%)	5.6 (6%)	51.2 (58%)	0.0 (0%)	17.4 (20%)

Table 3.5. Area (ha) and area percentage of different planting method (dry seeding (DS), wet seeding (WS) and transplanting (TP)) and mid-season tillage practice in different field groups along drainage canal D2-1 and D2-7 in WSR 2008 and 2009.

Year	Field location	Planting method			Midseason tillage
		DS	WS	TP	
2008	1U	0.0 (0%)	7.0 (87%)	1.0 (13%)	0.0 (0%)
	1M	0.0 (0%)	20.9 (87%)	3.0 (13%)	6.9 (29%)
	1D	9.3 (38%)	15.2 (62%)	0.0 (0%)	24.5 (100%)
	7U	0.0 (0%)	3.2 (57%)	2.5 (43%)	0.0 (0%)
	7M	12.3 (60%)	3.9 (19%)	4.4 (21%)	15.4 (75%)
	7D	10.8 (100%)	0.0 (0%)	0.0 (0%)	10.8 (100%)
	Total	32.4 (35%)	50.2 (54%)	10.9 (11%)	57.6 (62%)
2009	1U	0.0 (0%)	6.1 (76%)	1.9 (24%)	0.0 (0%)
	1M	0.0 (0%)	16.2 (68%)	7.7 (32%)	3.5 (15%)
	1D	0.0 (0%)	24.5 (100%)	0.0 (0%)	1.4 (6%)
	7U	0.0 (0%)	2.4 (42%)	3.3 (58%)	0.7 (12%)
	7M	0.0 (0%)	10.5 (69%)	4.6 (31%)	3.0 (20%)
	7D	10.8 (100%)	0.0 (0%)	0.0 (0%)	7.6 (70%)
	Total	10.8 (12%)	59.7 (68%)	17.5 (20%)	16.2 (18%)

Table 3.6. Comparison of the amount of fertilizer, herbicide and insecticide used among 4 cropping seasons (wet season rice (WSR) 2008 and 2009 and dry season rice (DSR) 2009 and 2010)

Growing season	n	Organic fertilizer (kg ha^{-1})	Chemical fertilizer (kg ha^{-1}) N	P	K	Herbicide 2.4-D (g a.i. ha^{-1})	Insecticide (g a.i. ha^{-1})
WSR '08	28	784± 1,230	28.0±14.5a	13.2±13.6	0a	432±253a	16.6±25.3a
WSR '09	27	403± 746	38.0±15.4b	19.5±12.6	0a	443±199ab	27.2±27.2ab
DSR '09	22	191± 579	45.1±19.2b	22.4±19.0	1.5±2.8b	628±456b	38.4±39.6b
DSR '10	28	391± 734	44.0±19.6b	23.1±17.3	3.0±4.0c	367±312a	73.2±46.9c
Total	105	451± 877	38.4±18.3	19.4±15.9	1.1±2.7	460±319	39.0±41.5

Values are average ± standard deviation
Values within column followed by the same letter are not significantly different at 5%

3.3.4 Yield and yield components

Grain yields were 289 g m^{-2} for WSR on average of 2 years, ranging from 44 g m^{-2} to 473 g m^{-2}, and 267 g m^{-2} for DSR on average of 2 years, ranging from 51 g m^{-2} to 394 g m^{-2} among the 28 fields (Table 3.7). Grain yield in DSR 2010 was significantly lower than WSR 2008, WSR 2009 and DSR 2009 with only 86% of that in DSR 2009. The size of CV was also largest for DSR 2010. Harvest index, percentage of ripened grains and 1000-grain weight in DSR 2010 were significantly lower than in DSR 2009 while number of panicle per square meter in DSR 2010 was significantly higher than in DSR 2009.

Table 3.7. Comparison of yield and yield components among 4 cropping seasons (WSR 2008 and 2009, and DSR 2009 and 2010)*.

Items	Season	n	Mean[1]	Min.	Max.	CV (%)
Grain yield (g m^{-2})	WSR '08	28	286 b	44	398	30
	WSR '09	27	292 b	168	473	28
	DSR '09	22	287 b	152	390	19
	DSR '10	28	247 a	51	394	33
Final plant height (cm)	WSR '09	27	128 b	58	160	21
	DSR '09	22	93 a	82	104	7
	DSR '10	27	90 a	67	101	9
Shoot dry matter (g m^{-2})	WSR '09	27	809 b	407	1,262	30
	DSR '09	22	703 ab	405	907	17
	DSR '10	27	689 a	501	912	13
Harvest index (%)	WSR '09	27	32 a	17	42	16
	DSR '09	22	35 b	26	50	14
	DSR '10	27	31 a	7	41	28
No. of panicles per m^2	WSR '09	27	199 a	71	400	38
	DSR '09	22	329 b	196	462	26
	DSR '10	27	432 c	242	726	32
No. of spikelets per panicle	WSR '09	27	95 b	30	150	36
	DSR '09	22	50 a	25	76	28
	DSR '10	27	42 a	22	68	29
No. of spikelets per m^2	WSR '09	27	16,740 a	8,978	26,365	25
	DSR '09	22	15,728 a	7,154	22,956	21
	DSR '10	27	16,790 a	8,832	24,114	19
Percentage of ripened grains	WSR '09	27	74 c	59	85	9
	DSR '09	22	65 b	54	78	9
	DSR '10	27	60 a	26	78	23
1000-grain weight (g)	WSR '09	27	24 a	19	31	13
	DSR '09	22	28 b	26	30	4
	DSR '10	27	25 a	20	27	6

*Yield components were not measured in WSR 2008.

[1] values within column for each item followed by the same letter are not significantly different at the 5% level

3.3.5 Yield and environmental and management factors

In WSR 2008, the values of grain yield in 1M (341 g m^{-2}) and 7D (331 g m^{-2}) were significantly higher than the value in 7U (196 g m^{-2}) (Table 3.8). Conversely, the value of grain yield was highest in 7U (358 g m^{-2}) and lowest in 7D (201 g m^{-2}) while there was no significant difference among other field locations in WSR 2009. In DSR 2009, the values of grain yield were not significantly different among field locations except 7M with the lowest value of 200 g m^{-2} (Table 3.8). The value of grain yield in DSR 2010 was highest in 7U (322 g m^{-2}) and lowest in 7D (only 131 g m^{-2}).

The values of grain yield for Raing Chey variety were significantly higher than those for other varieties and yields for transplanted fields were higher than those for direct seeded fields in WSR 2009 (Table 3.8). The tendency of higher yield of Raing Chey variety and transplanting was observed also in WSR 2008.

Grain yield showed the strong positive and negative correlations with distance from main irrigation canal in D2-7 in 2008 and 2009, respectively, in WSR (Table 3.9). Grain yield was correlated positively with water score in August but negatively with that in December in WSR 2009. Transplanting method, Raing Chey variety, and larger amount of herbicide significantly contributed to grain yield increment in WSR 2009. Use of larger amounts of N inorganic fertilizer significantly increased grain yield in both WSR 2008 and WSR 2009.

The correlation coefficients of distance from main irrigation in D2-7 and grain yield were strongly negative in both DSR 2009 and 2010 (Table 3.9). Grain yield was negatively correlated with both planting time and crop duration in DSR 2010. Lower values of water score in March and high values of water score in June negatively affected grain yield in DSR 2010. Grain yield was also negatively affected by weed infestation in both DSR 2009 and 2010. Amount of organic fertilizer, chemical N fertilizer and herbicide were moderately positively correlated with grain yield in DSR 2010.

Table 3.8. Grain yield variation among field location (1U, 1M, 1D, 7U, 7M, 7D), between varieties (Raing Chey, the others), and between planting methods (transplanting, direct seeding) in WSR 2008 and 2009 and DSR 2009 and 2010.

Items		WSR				DSR			
		2008		2009		2009		2010	
Field location[1]	1U	31 ± 94 (4)	ab	257 ± 57 (4)	ab	313 ± 18 (4)	b	195 ± 135 (4)	ab
	1M	341 ± 44 (6)	b	316 ± 88 (6)	ab	311 ± 45 (6)	b	277 ± 29 (6)	bc
	1D	260 ± 64 (6)	ab	315 ± 63 (6)	ab	288 ± 49 (6)	b	266 ± 33 (6)	bc
	7U	196 ±145 (4)	a	358 ± 80 (4)	b	288 ± 47 (3)	b	322 ± 57 (4)	c
	7M	262 ± 48 (4)	ab	277 ± 87 (3)	ab	200 ± 45 (3)	a	266 ± 46 (4)	bc
	7D	331 ± 35 (4)	b	201 ± 38 (4)	a	-		131 ± 15 (4)	a
	Total	286 ± 86 (28)		292 ± 80 (27)		287 ± 54 (22)		247 ± 81 (28)	
Variety	RC	325 ± 77 (7)		330 ± 83 (12)					
	others	273 ± 86 (21)		261 ± 66 (15)	*				
Planting method	TP	243 ±174 (3)		358 ± 94 (7)	**				

Values are average ± standard deviation

[1] Values within column followed by the same letter are not significantly different at the 10% for WSR 2008 and WSR 2009 and at 5% for DSR 2009 and DSR 2010

*P < 0.05 and **P < 0.01

Values in the brackets indicate number of fields

Table 3.9. Simple correlation coefficients between grain yield and environmental and management factors

Items		WSR		DSR	
		2008	2009	2009	2010
Distance from main irrigation canal (m)	D2-1	-0.457	0.109	-0.368	0.217
	D2-7	0.672 *	-0.826 **	-0.768	-0.925 **
Water score	March	-	-	-0.034	0.651 **
	April	-	-	-0.340	0.193
	Jun	-	-	-0.113	-0.469 *
	Aug	0.130	0.396 *	-	-
	Oct	-0.080	-0.130	-	-
	Dec	-0.172	-0.393 *	-	-
Weed at maturity of rice (g m^{-2})		-0.102	0.115	-0.627 **	-0.547 **
Field management	Planting time (DOY)^{a}	-0.188	0.310	0.313	-0.810 **
	Crop duration ^{b}	0.182	-0.289	-0.252	-0.501 **
	Transplanting method^{c}	-0.176	0.499 **	-	-
	Raing Chey variety^{d}	0.269	0.539 **	-	-
	Hand weeding (times)	-0.018	-0.031	0.380	0.139
	Organic fertilizer (kg ha^{-1})	0.277	0.047	-0.132	0.492 **
	Chemical N fertilizer (kg ha^{-1})	0.541 **	0.599 **	-0.008	0.401 *
	Herbicide 2.4 D (g a.i. ha^{-1})	0.346	0.387 *	0.268	0.490 **
	Insecticide (g a.i. ha^{-1})	0.147	-0.090	0.102	0.124

Total sample number for all items except for distance from main irrigation canal: n=28, 27, 22 and 28 for WSR 2008, WSR 2009, DSR 2009 and DSR 2010, respectively.

Total sample for distance from main irrigation canal: n=16 for D2-1 and n=12, 11, 6 and 12 in WSR 2008, WSR 2009, DSR 2009 and DSR 2010, respectively, for D2-7.

*P <0.05 and **P < 0.01.

[a] day of the year from 1 January (e.g. if rice was sowing on 15 February, DOY for sowing time will be equal to 45).

[b] duration from sowing or transplanting to harvesting.

[c] values for transplanting method and those for direct seeding method were 1 and 0 respectively, as dummy variables.

[d] values for Raing Chey variety and for those for other varieties were 1 and 0 respectively, a dummy variable.

3.4 Discussion

3.4.1 Spatial variation in water environment in irrigation rehabilitation area

The first hypothesis of large spatial variation in field water environment within the irrigation rehabilitation area was supported in our study. It was shown that water depth of the surveyed fields during WSR increased along the transects of the 2 secondary canals D2-1 and D2-7 from upstream to downstream, and the standing water disappeared earlier (i.e. November) in the upstream fields (e.g., 1U) while it remained longer with deeper depth in the downstream fields (e.g., 1D, 7D) (Fig. 3.3). This spatial variation in water depth is in a sense similar to the toposequential variation in rainfed lowlands i.e. between upper and lower toposequential fields (e.g., Miyagawa and Kuroda, 1988; Wade et al., 1999; Tsubo et al., 2006; Homma et al., 2007; Boling et al., 2008). The deepest field in 7D (with water depth of 76 cm in early November 2009) can be grouped into intermediate rainfed area according to Huke and Huke (1997). Deep water at downstream fields during WSR was a consequence of poor drainage system in the KPIR area. Thun et al. (2009) also indicated unequal distribution of irrigation water between upstream and downstream fields in small irrigation rehabilitation schemes in Takeo province due to poor irrigation design, field toposequences, and illegal water use by farmers.

Farmers adapted to the variation in the water environments in WSR by planting different types of rice variety with different maturity times. Medium and late maturing varieties were generally planted early but harvested late in midstream and downstream fields with deeper water depth while early and early medium maturing varieties were planted later but harvested earlier in upstream shallower fields (Table 3.4 and Fig. 3.5). These spatial patterns of planting time and type of rice variety between the upstream and downstream fields were also similar to those observed in rainfed lowlands with toposequential variation (Wade et al., 1999, Ouk et al., 2001). However the differences between our study and rainfed lowland studies are (1) that the both single field area and single farm size in KPIR area are much larger (e.g., 0.7 ha per field from Table 3.1, and 2-4 ha per household from Kamoshita et al. (2009), respectively) than the small scale rainfed lowlands farms and (2) that WSR in KPIR area is not only for family-consumption but also for selling to market. By uniformly planting a single higher yielding and good quality rice variety, it will be easier for farmers to sell rice to wholesalers, especially to rice exporting enterprises. However, to obtain this, field water needs to be more uniform among field groups during WSR and more labor force are needed by agricultural mechanization for simultaneous farm operation.

It should be emphasized that field water conditions in DSR were shallower and less different both in time and space than WSR (Fig. 3.3) which would have allowed a single rice variety San CraOrb (as later discussed) to be grown with uniform crop calendar across all the field groups during dry season. This was due to the little rainfall and the controlled irrigation water supply from the reservoir to the planned irrigation area during dry season. However, our study revealed that the judgment up to where to plant DSR is still to some extent with trial and error: the fields in 7D, which had not been planted with DSR before 2009 but for the first time planted in 2010, suffered from water shortage during planting time in whole March 2010 (Fig. 3.3). This indicates immature experiences of farmers and water user groups (WUGs) for the irrigation planning and implementation in order to attain better distribution of irrigation water between upper and lower canals and within a canal. There are 5 WUGs within 950 ha, each of which is responsible for the management of each secondary irrigation and drainage canal, and better communication would be required among the different WUGs. Improving the tertiary canal systems or/and better farmers' collaboration for sharing water between fields nearby may help to enhance more uniform field water distribution in the surveyed area.

3.4.2 Effects of introduction of double cropping

The second hypothesis of our study for the influences of introduction and expansion of irrigated DSR in KPIR area on the whole cropping schedule (including the management of WSR) was supported and qualified by the following data of yearly changes in management practices in WSR such as (1) planting time, (2) planting method and (3) weed management method. (1) The planting time for WSR in 1D and in 7M and 7D shifted later (i.e. from late May to early June in WSR 2008 to early June to mid July in WSR 2009) as a consequence of introduction of DSR 2009 within a crop calendar (Fig. 3.5). (2) With the progress of introduction of DSR, dry seeding method has sharply declined and has been replaced by wet seeding method in WSR (Table 3.5). When DSR is fully cultivated in the KPIR area with the present crop calendar, earliest possible time of planting of the following WSR is late June, which would be too late to use dry seeding methods due to the rainfall in early wet season. (3) As a result of the later sowing and later plant establishment in WSR 2009, the chance for conducting mid-season tillage practice was narrowed, and the area with this practice declined from 2008 to 2009 in the studied area (Table 3.5).

Farmers in KPIR area are considered to be facing with the 3 technical challenges in rice production due to these changes in management practices as a consequence of introduction of double cropping system. (A) The first challenge is the tight schedule and shortage of labor from DSR harvest to WSR planting. In the present cropping calendar, in which DSR was harvested mainly in June, planting window for WSR (e.g., late June to August) was narrow and farmers had to become too busy. One possible solution to mitigate the labor pressure would be to finish DSR earlier by planting earlier. The planting time of dry season irrigation in DSR 2010 was made earlier due to earlier beginning of irrigation (1st February 2010) than that of DSR 2009 (early February vs late February); this would probably be as a result of farmers learning of the very tight labor requirement in June and July in the newly introduced double cropping system in 2009. The planting time of DSR can be shifted further earlier in January only if the late maturing varieties (i.e. Neang Khon) with their harvest time around early to mid January were replaced with earlier maturing varieties in WSR, as discussed in the next section. Introduction of harvesting machine for both WSR and DSR will be also helpful to reduce the duration of harvest so as to provide wider windows for WSR planting.

(B) The second challenge is the techniques for improving plant establishment in WSR. While dry seeding method allows wider windows for planting and requires less managemental efforts, wet seeding method requires careful land preparation (i.e. land leveling) and field water management for successful crop establishment. Furthermore, farmers in KPIR area, particularly in 950 ha area may lack options for wet seeding methods because of just recent introduction of DSR. Therefore, the introduction of improved technologies related to wet seeding method (i.e. land leveling method, drum seeding) to farmers may contribute to increase rice productivity in KPIR area.

(C) The third challenge is an alternative weed management in WSR. Mid-season tillage is a unique traditional practice in Northwest Cambodia in order to control weeds in an ecologically harmonized way without solely relying on herbicides (Kamoshita et al., 2009, 2010). The decrease or disappearance of this practice may lead to the necessity for new weed management such as use of herbicide in KPIR area. Effective herbicide types and proper application techniques should be introduced to the farmers.

3.4.3 Grain yield assessment

Irrigated rice is usually taken as much higher yielding than rainfed rice (e.g., Fairhurst and Dobermann, 2002), but our study supported the third hypothesis, showing lower actual yield level in KPIR area than expected yield potential of irrigated rice, clarifying several yield limiting factors, and indicating the necessity of agronomic analysis and extension support to farmers.

Grain yield on average for both DSR 2009 and 2010 in our study were 32% lower than grain yield of 4 t ha^{-1} (USDA, 2010) recorded as for the whole Cambodia in DSR 2008. This is primarily due to the low yield potential of San CraOrb in KPIR area in our study with maximum yield of only 3.9 t ha^{-1} (Table 3.7) while most of the Cambodian DSR (estimated as 85% in area) is cultivated with one of the high yield potential IR varieties, IR66 (Koma, 2008). In addition, Cambodian government figures on grain yield for DSR refer to both irrigated rice in double cropping system (such as in KPIR area) and recession rice (in a single cropping system to use receding water in deep water area) with larger proportion of the latter (Ouk et al., 2001; USDA, 2010), which yields generally higher than the former (because of high fertility of the silt deposited by the floods). These might be the reasons for the differences in yield in DSR in this study and the national recorded data.

Grain yield in KPIR area was reported in a few publications such as JICA (2003) and Try (2007). In comparison with the average grain yield in DSR 2002 in KPIR area with the value of 2.3 t ha^{-1} (JICA, 2003), the average grain yield for both DSR 2009 and 2010 was only 17% higher. According to Try (2007), grain yield in irrigated area in KPIR area was estimated to range from 2.5 to 4 t ha^{-1} (no average data presented) in DSR 2007. In our study, the higher limit of grain yield was similar to Try (2007), but the lower limit was much lower. This is probably because our study could capture wider variation in environments and farmers' management practices from upstream to downstream fields. It should be also noticed that grain yields in our study were from the downstream zone (950 ha area), not necessarily representing for the whole KPIR area (about 5000 ha); the 950 ha area might have been less advantageous in irrigation water access. The lower yield

(2.5 t ha^{-1}) than the expected outputs from the irrigation rehabilitation project was also reported in Stung Chinit irrigation scheme (Try, 2008).

Yield limiting factors for DSR suggested from our study are (1) weed infestation (Table 3.9), (2) disease occurrence (for 2010), (3) high temperature (for 2010), (4) small agricultural inputs such as inorganic N fertilizers and herbicides, (5) unavailability of some agricultural resources such as herbicides for grass and fungicides, (6) farmers' lack of knowledge for photoperiod sensitivity of variety for DSR, (7) immature experiences of water management for DSR.

For example of (4), the average rates of herbicide used in the studied area (628 and 367 g a.i. ha^{-1} in 2009 and 2010, respectively) were lower than recommended rate written on the products (about 800 g a.i. ha^{-1}), which had allowed weed infestation and reduced yield in DSR. Besides that all of the herbicides are 2,4-D, and no herbicides effective to kill grass was available for the surveyed farmers in KPIR area (i.e. example of (5)), in spite of common presence of grass species such as *Echinochloa colona* (Araki et al., in preparation). Another problem on plant protection was the extensive occurrence of brown spot (*Bipolaris oryzea*) and narrow brown spot (*Cercospora oryzea*) diseases from flowering stage in most of the fields in the 950 ha area in DSR 2010 (i.e. example of (2)), which reduced 1000-grain weight and yield (Table 3.7). High plant density in DSR 2010 (432 panicles m^2 in DSR 2010 vs. 329 panicles m^2 in DSR 2009) might have been a factor to create a favorable condition for the development of these diseases, but the problem was that fungicides are not sold in the shops in the KPIR area, and that farmers wrongly applied insecticide in DSR 2010 instead of fungicides (i.e. example of (5)).

The amounts of applied N fertilizer for DSR (about 44 kg ha^{-1} in Table 3.6) were also small (i.e., example of (4)), only about one-third of the recommendation rate for DSR (120 kg N ha^{-1} in Balasubramnian and Hill, 2002). It is not known whether insufficient application is derived from lack of money for purchasing, lack of knowledge for the optimum application of N fertilizer, or farmers' consideration of risk and further investigation is needed.

As examples of (6), some farmers bought and planted wrong seeds of photoperiod sensitive varieties from rice millers in the village for DSR, and lowest yields of DSR were recorded in 7M (2009) and 7D (2010) (Table 3.8) where DSR was cultivated for the first time (Fig. 3.5) (i.e., example of (7)).

As the other possible cause for lower grain yield in DSR 2010 than DSR 2009, with lower percentage of ripened grain, 1000-grain weight and harvest index (Table 3.7), we speculated the occurrence of high temperature in April and May (i.e. average max. of about 37 ^{0}C) in 2010 (Table 3.2) (i.e., example of (3)). According to Jagadish et al. (2007), less than 1 hour exposure to high temperature ($\geq$ 33.7 ^{0}C) at flowering stage caused rice spikelet sterility while Lin et al. (2010) found that high temperature (35/30 ^{0}C day/night) during grain-filling significantly reduces grain weight and grain quality. Although the higher temperature in 2010 was an extreme event not only in Cambodia but also in many parts of the world which was mainly due to El Niño effect (NOAA, 2011), air temperature in Cambodia is relatively high in every dry season with peak in April (average max. of 35 ^{0}C). Therefore, sowing time in DSR is an important factor affecting grain yield through the timing of flowering and grain-filling which are sensitive to high temperature. Sowing early in January will give an advantage to widen the planting window for WSR as discussed in the previous section but there will be a high chance for flowering and/or grain-filling period falling in the highest temperature period in April.

Average grain yield values in WSR 2008 and 2009 in KPIR in this study was almost comparable (about 12 % higher) to the reported value of yield for improved varieties for the whole Cambodia in 2008 (2.6 t ha^{-1}) (USDA, 2010). In comparison with the grain yield in WSR 2002 (2.4 t ha^{-1}) recorded in irrigated area in KPIR area (JICA, 2003), the average grain yield in both WSR 2008 and 2009 in this study were about 20% higher.

Results of our study suggested that increasing farmers' adoption of higher yielding Raing Chey variety has contributed to the yield improvement of WSR in KPIR area. This variety also has been increasingly adopted by farmers in many provinces in Cambodia (Fukai, 2006). However, the constraint of further adoption of Raing Chey variety in the 950 ha area in KPIR area is deepwater in downstream fields. Improving the drainage system may help to prevent the 7D fields from flood and expand Raing Chey variety to this downstream area for increasing rice productivity in WSR. Enlarging and deepening the main drainage canal as well as improving the connection from the canal to the Outaki River may help to drain the exceeding water in the canal during October and November.

In general, agricultural extension is extremely needed in order to enhance productivity in both DSR and WSR in KPIR area. As dry season rice has still been new to the farmers, knowledge on DSR varieties, technical advices and agricultural resources for crop management and plant protection should be introduced to them as soon as possible. High temperature may be also an important factor limiting grain yield in DSR in KPIR area and it should be further studied including the optimum planting time for maximizing attainable yield and for reducing labor demand pressure from DSR harvest to WSR planting seasons in June to August. Irrigation water management in DSR and drainage system are also need to be improved so that downstream fields in D2-7 will not encounter the water shortage at establishment stage in DSR and flood problem in WSR.

Chapter 4

Assessment of management practices and grain yield in deepwater rice in Northwest Cambodia

4.1 Introduction

Deepwater rice (DWR) area is defined as rice growing area where water depth is more than 50 cm for a month or longer during the growing season (Catling et al., 1988). Rice varieties which can grow in such environment are those that can tolerate to deepwater and submergence by elongation or remain stunted under water until flood recedes (Nagai et al., 2010). There are about 11 million ha of DWR which is located mainly in South and Southeast Asia and some in West Africa, with very low crop productivity of only 1.5 t ha^{-1} (Bouman, 2007) due to unpredictable combinations of both drought and flood.

In Cambodia, DWR areas are located in the provinces near to the Tonle Sap Lake, the Mekong River, and Tonle-Bassac River. Main DWR areas are located in Kampong Thom, Banteay Meachey, and Battambang provinces. In 1960s, the DWR area occupied up to 16% of Cambodia's rice land (about 400,000 ha) (Javier, 1997; Seng et al, 1988). However, as the discouragement of growing DWR during Pol Pot regime, DWR area decreased sharply and it was only 120,000 ha in 1988 (Seng et al., 1988). The area has been further decreased due to the conversion of DWR into recession dry season rice (planting around November after flood receding and harvesting in February or March, see more explanation in the Chapter 2) which can give higher yield.

DWR represented only 3.9 % of the cultivated area in 2006 (MAFF, 2006). Although DWR occupied only small part of the rice cultivated area, it is important source of livelihood to many poor villages that do not have access to better agricultural land higher up and the conversion may not be feasible due to difficulty in the socio-natural conditions of the target areas. For instance, in Battambang province, DWR area occupied 8% (21,930 ha) of the rice cultivated area in 2009 and in some districts of the province such as Sangkea and ExPhnom, DWR occupied very large area of the rice cultivated area with 29% (9,056 ha) and 57% (5,041 ha) in 2009, respectively (BPDA, 2010). DWR area has increased rapidly from 16,810 ha in 2007 to 21,930 ha in 2009 in Battambang province due to the availability of tools for clearing flooded bushes/forest near Tonle Sap Lake. Furthermore, DWR area does not provide only food but also many other external goods such as fish and plants. Hence, there is a need to further improve productivity of DWR in order to improve the local farmers' livelihood and to conserve the DWR area.

DWR growing environments vary from upland conditions often prone drought stress in early growth stage to deep water conditions (>100 cm) with year to year unpredictable flooding patterns during the booting and flowing stage, and shallow water or/and to upland condition at near maturity (at the end of rainy season) (Catling et al, 1988). Cambodian's Tonle Sap Lake (TSL) floodplain is well known for its unique dynamic flooding pattern between dry and rainy season. Volume of the Lake ranges from about 1.3 km^3 up to 75 km^3, its surface area varies from 2,500 km^2 up to about 15,000 km^2, and its water level increases from 1.4 m to 10.3 m above sea level, between dry and rainy season (MRC, 2010a). On large flat plain with very gentle slope, which spreads in Battambang, Banteay Meachey and Kampong Thom provinces, different rice types (floating rice (FR) and lowland rice (LR)) are planted depending on water depth and distance to the Lake. Along transect from TSL to the national road surrounding the Lake, lowest part could be a floating rice area with water depth of more than 100 cm and the highest may be suitable for late maturity rainfed lowland rice (medium DWR) with water depth of 50-100 cm (Javier, 1997). However, flooding pattern of DWR area in TSL floodplain has not been studied and it is unknown how management practices and rice yield are spatially different among these two rice types and how the area proportion of these two rice types may change from year to year in a given DWR area.

We conducted a study to quantify the yearly and spatially difference in field water condition in DWR area in Northwest Cambodia, and to assess rice management practices and grain yield in the area. We have two hypotheses (1) yield performance spatially vary in/around floodplain of TSL depending on field water environment and farmers' management practices; and (2) farmers should adapt their management practices so that they can balance to maximize yield and to avoid risk of flood damage.

4.2 Materials and methods

4.2.1 Study site

The Mekong River joins the Tonle Sap River and separates with the Bassac River in the central part of Cambodia (Fig.4.1.). The flood plain area and its flooding depth differ from year to year due the changing direction in Tonle Sap River. Water flows from Tonle Sap River to the lake during May/June and the stored water flows back to the Mekong River in September/October (Shimizu et al., 2006). The study was carried out at a DWR area inside a flood plain area of Tonle Sap Lake located in Kompong Preah village, Kompong Preah commune, Sangkea district, Battambang province, Northwest Cambodia. The village has 1,050 ha of rice land, of which DWR area constitutes of 39% (480 ha). In 2008, we selected 8 fields located along a transect line from the National Road Number 5 (i.e. topo-sequentially upper part) to Tonle Sap Lake (lower part) to study (★1 to★8) (Fig.4.1). In 2009 and 2010, the survey was conducted more intensively in 85 fields (91.2 ha in planting area) located continuously along the same transect line but only between ★ 3 and ★ 8 (approximately flood plain of the TSL) which was flooded in 2008 and spatially different for both water environments and rice variety type (LR) and FR). These 85 fields were divided into 3 groups according to their field locations: (1) upper fields located closer to the National Road Number 5 where only LR was grown (19 fields; 11.4 ha); (2) middle fields where both LR and FR were grown (19 fields; 31.6 ha); and (3) lower fields located near to the Lake where only FR was grown (37 fields; 48.2 ha). The boundary of middle fields were defined by upper limit in 2009 (the furthest point to the upper fields where FR was grown) and lower limit in 2010 (the furthest point to the lower fields where LR was grown) (Fig.4.1 and and Table 4.1). In 2010, a path road was constructed along our surveyed transect and this contributed to deepen the canal up to most end of the middle fields.

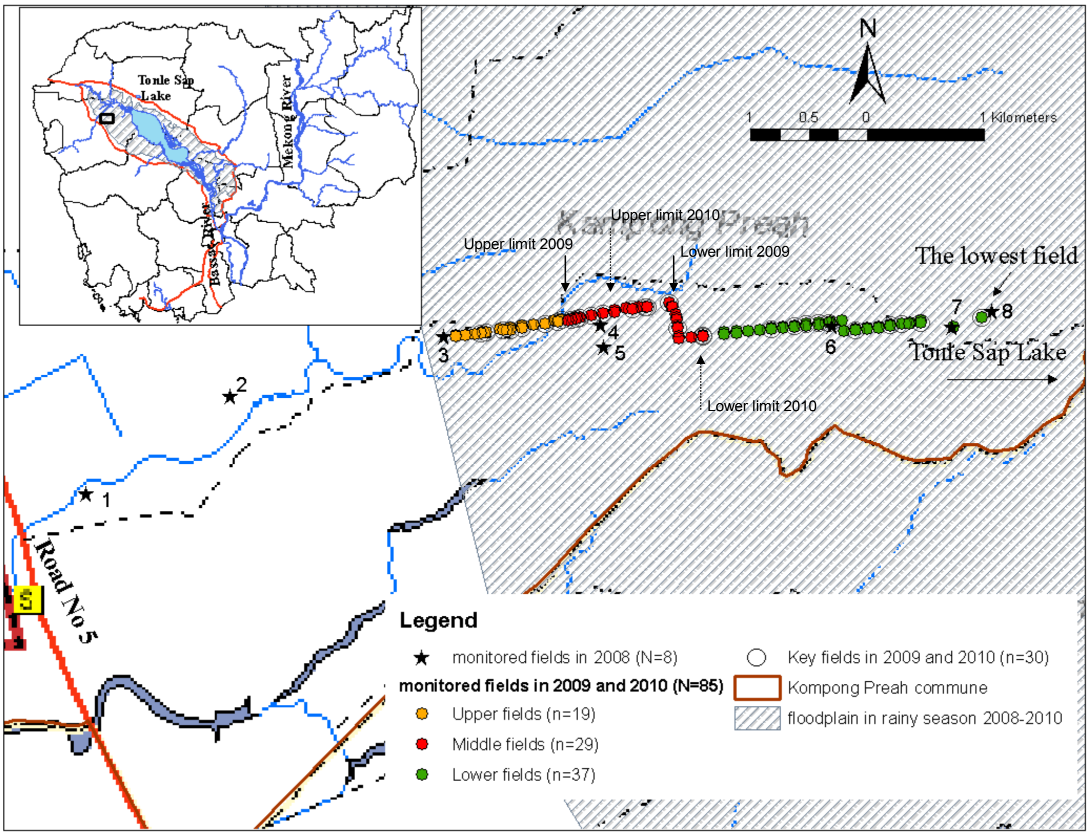

Fig.4.1. Location of study site

Table 4.1. Numbers and area of the surveyed fields from 2008 to 2010

2008			2009 and 2010				
						field size (ha)[4]	
field name	rice type	field size (ha)	field location[1]	N[2]	n[3]	single	total
★1	LR	0.5	upper	19	8	0.6±0.2	11.4
★2	LR	0.3					
★3	LR	0.5					
★4	FR	1	middle	29	12	1.1±0.8	31.6
★5	LR	1.4					
★6	FR	2	lower	37	10	1.3±0.8	48.2
★7	FR	4					
★8	FR	8					
Total				85	30	1.1±0.8	91.2

[1] The boundary of middle fields were defined by upper limit in 2009 (the furthest point to the upper fields where FR was grown) and lower limit in 2010 (the furthest point to the lower fields where LR was grown)

[2] N indicates number of fields where rice type, rice verities and visual yield were monitored

[3] n indicates number of key fields where rice has been sampled for yield evaluation and yield component analysis, and farmers' management practices of the fields were interviewed.

[4] Area was calculated based on N samples

4.2.2 Measurement

Variety, field size and type of rice were determined for the 8 fields in 2008 and for the 85 fields (visual yield level were determined in 2009 and 2010 at flowering to grainfilling stage (late November to mid December)) in 2009 and 2010. In our study, LR, often called *srau srok* in Khmer by farmers, includes both rainfed lowland rice and DWR growing in areas with water depth of 50-100 cm over a period of at least one month as defined by Catling (1992). FR, often called *srau langtak* or *srau vea* in Khmer by farmers, involves varieties growing in areas with water depth greater than 100 cm for at least a month. This rice type has good elongation ability and they elongate as the water level rises (Fig.4.2). A farmer with good knowledge on rice farming in the area was asked to company us along the transect for his visual assessment of yield level (bad, medium, good) of each field, and for clarification of rice type and variety. According to the farmer' perception, yields with less than approximately1.5 t ha^{-1} were assessed at bad level while yields ranging between approximately1.5 and 2.5 t ha^{-1} and greater than approximately 2.5 t ha^{-1} were assessed at medium and good level, respectively.

For measurement of water depth and grain yield, and assessment of farmer's management practices in 2009 and 2010, thirty fields within the 85 fields on the transect were selected based on the field locations as shown in Table 4.1 (8 fields in the upper part, 12 fields in the middle part, and 10 fields in the lower part).

Owners of the 30 key fields were identified and interviewed in ending time of each for information on sowing time, seed rate, mid-season tillage practice, fertilizer input, pest control and grain yield.

Water depth was measured for each of the 30 field once in about every 2 weeks. Water conditions at heading stage was recorded based on 3 categories of non-flooded dry, saturated, and flooded.

Grain yield in 2009 was measured by sampling one quadrate of 1m x 1m in each field at maturing time. Procedures for rice sampling and processing for yield components were similar as those described in Chapter 3. Grain yields in 2010 were obtained from yields from farmers' interview.

Analysis of variance using Waller-Duncan (Waller and Duncan, 1969) was conducted to examine the differences in yields and yield components among the 4 combinations of field location and rice type (LR upper fields, LR middle fields, FR middle fields and FR in lower fields); and the differences in yield among the 3 field locations with various field water condition at heading stage (non-flooded, saturated and flooded). Independent-samples t-test was used to test the yearly differences in fertilizer and herbicide use, the effect of midseason tillage practice (without or with midseason tillage), method of midseason tillage (harrowing or plowing, and time), and N fertilizer application (before flood or others) on yield. The relationship between yield and maximum water depth, sowing time, amount of N fertilizer and herbicide were analyzed using simple coefficients. As sampled yield was only available in 2009, interviewed yield was used for all analysis except in Table 4. 6 which is related to yield components. In 2009, one FR field in lower area was not use for analysis because it was seriously damaged by rats.

Fig.4.2. Floating rice at booting stage in mid November (a) and harvesting time in early January (b) in DWR area in Kompong Preah village

4.3 Results

4.3.1 Field water environment

In general the presence of standing water started in September and reached maximum in October in the studied area (Fig.4.3). Fields became non-flooded conditions in early December. However, field water regime of the studied area in 2008 and 2009 was completely different from that in 2010. In 2008 and 2009, water came to the fields from both the Tonle Sap Lake and rainfall. Flood started earliest in lower fields in September, then middle and upper fields afterward. Flood started receding to the Lake in late October and rice fields became non-flooded conditions in middle fields and upper fields in late November and in lower fields in early to mid December. There was large difference in water depth between the 3 field locations in 2008 and 2009. In 2009, average maximum water depths of upper, middle and lower fields in mid October were 40 cm, 85 cm, and 169 cm, respectively. In 2010, water came to the fields from only rainfall, field water regime was relatively similar in all the 3 field locations with the average maximum water depths of 25 cm, 24 cm, and 26 cm for upper, middle and lower fields in mid October, respectively (Fig.4.3).

4.3.2 Management practices

4.3.2.1 Crop calendar

Planting season for FR fields is earlier than that for LR fields. For FR fields, farmers start land preparation from early March to late April (Fig.4.3). Dry seeds with rate of about 100 kg ha^{-1} are broadcasted mainly from early April to early May. Farmers sometimes have to broadcast seeds for the second time in late May or early June if rice establishment failed due to drought. For LR fields, land preparation is often from mid April to mid May. Dry seeds with higher rate in comparison with FR (150 kg ha^{-1}) are broadcasted from mid May to mid June. Farmers often redistribute the seedlings in LR fields where the establishment is not uniform in August or September depending on the availability of water in the fields.

Rice is harvested from early December to early February depending on rice varieties in FR fields while it is from late November to early January in LR fields (Fig.4.3).

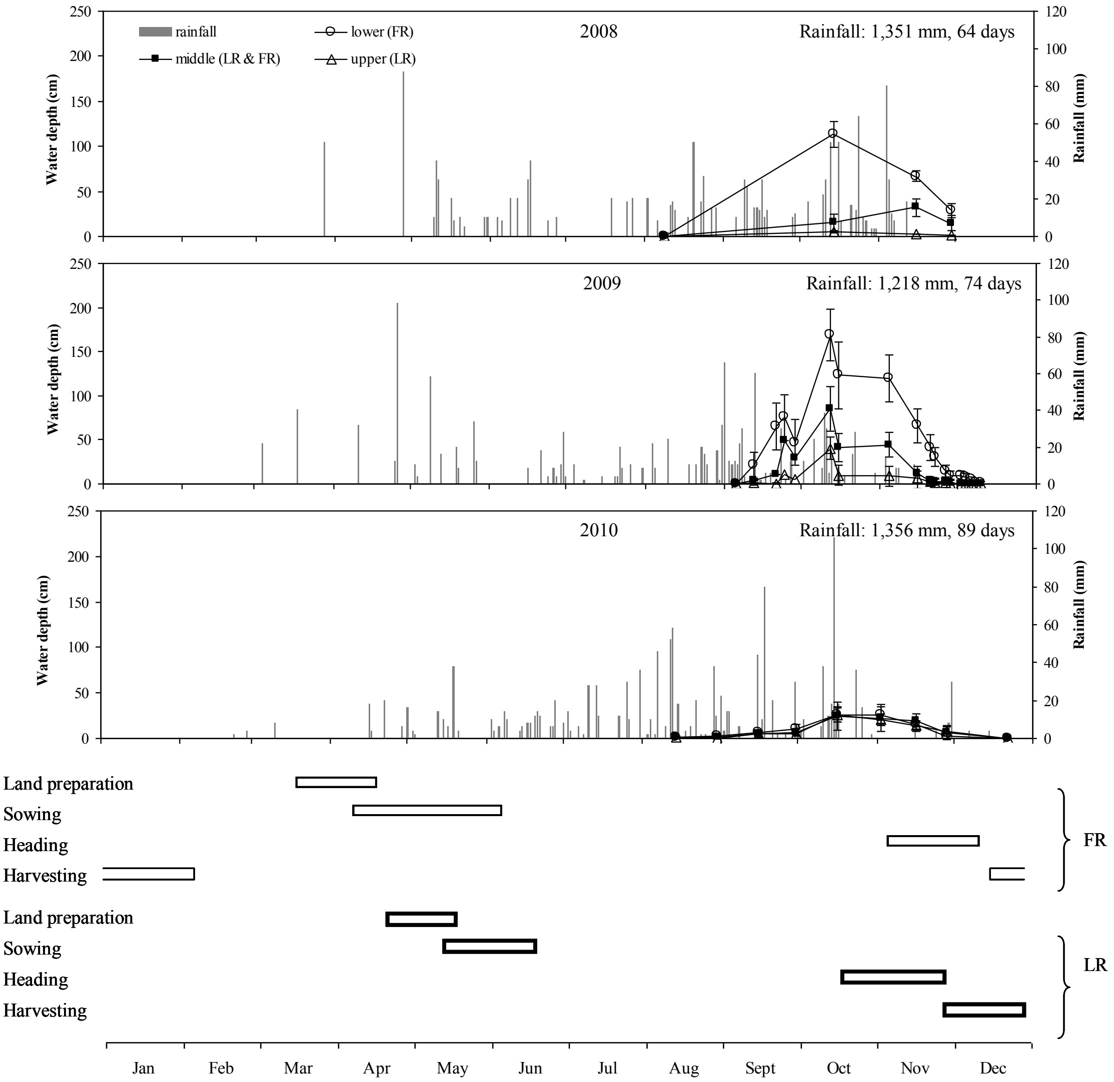

Fig.4.3. Rainfall distribution and water depth in the 3 field locations (upper, middle and lower) in 2008, 2009 and 2010, and cropping calendar for FR and LR in the studied area. The error bars indicate standard deviations. In 2008, upper fields are with field number from ★1 to ★3, middle fields with number ★4 and ★5, and lower fields with number from ★6 to★8 (Table 4.1).

4.3.2.2 Distribution of rice type and varieties

There were 4 varieties with different heading time for the each rice type (FR, LR) (Table 4.2). LR varieties belong to two variety groups, early medium maturity variety (Phka Rumdoul) and medium maturity variety (Phka Knei, Raing Chey and Kon Cham Cham). FR varieties belong to three varieties groups: early maturity variety (Veal Sra), medium variety (Sar Kranhanh) and late varieties (Sar Kranhak and Veal Veng). Although all these 4 FR varieties are traditional ones, only Sar Kranhak is a local variety in the study site. The others have been adopted by farmers from other deepwater area around Tonle Sap Lake such as in Kompong Thom province. Local farmers said that most of their local FR varieties were lost due to the serious flood in 1978 in combination with the policy of elimination of deepwater and rainfed lowland rice during Pol Pot regime.

In general, early medium variety of LR was only planted in upper fields while medium variety of LR was planted in both upper and middle fields (Table 4.2). The same pattern was observed in FR fields. Early variety was only planted in middle fields while medium and late varieties were planted in both middle and lower fields. However, late variety of FR was mainly planted in lower fields.

In comparison between 2009 and 2010, there was a small change in the area ratio of LR and FR in middle area. Area of LR decreased from 38% in 2009 to 30% in 2010 but area of FR increased from 62% in 2009 to 70% in 2010. Among the 8 varieties planted in the studied area, Veal Sra in the middle area had the largest increase in area percentage, from 22% in 2009 to 47% in 2010 (Table 4.2). The second largest increase in area percentage was Sar Kranhanh in the lower area (from 67% in 2009 to 83% in 2010). However, there were decreasing trend from 2009 and 20010 for the area percentage of Kon Cham Cham in middle area (14% vs 0%), Sar Kranhanh in the middle area (34% vs 23%), and Veal Veng in the lower area (28% vs 17%).

Table 4.2. Area (ha) and area percentage of varieties and rice type in the 3 field locations in 2009 and 2010 in the studied area

					Field location			
Year	Variety	Rice type	Heading time	Variety type	Upper	Middle	Lower	Total
2009	Phka Rumdoul	LR	mid Oct	early medium maturity	1.5 (13%)			1.5 (2%)
	Kon Cham Cham	LR	mid to late Nov	medium maturity	3.5 (31%)	4.5 (14%)		8.0 (9%)
	Raing Chey	LR	mid to late Nov	medium maturity	6.4 (56%)	7.5 (24%)		13.9 (15%)
	Veal Sra	FR	early to mid Nov	early maturity		6.7 (22%)		6.7 (7%)
	Sar Kranhanh	FR	late Nov	medium maturity		10.9 (34%)	32.2 (67%)	43.1 (47%)
	Sar Kranhak	FR	late Nov to early Dec	late maturity			2.5 (5%)	2.5 (3%)
	Veal Veng	FR	early to mid Dec	late maturity		2.0 (6%)	13.5 28%)	15.5 (17%)
	Total				11.4 (100%)	31.6 (100%)	48.2 (100%)	91.2 (100%)
2010	Phka Rumdoul	LR	mid Oct	early medium maturity	2.9 (25%)			2.9 (3%)
	Phka Knei	LR	early to mid Nov	medium maturity	4.4 (39%)	1.0 (3%)		5.4 (6%)
	Raing Chey	LR	mid to late Nov	medium maturity	4.1 (36%)	8.5 (27%)		11.6 (13%)
	Veal Sra	FR	early to mid Nov	early maturity		14.9 (47%)		14.9 (17%)
	Sar Kranhanh	FR	late Nov	medium maturity		7.2 (23%)	40.2 (83%)	47.4 (52%)
	Veal Veng	FR	late Nov to early Dec	late maturity		0.0 (0%)	8.0 (17%)	8.0 (9%)
	Total				11.4 (100%)	31.6 (100%)	48.2 (100%)	91.2 (100%)

4.3.2.3 Fertilizer use and weed control

Farmers did not apply organic fertilizer in the area in both 2009 and 2010. Inorganic fertilizer was only applied for LR upper fields and LR middle fields in both years (Table 4.3). Urea fertilizer (46-0-0) produced either in Vietnam or in Thailand was the most popular fertilizer in the area. Only few farmers used phosphorus fertilizer (16-20-0). Average amounts of applied N fertilizer in 2010 for both LR upper fields (20.9 kg ha^{-1}) and LR middle fields (20.5 kg ha^{-1}) tended to be higher than those in 2009 (15.3 kg ha^{-1} for LR upper fields and 4.4 kg ha^{-1} for LR middle fields) although it was statistically different only in LR middle fields.

Weeds were controlled by both herbicide of 2,4-D and midseason tillage for LR and only by herbicide of 2,4-D for FR. Most of farmers applied herbicide of 2,4-D before flood came (July, August) to control weeds in all field groups with the average amount ranged from 282 (FR in lower fields) to 417 (LR upper fields) g a.i. ha^{-1} in 2009 and from 359 (LR middle fields) to 792 (FR in lower fields) g a.i. ha^{-1} in 2010. In FR lower field area, average amount of herbicide in FR lower fields in 2010 was significantly higher than that in 2009 (Table 4.3). Midseason tillage (described in Chapter 3) was conducted in 75% of fields in LR upper fields and only 20% of fields in LR middle fields in 2009 while it was conducted in all LR upper fields and LR middle fields in 2010.

Table 4.3. Use of nitrogen fertilizer and herbicide and practice of midseason tillage in LR upper fields (ULR), LR middle fields (MLR), FR middle fields (MFR) and FR lower fields (LFR) in 2009 and 2010 in the studied area

Items	Year	Location and rice type			
		ULR	MLR	MFR	LFR
n		8	5	7	9
N (kg/ha)	2009	15.3 ± 10.5	4.4 ± 6.0	0	0
	2010	20.9 ± 9.2	20.5 ± 11.7	0	0
P			**		
Herbicide (g a.i.ha^{-1})	2009	417 ± 731	335 ± 107	406 ± 275	282 ± 153
	2010	385 ± 322	359 ± 284	583 ± 417	792 ± 408
P					***
Mid-season tillage (% of fields)	2009	75	20	0	0
	2010	100	100	0	0

**P<0.05 and ***P<0.01

4.3.3 Relationship between grain yield and environmental and management factors

4.3.3.1 Comparison of yield and yield components among the 4 field groups

4.3.3.1.1 Visual yield level in 2009 and 2010 (N=85)

In general, fields with medium visual yield level (with the same absolute standard) occupied highest area percentage in both 2009 and 2010, which were 50% and 60%, respectively (Table 4.4). The next high area percentage was for fields with bad visual yield level for both 2009 and 2010 with 29% and 31%, respectively. There were 30% of fields with good visual yield level in 2009 while it was only 8% in 2010.

In 2009, area percentage of bad visual yield level was found to be highest in middle area for both LR and FR, which were 58% and 52%, respectively. In LR upper area and FR lower area, yield of about half of the field area was visually assessed as medium level. There was not any field with good visual yield level in FR middle area while there were 26%, 8% and 30% of field area with good visual yield level in LR upper, LR middle and FR lower area respectively. Differently from 2009, area percentage of bad visual yield level was found to be highest in only FR middle area (67%) while this yield level was not found in any LR fields in both upper and middle area in 2010. In 2010, good visual yield level was observed in 60% and 22% of the area in LR upper and middle location, respectively while it was not found in any fields in both FR middle and lower area.

4.3.3.1.2 Interviewed yield in 2009 and 2010 (n=30)

In general, grain yield of LR was significantly higher than that of FR (177 g m^{-2} vs 108 g m^{-2}) (Table 4. 5). Grain yield of LR in 2010 was highest (262 g m^{-2}) compared with both FR in both 2009 (117 g m^{-2}) and 2010 (101 g m^{-2}) and LR in 2009 (93 g m^{-2}).

In 2009, grain yields of LR upper fields and FR lower fields were significantly higher than those of LR and FR in middle area (Fig.4.4). Average grain yields were 120 and 164 g m^{-2} for LR upper fields and FR lower fields, respectively while they were 50 and 56 g m^{-2} for LR and FR in middle fields, respectively. However, in 2010, grain yields of both LR and FR middle fields were significantly higher than those of FR middle and lower fields. Average grain yields were 262 g m^{-2} for both LR upper and middle fields while they were 87 and 111 g m^{-2} for FR in middle and lower fields, respectively. There was no significant difference in yields between FR middle and FR lower fields in 2010.

4.3.3.1.3 Sampled yield and yield components in 2009

Similar to the interviewed yields in 2009, sampled yields of LR upper fields and FR lower fields were significantly higher than those of LR and FR in middle fields (Table 4.6). Plant heights of FR were significantly higher than those of LR and the highest plant height was found in FR lower fields with average of 284 cm. Among the 4 field groups, FR lower fields had highest shoot dry matter (1,082 g m^{-2}) while LR upper fields has highest harvest index (27%). Number of spikelets per square meter of LR upper fields and FR upper fields were significantly higher than those of LR and FR middle fields. The 1000-grain weight of FR was higher than that of LR (26 g vs 22 g).

Table 4.4. Area (ha) and area percentage with visual yield levels (good, medium or bad) for LR upper (ULR), LR middle (MLR), FR middle (MFR) and FR lower (LFR) in 2009 and 2010 in the studied area

Year	Filed location	Variety type	good		medium		bad		Total	
2009	ULR	medium	0	0%	1	67%	0.5	33%	1.5	100%
		late	3	30%	4.3	43%	2.6	26%	9.9	100%
		total	3	26%	5.3	46%	3.1	27%	11.4	100%
	MLR	late	1	8%	4.0	33%	7.0	58%	12	100%
		total	1	8%	4.0	33%	7.0	58%	12	100%
	MFR	early	0	0%	6.7	100%	0	0%	6.7	100%
		medium	0	0%	2.8	26%	8.1	74%	10.9	100%
		late	0	0%	0.0	0%	2.0	100%	2.0	100%
		total	0	0%	9.5	48%	10.1	52%	19.6	100%
	LFR	medium	5.2	15%	23.5	68%	6.0	17%	34.7	100%
		late	9.5	70%	4.0	30%	0.0	0%	13.5	100%
		total	14.7	30%	27.5	57%	6.0	12%	48.2	100%
	total		19	21%	46.0	50%	26.2	29%	91.2	100%
2010	ULR	medium	0.4	14%	2.5	86%	0.0	0%	2.9	100%
		late	5.1	60%	3.4	40%	0.0	0%	8.5	100%
		total	5.5	48%	5.9	52%	0.0	0%	11.4	100%
	MLR	late	2.1	22%	7.4	78%	0.0	0%	9.5	100%
		total	2.1	22%	7.4	78%	0.0	0%	9.5	100%
	MFR	early	0.0	0%	7.4	50%	7.5	50%	14.9	100%
		medium	0.0	0%	0.0	0%	7.2	100%	7.2	100%
		total	0.0	0%	7.4	33%	14.7	67%	22.1	100%
	LFR	medium	0.0	0%	31.2	78%	9.0	22%	40.2	100%
		late	0.0	0%	6	75%	2.0	25%	8.0	100%
		total	0.0	0%	37.2	77%	11.0	23%	48.2	100%
	total		7.6	8%	54.9	60%	28.7	31%	91.2	100%

Table 4. 5. Interviewed grain yield (g m^{-2}) by rice type in wet season rice 2009 and 2010

Year	Rice type	n	Mean		Minimum*	Maximum	CV (%)
2009	floating rice	16	117	a	8	233	64
	lowland rice	13	93	a	0	188	70
2010	floating rice	17	101	a	50	145	23
	lowland rice	13	262	b	200	360	16
Total	floating rice	33	108	a	8	233	50
	lowland rice	26	177	b	0	360	57

Values within the column followed by the same letter are not significantly different at 0.1%.

* Including 2 fields of lowland rice in middle area that are completely damaged by flood

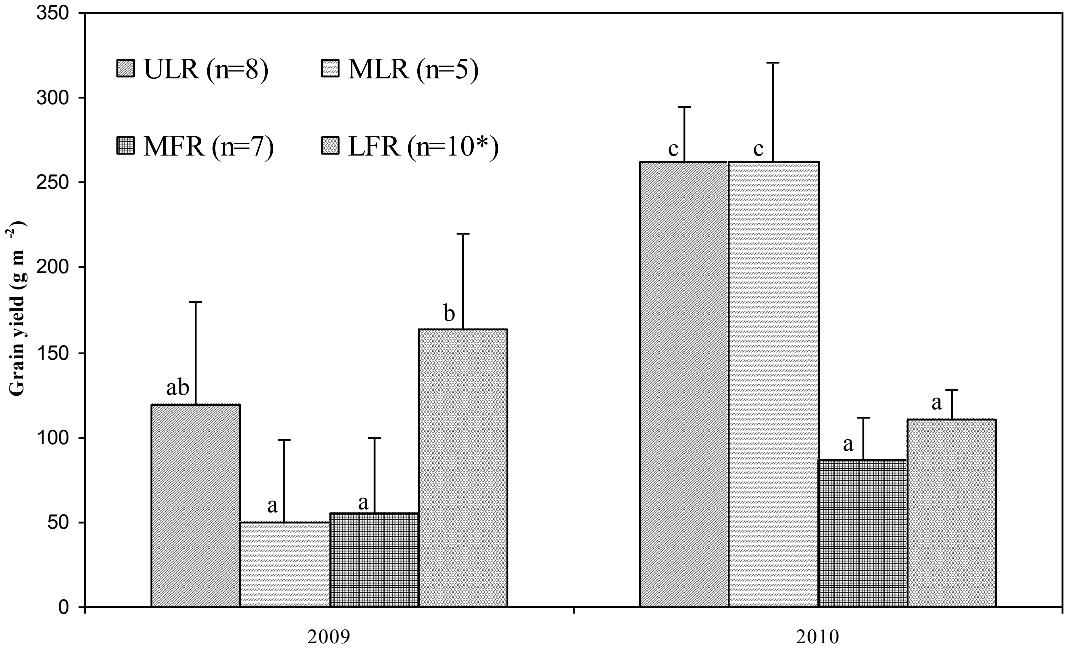

Fig.4.4. Grain yield (interviewed) for LR upper (ULR), LR middle (MLR), FR middle (MFR) and FR lower (LFR) in 2009 and 2010 in the studied area. Values above bars followed by the same letter are not significantly different at 1% level for the both years. *n=10 in 2010 and n=9 in 2009 (one field was seriously damaged by rats). The error bars indicate standard deviations.

Table 4. 6. Grain yield (sampled) and yield components for LR upper (ULR), FR middle (MLR), FR middle (MFR) and FR lower (LFR) in 2009

Items	Location and rice type	n[1]	Mean[2]		Minimum	Maximum	CV%
Grain yield (g m^{-2})	ULR	8	229	b	38	365	55
	MLR	5	109	a	-	251	100
	MFR	7	101	a	18	210	74
	LFR	9	231	b	135	357	33
Plant height (cm)	ULR	8	121	a	92	145	15
	MLR	3	130	a	114	146	17
	MFR	6	181	b	155	204	12
	LFR	9	284	c	244	322	11
Shoot dry matter (g m^{-2})	ULR	8	653	a	252	952	39
	MLR	3	651	a	429	891	36
	MFR	7	594	a	441	808	23
	LFR	9	1,082	b	505	1,568	35
Harvest index (%)	ULR	8	27	b	10	38	41
	MLR	3	24	ab	22	26	82
	MFR	7	13	a	3	23	62
	LFR	9	19	ab	12	27	23
No of panicle per m^2	ULR	8	130	a	57	178	33
	MLR	3	132	a	93	162	27
	MFR	7	87	a	28	136	50
	LFR	9	105	a	56	150	27
No of spikelets per panicle	ULR	8	97	a	41	167	41
	MLR	3	91	a	70	110	22
	MFR	7	78	a	51	118	33
	LFR	9	137	b	101	165	17
No of spikelets per m^2	ULR	8	13,085	b	3,570	20,506	50
	MLR	3	11,862	ab	8,659	15,579	29
	MFR	7	6,311	a	1,954	10,030	46
	LFR	9	14,385	b	7,810	20,316	30
Percentage of ripened grains	ULR	8	70	a	44	84	23
	MLR	3	70	a	67	75	6
	MFR	7	53	a	32	82	36
	LFR	9	60	a	49	70	13
1000-grain weight (g)	ULR	8	22	a	18	24	9
	MLR	3	22	a	21	22	2
	MFR	7	26	b	22	29	46
	LFR	9	27	b	25	30	5

[1] the 2 field completely damaged by flooded were included for yield calculation by not for the yield components.

[2] values within column for each item followed by the same letter are not significantly different at 5% level.

4.3.3.2 Effect of water condition on yield

Among LR, deeper maximum water depth significantly decreased grain yield ($R^2 = 0.61$, $P<0.05$) while yield of FR increased with deeper maximum water depth ($R^2 = 0.49$, $P<0.001$) in 2009 but not in 2010 (Fig. 4.5 and Fig.4.6). In middle fields with high maximum water depth (e.g. 100 cm), yields of Veal Sra tended to be higher than those of other FR land LR varieties in 2009 (Fig.4.6).

Field water condition at heading stage significantly impacted on grain yield in 2009 regardless of rice type and field location. Grain yield of fields with flooded condition at heading stage was more than double of that of fields with saturated condition at heading stage and triple of that of fields with non-flooded condition at heading stage (Fig.4.7). Fields with non-flooded and saturated water condition at heading stage were located only in upper and middle part. All the key fields were at shallow-flooded condition at heading stage in 2010.

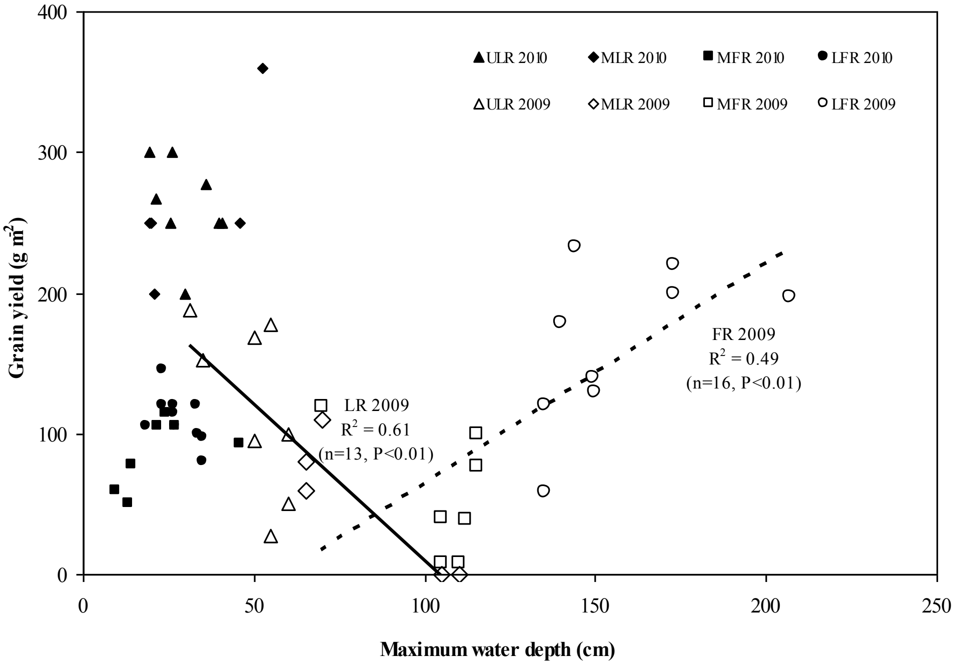

Fig.4.5. Relationship between grain yield (from interview) and maximum water depth for each combination of rice types and field locations (ULR: lowland rice upper; MLR: lowland rice middle; MFR: floating rice middle; LFR: floating rice lower) in 2009 and 2010. The Liner regressions were draw for lowland rice (LR) 2009 and floating rice (FR) 2009

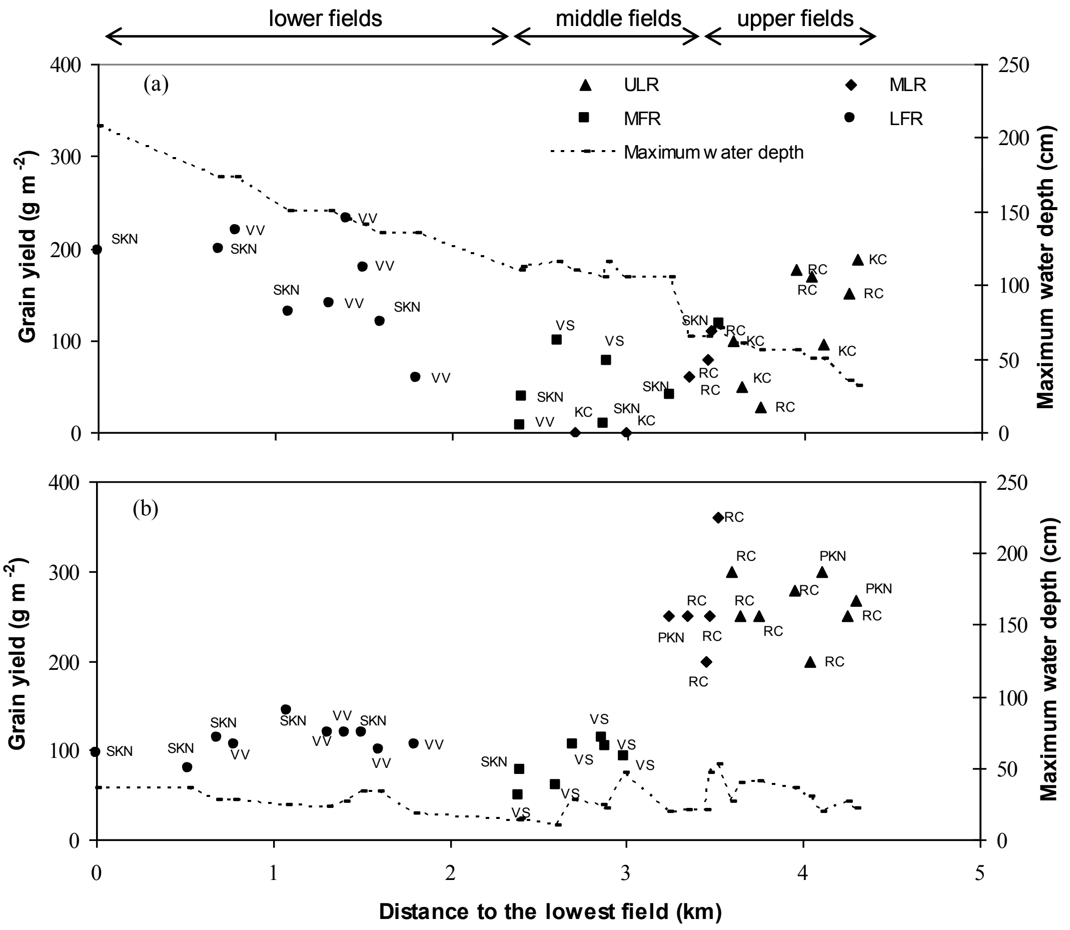

Fig.4.6. Spatial distribution of grain yield (from interview), varieties (Kon Cham Cham (KC), Raing Chey (RC), Pkha Knei (PKN), Veal Sra (VS), Sar Kranhanh (SKN), and Veal Veng (VV)) and maximum water depth along the studied transect in 2009 (a) and 2010 (b).

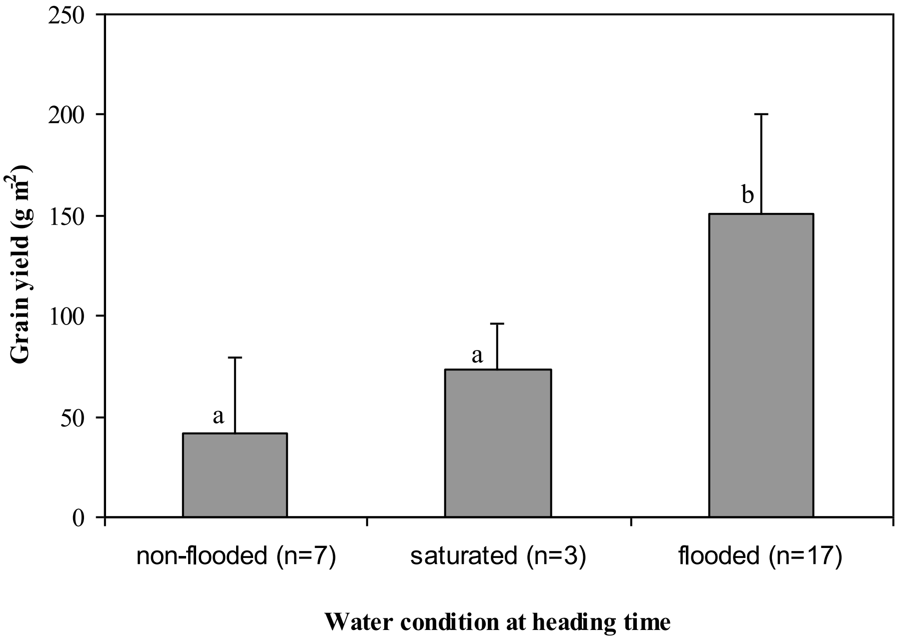

Fig.4.7. Comparison of grain yield (from interview) of fields with non-flooded, saturated, or flooded condition at heading stage in 2009. Values on each column followed by the same letter are not significantly different at 1% level. The error bars indicate standard deviations. Two lowland rice fields which were total damaged due to flood were not included.

4.3.3.3 Effect of sowing time on grain yield of FR

Late sowing significantly decreased grain yield only for FR lower fields in 2009 (R^2 = 0.36, $P<0.1$) (Fig.4.8). Sowing time did not show the effect on grain yield in other cases.

4.3.3.4 Effect of N fertilizer on grain yield of LR

In 2009, time of inorganic fertilizer application significantly impacted on grain yield of LR ($P<0.05$) (Fig.4.9). Grain yield of fields where N inorganic fertilizer was applied before flood came (from Tonle Sap Lake) was higher than that of fields where N inorganic fertilizer was not applied or applied after flood came (others) (132 g m^{-2} vs 59 g m^{-2}). Among 7 fields which belong to "others" category, there were 5 fields where farmers did not apply N organic fertilizer and 2 fields where farmers used boat to applying N fertilizer after flood came. In 2010, whether farmers applied N organic fertilizer before flood or did not apply because flood did not come from the Tonle Sap

Lake. However, grain yield of LR in 2010 was positively correlated with applied amount of N fertilizer ($R^2 = 0.25$, $P<0.1$) (Fig.4.10).

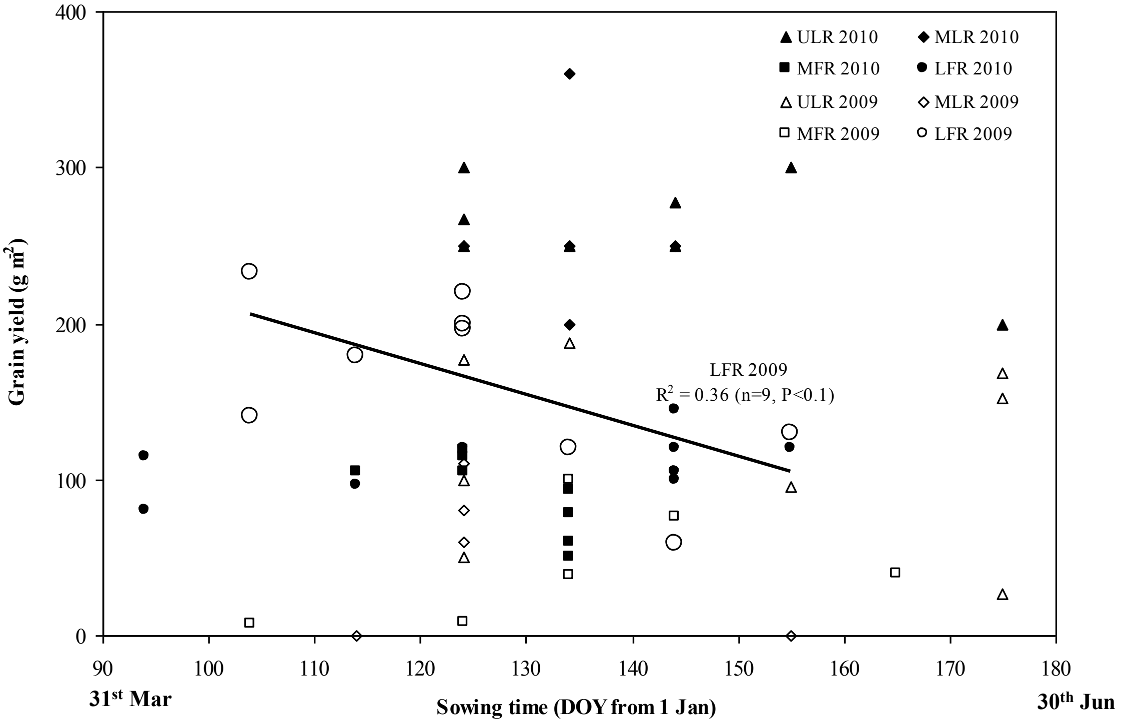

Fig.4.8. Relationship between sowing time and grain yield (from interview) in 2009 and 2010

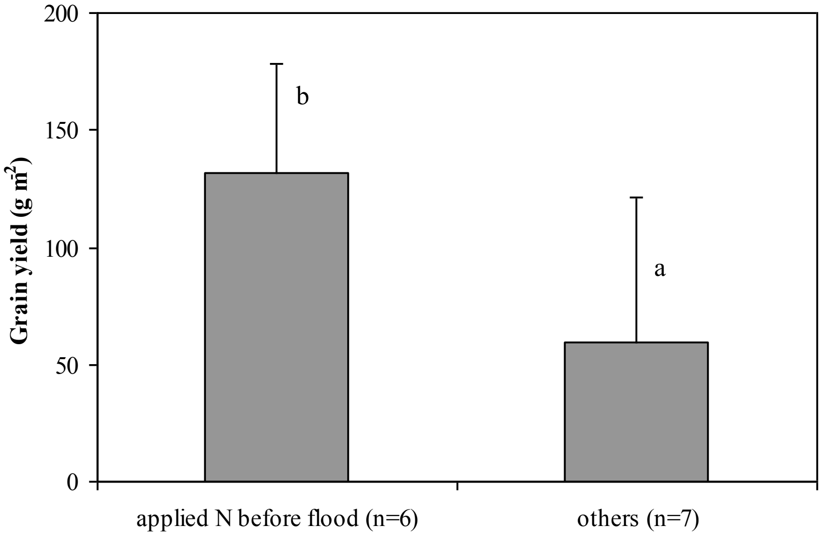

Fig.4.9. Comparison of grain yields (from interview) of LR with or without applying N fertilizer before flood commenced in 2009. Values on each column followed by the same letter are not significantly different at 5% level. The error bars indicate standard deviations.

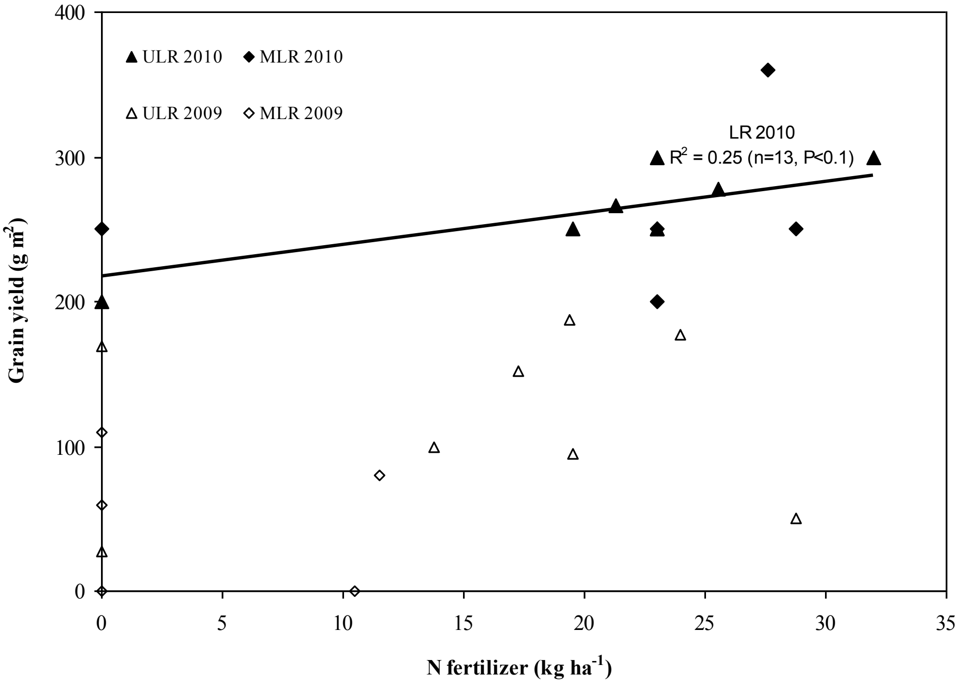

Fig.4.10. Relationship between amount of applied N fertilizer and grain yield (from interview) in 2009 and 2010

4.3.3.5 Effect of weed management method on grain yield of LR

In 2009, grain yield of LR fields with midseason tillage was significantly higher than that of fields without midseason tillage (121 g m^{-2} vs 60 g m^{-2}) (Fig.4.11). In 2010, midseason tillage were conducted in all LR fields but grain yield of fields where midseason tillage was conducted by plowing was relatively higher than that of fields where midseason tillage was conducted by harrowing (286 g m^{-2} vs 233 g m^{-2}).

Amount of herbicide used in 2010 was positively correlated with grain yield of FR fields (R^2 = 0.39, P<0.05). However, herbicide amount did not significantly affect on grain yield of all field groups in 2009 and that of LR fields in 2010 (Fig.4.12).

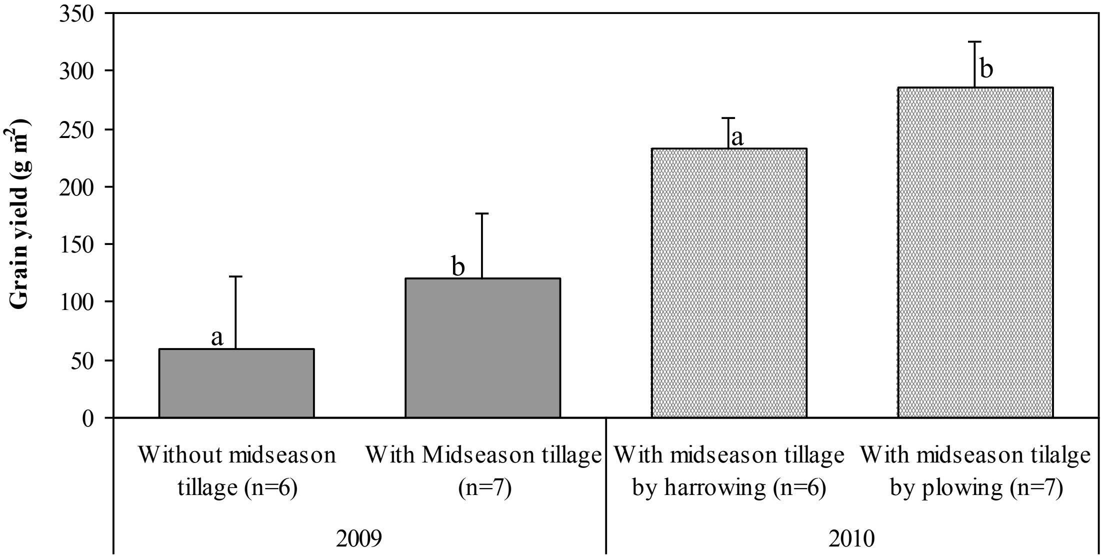

Fig.4.11. Comparison of yields (from interview) for fields without and with midseason tillage practice in 2009 and for fields with midseason tillage by harrowing and with midseason tillage by plowing in 2010 in the studies area. Values on the columns within each year followed by the same letter are not significantly different at 10% in 2009 and 5% in 2010.

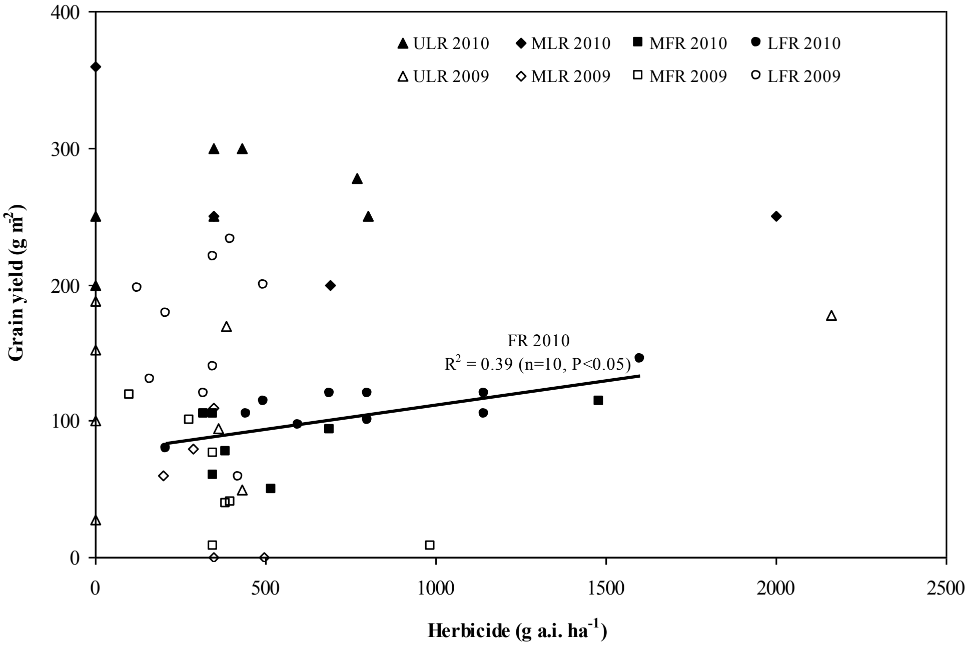

Fig.4.12. Relationship between grain yield (from interview) and used herbicide amount (ULR: lowland rice upper; MLR: lowland rice middle; MFR: floating rice middle; LFR: floating rice lower) in 2009 and 2010. The Liner regressions were draw for floating rice (FR) 2010.

4.4 Discussion

4.4.1 Spatial and yearly variability in field water environment in/around the floodplain of Tonle Sap Lake

This study showed that field water environments spatially varied in the floodplain area as shown in Fig.4.3. The difference in maximum water depth between the lowest and highest fields was 170 cm in 2009 while distance between these fields is about 4 km (Fig.4.6). This indicates the very gentle and almost flat slope (only 40 cm elevation differences in 1 km distance) of the floodplain area surrounding the Tonle Sap Lake. With the average maximum water depths of 169, 85 and 40 cm in mid October for lower, middle and upper fields in 2009 (Fig.4.3), rice ecosystem of the three locations could be classified as DWR for middle and lower fields and medium-deep rainfed lowland rice for upper fields based on the classification of Mackill et al. (1996).

There were also large yearly differences in flood from the Tonle Sap Lake. In 2008 and 2009, water came to the paddy fields from both the inundation from Tonle Sap Lake and rainfall with the maximum water depth reaching in October (165 cm) while in 2010, flood did not come from the Lake and all the 3 rice locations had less than 30 cm of maximum water depth which is the same as rainfed lowland rice environments. Low water level in Tonle Sap Lake leading to shrink floodplain area in 2010 was probably due to extremely low water level in Mekong River (IRIN news, 2010). The main causes of low water level in Mekong River were a combination of an early end to the 2009 wet season, low monsoon rainfall and very low rainfall in the dry season (MRC, 2010b). There are also some opinions that dam construction in upper Mekong River was the reason leading to this low water level in lower part of the River; however, it is still on discussion. According to the local farmers, the flooding pattern in 2008 and 2009 was considered as a normal year, while that in 2010 was an extreme event.

4.4.2 Yield variability according to water conditions and management practices

Results of our study supported that grain yield of FR and LR in the study area was variable depending on year and field location (distance from the Tonle Sap Lake) due to the difference in water condition and farmers' field management practices.

The yearly and spatial difference in field water condition caused the yield differing with year and field location (Fig.4.5 and Fig.4.6). In 2009, field water environment was relatively suitable for LR at upper fields with average maximum water depth of 40 cm and FR at lower fields with average maximum water depth of 169 cm, but it was too deep for LR and too low FR middle fields with the average maximum water depth of 85 cm (115 cm in the deepest field). This led to the lowest yield to be recorded in the middle part (Fig. 4.5). In contrast, in 2010, shallow water depth with longer flooded period due to higher precipitation and more number of rain days compared with 2009 (Fig.4.3: 1,356 mm and 89 days in 2010 vs 1,218 mm and 74 days in 2009) was more favorable for the growth of LR than for FR in the floodplain area. Hence, yield of LR was higher than that of FR in 2010.

The study showed that grain yield in the study area (Kompong Preah village) was low. The overall average grain yield over both years (2009 and 2010) was only about 1.1 t ha^{-1} for FR and 1.8 t ha^{-1} for LR (Table 4. 5). There have not been any studies reporting on grain yield for FR recently, but only few studies conducted in Cambodia, Bangladesh or Thailand in late 1980s or early 1990s such as Seng et al. (1987), Lando and Mak (1994), Catling (1982) or Puckridge (1994). The overall grain yield in our study was similar to the average yields of FR in Cambodia, reported by Seng et al (1987), with the range from 0.7 to 1.4 t ha^{-1} depending on growing area, but it was only about half of the average grain yields in Bangladesh and Thailand with 2.3 t ha^{-1} (Catling, 1982) and 2.1 t ha^{-1} (Puckridge, 1994), respectively. However, it should be noticed that grain yield reported in Catling (1982) and Puckridge (1994) was assessed by sampling while it was by interviewing farmers in our study. Catling (1982) also discussed that grain yield of DWR in his study was higher in many previous reports which yields were mainly from agricultural extension officers. For LR, in comparison with grain yield in rainfed lowland rice in 2008 which reported in USDA (2010), the overall average grain yield in our study was also about 31% lower (1.8 vs 2.6 t ha^{-1}), but the average grain yield for LR in 2010 (2.6 t ha^{-1}) was comparable.

Low yield in 2009 was mainly due to (1) the water shortage at heading stage for both FR and LR, (2) non- or late application of N fertilizer for LR, (3) insufficient weed management for LR and (4) late sowing for FR. These four aspects are augured more in details. (1) Due to low rainfall occurring at pre-flood period (Jun to Aug; Fig.4.3) in

2009, rice plants were suffered drought stress leading to delay heading, mainly from late Nov to mid December while there was also low rainfall in the late season. This caused the shortage of water at heading stage of 10 out of total 29 fields (Fig.4.7). Those fields where rice plants were not suffered drought at late stage were mainly located in lower part, or bunded with high levees, or pumped water from the water source nearby. This indicates that well-water management, especially at heading stage, is very crucial to improve yield in DWR area, particularly in middle and upper fields. (2) In 2009, LR plants were likely submerged during high flood (Fig. 4.3: 40 cm in upper fields and 85 cm in middle fields). In such cases, the growth of rice plants before flood commence was very crucial for gaining high grain yield. Taller and more vigorous rice plants, which could be improved by basal application of N fertilizer (before flood commence), were able to withstand submergence and hence gave higher yield and this was also indicated in Puckridge (1991). It was suggested that rice plant should be able to uptake more than 20 kg N ha^{-1} before onset of flooding in order to reduce yield loss due to submergence (Puckridge, 1991) while Sharma and Gosh (1998) reported that optimum basal fertilizer rate for semi-deep water environment was 30 kg N ha^{-1}. The average N fertilizer applied in LR field in 2009 was less than half of this recommendation rate (4-15 kg N ha^{-1}; Table 4.3). (3) Our study showed that conducting midseason tillage practice, a weed control method, helped to improve yield of LR in 2009 (Fig.4.11). This practice was conducted in all LR fields in 2010 while at about half of LR fields, it was not conducted in 2009, perhaps due to the water constraint (drought or flood at the time farmers wanted to do the practice). (4) Late sowing significantly decreased yield of FR in lower fields (Fig.4.8). In order to obtain better yield (more than 1.5 t ha^{-1}), sowing time should be earlier than mid May in 2009. High rainfall occurred mainly from late April to mid May while only few rains with small amount occurred in June and July (Fig.4.3). This might be the reason leading to the poor establishment of crop with late sowing. When the flood arrived, this late sowing rice was likely more susceptible to the rapidly rising water in September. The importance of sowing in time was also mentioned by Catling (1983), Javier (1997) and Sing et al. (2004).

Low yield of FR in 2010 was mainly due to low water level as the discussion at beginning of this section. Beside that insufficient weed control was also another reason. Higher rate of herbicide was applied in 2010 in comparison with that in 2009 and low application rate of herbicide significantly reduced yield of FR in 2010 (Fig.4.12). This was because that weed infestation was more severe through out the crop season due to the low water level in 2010 while FR fields were not conducted midseason tillage for controlling weed like LR.

Different from 2009, water condition in 2010 was more favorable for growing LR like in rainfed lowland environment. Therefore, yield of LR in 2010 could be further improved by conducting midseason tillage with plowing for controlling weed (Fig.4.11) and increasing application rate of N fertilizer. The N fertilizer rate applied this was only about one third of the recommendation rate for rainfed lowland rice in drought or submerged prone area with rate of 60 kg ha^{-1} (Balasubramnian and Hill, 2002). However, it should be noticed that field water environment in 2010 was not representative for most years in the studied area.

4.4.3 Farmers' response to risky water environment

As discussed in the earlier section, it is risky to grow either FR or LR middle fields due to its unfavorable water environment in middle part in a normal year like 2009. Farmers responded to this risky water environment by changing rice type and variety within the middle location based on mainly the justification of yield from previous year. In 2009, although yield of both LR and FR middle fields were lower than that of LR upper and FR lower fields, yields tended to differ with varieties and field location within the middle part. Veal Sra, an early maturity FR variety, tended to have higher yield than the other medium and late FR varieties (Sar Kranhanh and Veal Veng) (Table 4.4) as well as LR varieties growing at the same location (closer to lower part, less than 3 km from the lowest field; Fig.4.6). This is because that Veal Sra is an early maturity FR variety, it does not require high water depth to have a better growth and more suitable for the upper field in DWR area (Lando and Mak, 1994). Furthermore, earlier heading of this variety (early to mid November) compared with the other medium and late maturity FR varieties (late November to mid December) might make it to escape from the water shortage at heading stage and therefore giving better yield. Lacking of water at heading stage significantly reduced yield in 2009 (Fig.4.7). LR growing in the fields nearby lower part could not survive because of very high water level with maximum water depth of more than 100 cm (Fig.4.6). Catling et al. (1983) also found that a water deficit between panicle initiation and grain filling was a factor reducing grain yield in DWR area in Bangladesh. By doing this justification, farmers preferred growing Veal Sra than the other FR varieties in 2010. Area percentage of Veal Sra in middle fields increased from 22% to 47% (Table 4.2). There was not any LR planted at fields with distance less than 3 km from the lowest field (Fig.4.6). If farmers are going to decide rice type to grow in middle fields in 2011 based on the obtained yield in 2010, LR will be perhaps a dominant rice type not only in middle part but also in lower part due to the much higher yield of LR compared with that of FR in middle fields in 2010 (Fig. 4.4: 262 g m^{-2} vs 86 g m^{-2}) and water level was favorable for growing LR in all the area. However, water regime in 2010 was an exceptional which occurred only in every 50 years.

In general it is very risky for farmers to decide rice type/variety for growing in the middle part of the floodplain of the Tonle Sap Lake just based on the yield obtained from the previous year as field water environment differs from year to year. It is desirable if information on water situation in the area is informed to farmers by a long-term weather forecast before the cropping season (February or March). So that farmers will be able to make a right decision of selecting rice type/variety to grow in the area. Beside that early maturity varieties with higher yield potential and tolerance to submergence (suitable for medium-deep water area) can be introduced in to the area in order to improve grain yield in a sustainable manner.

Chapter 5

Transfer and adoption of improved rice production technologies in rainfed lowland environment of Cambodia

5.1 Introduction

Rice yield in rainfed lowland rice (RLR) area is low with only 2.3 t ha^{-1} in 2008 (Yu and Diao, 2011) and is substantially due to drought and poor soil fertility. About half of the rice area under rainfed lowland conditions belongs to Prey Khmer and Prateah Lang soil type which have sandy surface horizons, low organic matter and low exchangeable cations (White et al., 1997). In order to improve rice yield in this area, farmers have been recommended to apply fertilizer and improved rice varieties. There had been a considerable amount of work on soil analysis for the whole country (Bell and Seng, 2004; Oberthur et al., 2000; White et al., 2000; White et al., 1997). The recommendation rate of inorganic fertilizer has been developed for each soil type based on that soil database and delivered to farmers by Cambodian agricultural Research and Development Institute (CARDI) (Ouk, 2011).

Like in other RLR area in the world, Cambodian farmers used to grow photoperiod sensitive varieties with early, medium or late maturity depending on upper, medium or lower fields, to match with available water and hydrology of the fields (Javier, 1997; Nesbitt and Phaloeun, 1997; Ouk et al., 2001; Tsubo et al., 2009). However, these varieties are mostly local varieties, owing low yield potential and low response to fertilizer. Many improved varieties of rice suitable for different rainfed lowland environments, with higher yield potential and taste preference, developed by CARDI have also been availably recommended for rainfed lowland farmers (ACI, 2002; Ouk, 2011).

However, the actual adoption level of these improved technologies (i.e., appropriate application of inorganic fertilizer, improved higher yielding rice varieties) is still very low. Although 79% of cultivated area was applied inorganic fertilizer, the application rate was only 35 kg ha^{-1} in wet season rice 2007 which is still far below nationally recommended rate (Yu and Diao, 2011; USDA, 2010). CARDI has recently put a considerable attempt to spread improved varieties widely in rainfed lowland area but only 40% of farmers used them in WSR 2008 (USDA, 2010). There may be issues of both bio-physical and socio-economic nature, from farmers' view points, but may be apt to be neglected by researchers. According to Dobermann and White (1999), major socioeconomic factors are the poverty and risk/uncertainty which are the natures of rainfed lowlands. Compared with farmers in irrigated systems, farmers in the rainfed lowlands generally have fewer resources for capital expenditure and limited access to credit. Therefore, the farmers' capacity to invest in improved technologies is restricted. Furthermore, the uncertainty in crop success in rainfed lowlands is higher than in irrigated systems, and if crops fail, rainfed-rice farmers often have fewer options to generate supplementary food or income. Risk avoidance, therefore, occupies a more important position in decision making for rainfed-rice farmers than it does for irrigated-rice farmers.

We conducted (1) a farmer survey at village level in 2008 and field survey at landscape level in WSR 2008 and 2009 to understand the background of rice production in the target sites of rainfed lowland areas; (2) on-station participatory experiments at the target sites to examine the effectiveness of improved technologies in WSR 2009 and 2010; and (3) an investigation of process and results of technology deliver to understand natures of farmers' adoption of the introduced technologies in WSR 2009 and 2010. The overall objective is to produce a more fruitful manner of technology development and transfer at RLR fields in order to improve rice productivity in this rice growing environment. There are 3 hypotheses in this Chapter (1) information on improved varieties and recommended rates of fertilizer have not yet or been limitedly introduced to farmers in RLR area; (2) RLR yield can be improved by planting improved varieties and applying inorganic fertilizer but the efficient level of those technologies will depend on the water availability; and (3) the introduced technologies will not be automatically adopted but the adoption level will depends on the availability and popularity of resources (e.g. seeds and fertilizers).

5.2 Materials and Methods

5.2.1 Study site

Our field survey and farmers' interview were carried out from 2008 to 2010 in the two villages of Thlok Yol (TY) (Taches commune, Kompong Tralach district) and Noneam Totan (NT) (Teuk Hauth commune, Roleaphiear district), located in Kampong Chhnang province, about 30 km north of Phnom Penh (Fig. 5. 1), where the rice production is under a typical rainfed lowland environment in Cambodia. Beside that the experiments were conducted in 2009 and 2010 in Boeng Po Agricultural Experimental Station (under Provincial Department of Agriculture in Kampong Chhnang), which is located closely to Thlok Yol village.

According to DANIDA (2007), there are two soil types, Prey Khmer and Krakor, in TY and NT villages. Krakor soil is only located near the Tonle Sap River and floating and/or recession rice are often grown in this area. Our study site is located in area with Prey Khmer soil which is mainly located in upper part near Road No5 and only rainfed lowland is planted. Prey Khmer soil possesses 73% sand, 22% silt and 5% clay, with pH 5.6, organic carbon 4.7 g kg^{-1}, total nitrogen 0.5 g kg^{-1}, Olsen phosphorus 1.3 mg kg^{-1}, exchangeable potassium 0.04 cmol kg^{-1} and cation exchange capacity 1.45 cmol kg^{-1} (Bell and Seng, 2004; Seng et al., 2001).

Monthly rainfall from 2008 to 2010 was measured at the Boeng Po Agricultural Experimental Station (Table 5.1). Rainfall in 2010 was lowest among the three years with the total rainfall of only 823 mm, especially in the period of land preparation and planting time from May to September.

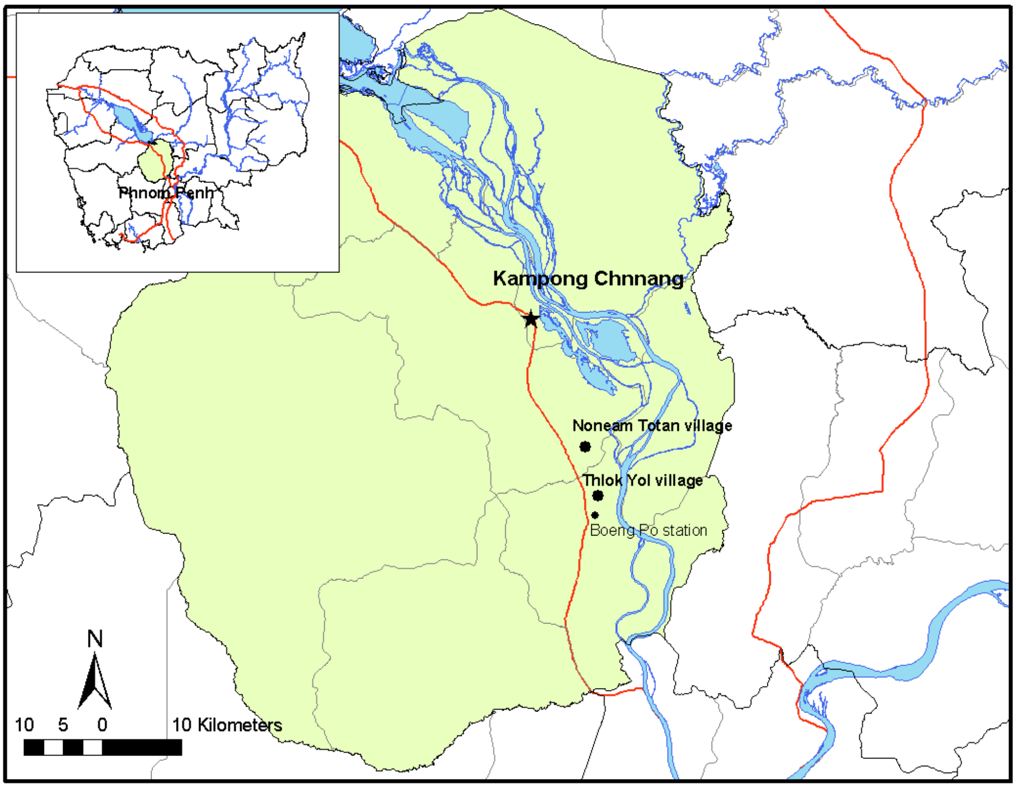

Fig. 5. 1. Location of the study sites

Table 5. 1. Monthly rainfall (mm) in Boeng Po station from 2008 to 2010.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2008	12	0	0	55	423	109	187	135	395	310	217	0	1,844
2009	0	97	89	176	214	80	159	95	193	148	10	0	1,261
2010	9	0	85	19	19	103	70	75	77	287	41	38	823

5.2.2 Methods

5.2.2.1 Field monitoring

Sixteen fields (10 fields in upper toposequential part and 6 fields in lower toposequential part; field locations were determined based on farmers' perception which has been described more detail in section 5.3.1.1) in TY and NT villages were selected to monitoring water condition and assess grain yield by sampling rice at maturity time in WSR 2008 and 2009 in the study area (Fig. 5. 1). Field water condition in WSR 2010 was also monitored. The procedures of rice sampling and processing for measuring grain yield and yield components were described in Chapter 3. Farmers owning the fields were identified to interview their management practices including the uses of variety and fertilizer and pest control for each rice season.

5.2.2.2 Farmer survey and group discussion

In order to understand the major features of rice production technologies practiced by farmers in WSR 2008 in rainfed lowland in Kampong Chhnang province, a total of 29 farm-households were randomly selected in TY (15 households) and NT (14 households) village for interviewing. A structured questionnaire was used for farmers' interviews. Detailed information on production systems such as establishment management, variety used, fertilizer input and pest management were drawn out. In addition, a group discussion was also conducted in each village in order to collect information on general land use and crop calendar in these villages. Basic information of the surveyed household was shown in Table 5.2

Table 5.2. Basic characteristics of the surveyed households interviewed in WSR 2008 in NT and TY villages

Items	
No. of respondents	29
Average household size (no.)	5
No of household (hh) member involved in agriculture production	3
Education level of male head (% of hh)	
no education	28
<grade 4	22
grade 4-7	17
grade 8-12	22
higher education	6
Others	5
Age level of male head (% of hh)	
<25	5
25-40	44
41-55	30
>55	21
farm size (ha)	0.9

5.2.2.3 On-station participatory experiments

5.2.2.3.1 Experimental design and materials

Two experiments were conducted in WSR 2009 and 2010 in two fields with different toposequences (upper and lower) in Boeng Po stations. Both experiments were conducted under rainfed condition except the supplementary irrigation for nursery. Each field in both upper and lower toposequence was divided into 8 plots with size of 5 m x 5 m for 4 treatments (2 inorganic fertilizer levels (no, yes) x 2 varieties (local, improved)) with a randomized complete block design and 2 replications in WSR 2009 while each of them was divided into 24 plots with the size of 3 m x 3 m for 12 treatments (2 potassium fertilizer levels (no, yes) x 3 other inorganic fertilizers (no, urea, urea + DAP) x 2 varieties (local, improved)) with split-split plot design and 2 replications in WSR 2010. The treatments in details in WSR 2009 and 2010 were described in Table 5.3 and Table 5.4, respectively.

5.2.2.3.2 Cultural management

Nursery sowing date was on 27 June for Thmar Ror-meal (TM; local variety) & Phka Rumduol (PRD; improved variety) for experiment in WSR 2009 while it was on 24 June for Chmar Sar (CMS) & CAR4 and on 3 July for TM & PRD for experiment in WSR 2010. Seedlings of TM & PRD were transplanted on 2 August for both upper and lower toposequence sites in WSR 2009. Seedlings of CMS & CAR4 were transplanted on 27 July for lower toposequence field and those of TM & PRD were done on 10 August for upper toposequence field in WSR 2010. Transplanting density was about 3 or 4 seedlings per hill and the planting density was 25 hills m^{-2} (20 x 20 cm) for both field locations in both WSRs. Cow manure was applied before transplanting time for all plots in both WSRs with rate of 0.5 kg m^{-2}. For both WSRs, 21 kg/ha of urea (46-0-0), 22 kg/ha of DAP (18-46-0) and 67 kg/ha of KCl (0-0-60) were applied just before transplanting time for all plots with fertilizer treatments as indicated in Table 5.3 and Table 5.4. Those plots with treatment of urea fertilizer were further applied two times with rate of 16 kg/ha of urea on (1) 22 August (20 DAT) for WSR 2009 and at 35 DAT for WSR 2010 (7 September for lower field, 25 September for upper field); (2) around panicle initiation period for WSRs (20 September for WSR 2009; 27 September for lower field and 5 October for upper field in WSR 2010). Due to long dry spell occurring during planting time in WSR 2010, water was pumped for transplanting for both upper and lower experiment sites in WSR 2010.

5.2.2.4 Yield assessment

One square meter and whole plot (3 m x 3 m) of rice were sampled from ground at maturity for grain yield assessment in each plot for WSR 2009 and 2010, respectively. Yield components were only determined with the samples in WSR 2009.

Head of Agronomy office of the Provincial Department for Agriculture, head of the Boeng Po station and farmers in TY village were invited to assess the yield performance in each plot at the maturity time of both WSR 2009 and 2010. A few farmers in NT village also came to assess the experiment exhibition in WSR 2010.

Table 5.3. Experiment treatments for both upper and lower toposequence in WSR 2009

Treatment	Explanation	Inorganic fertilizer	Variety
t1	common practice for resource-less farmers	no	local*
t2	inorganic fertilizer	recommended***	local*
t3	improved variety	no	Phkar Rumduol**
t4	improvement with fertilizer and variety	recommended***	Phkar Rumduol**

*common local variety in TY village; Thmar Ror-meal (TM, early – mid Nov maturity)

**Phka Rumduol (PRD); improved variety with high yield potential and market preference
***recommended fertilizer rate for Phka Rumduol (Urea21kg - DAP22kg-KCl67kg + Urea16kg (35DAT) + Urea16kg (PI))/ha;); farmyard manure applied in all the plots

Table 5.4. Experiment treatments for both upper and lower toposequence in WSR 2010

Treatment	Explanation	Potassium fertilizer	Other inorganic fertilizers***	Variety
t1	very resource-less field with local variety	0	0	local*
t2	test K on t1	KCl	0	local*
t3	urea field with local variety	0	urea	local*
t4	test K on t3	KCl	urea	local*
t5	urea+DAP field with local variety	0	urea+DAP	local*
t6	test K on t5	KCl	urea+DAP	local*
t7	very resource-less field with improved variety	0	0	improved**
t8	test K on t7	KCl	0	improved**
t9	urea field with improved variety	0	urea	improved**
t10	test K on t9	KCl	urea	improved**
t11	urea+DAP field with improved variety	0	urea+DAP	improved**
t12	test K on t11	KCl	urea+DAP	improved**

*local variety; Thmar Ror-meal (early - mid Nov maturity) for higher toposequence and Chimar Sar (CMS, mid December maturity) for lower toposequence

**Phkar Rumduol for higher toposequence, CAR4 for lower toposequence

***recommended fertilizer rates for Phka Rumduol (Urea21kg-DAP22kg-KCl67kg+Urea16 (35 DAT)+Urea16(PI) kg/ha) (N:P2O5:K2O=28:10:40); farmyard manure applied in all the plots

5.2.2.5 Adoption survey

In order to assess how farmers will utilize small amounts of resources externally provided and their effectiveness in the farmers fields, before planning WSR 2009 (i.e. middle June), 10 kg of PRD seeds (roughly estimated to cover 0.2 ha of paddy after transplanting) and 28 kg of fertilizer (which was enough for covering 0.2 ha with the recommendation rate (based on the CARDI Soil and Water Science Division rate for Phrey Khmer soil) of N:P2O5:K2O = 28:10:40 (kg ha^{-1})), were provided to a total of 45 farmers divided into 3 groups (1) 15 farmers with only PRD seeds provided; (2) 15 farmers with both PRD seeds and fertilizer provided; and (3) 15 farmers with only fertilizer provided. Information on the characters of PRD and recommended usage of fertilizer were clearly explained by CARDI staff at the time of providing the resources. At the end of WSR 2009, information on the field identity to which farmers applied those provided resources and their yield were collected from the 45 farmers.

To assess the adoption level of PRD and fertilizer in WSR 2010, sixty farmers (45 farmers provided resources and additional 15 non-provided resources in WSR 2009) were interviewed at the end of rice season using a structured questionnaire. The basic characteristics of the surveyed household are presented in Table 5.5. The information collected included area under PRD and fertilizer, reasons for not adopting PRD and fertilizer, and estimated grain yields.

5.2.2.6 Statistical analysis

Analysis of variance (ANOVA) was conducted to examine the difference in yield and yield components (from farmers field survey) between upper and lower fields in NT and TY village in WSR 2008 and 2009; and the effect of variety, fertilizer, field location and their interactions on grain yields of the on-station participatory experiments in WSR 2009 and WSR 2010.

Table 5.5. Basic characteristics of the surveyed households in WSR 2010 in TY village

Items	
No. of respondents	56
Average household size (no.)	5.4
No of household (hh) member involved in agriculture production	2.6
Education level of male head (% of hh)	
no education	46
<grade 4	30
grade 4-7	13
grade 8-12	11
Age level of male head (% of hh)	
<25	4
25-40	39
41-55	30
>55	27
farm size (ha)	
rainfed lowland	0.44
deep water	0.02
dry season	0.25
Total	0.7

5.3 Results

5.3.1 Farmers' survey in WSR 2008 and field monitoring from WSR 2008 to WSR 2010

5.3.1.1 General socioeconomic characteristics of TY and NT village

In 2008, there are 130 households with population of 610 people in TY village and 68 households with that of 374 people in NT village. The main income sources of the two villages are from rice production and livestock. Beside those making bamboo basket is an additional income source in NT village. Average income is from only 3,000 Riel ($0.75) to 15,000 Rield ($3.75) per day for TY village while it is less than 3,000 Riel per day in NT village.

Food shortage still occurs in the area. More than 30% of the surveyed households reported that they did not have enough rice to eat from one to six months in 2008.

5.3.1.2 Rice production

<u>Land use</u>: Agricultural land area is 99 and 174 ha in TY and NT village. All of these lands are paddy fields except only small proportion of wet land (5%) in TY village and uncultivated land (1%) in NT village. Rice is grown in 3 different ecosystems including deepwater rice, RLR and recession rice (dry season rice), but most of the land area is under RLR. We only focus on RLR in this study.

<u>Field location:</u> In both TY and NT village, farmers often classified paddy fields into upper, medium and lower locations. Upper fields are usually located closer to the farmers' house (Table 5.6: 0.7 km and 0.5 km from house for TY and NT village, respectively) while medium and lower fields are farer from their house (1.1 and 1.4 km for TY and NT village, respectively). Early maturity varieties (maturing from early to mid Nov) are often planted in upper fields, but medium and late varieties (maturing from late Nov to late Dec) are planted in medium and lower fields. In our study, field location is combined into 2 groups of upper fields and lower fields (covering medium and lower fields from farmers' perception). From the survey results of 15 farmers in each village, total planting area of WSR in 2008 was 8.8 and 9.4 ha for TY and NT village, respectively (or farm size of 0.6 ha for both villages). Of these, upper area occupied 46% and 40% in TY and NT village respectively. The rest of area in each village was for lower fields.

<u>Field water condition:</u> upper fields were under non-flooded (NF) condition at most of the rice growing season except in September and October when fields were at saturated or shallow flooded condition. However, lower fields were under saturated or shallow flooded condition at most of the time from June to November. Field water depth often reached a peak in October with the value of 6 cm for upper fields and 24 cm for lower fields in WSR 2010 (Fig. 5.2)

<u>Management practices</u>: According to farmer survey, there were 7 and 6 varieties planted in TY and NT village in WSR 2008, respectively (Table 5.6). Among these, there are two early maturity varieties (TM and Dam Neub), two medium maturity varieties (Neang

Phall and CMS) and three late maturity varieties (Neang Sar, Beikor and Neang Minh) for TY village while there are three (Phka Mlis, Cham Reak Pdao and Srauv Krahom), two (Neang Phall and Neacho) and only one (Kpo Daung) for early, medium and late maturity varieties in NT village. In TY village, the most popular planted variety was TM, making up 43% of the total area and the next one was CMS with 27% of the total area. In NT village, Kpo Daung was the most popular variety (29%) and the next popular was Neang Phall (22%) and Srauv Krahom (21%). All of the varieties planted by the surveyed farmers in the two villages are local ones.

Transplanting was only establishment method in WSR in the both villages. Seeds were usually broadcasted for nursery from May to June in fields near by transplanting fields or their house for both upper and lower fields. In TY village, seeds were often sown in fields surrounding farmers' houses by dibbling method due to the shortage of water and sandy soil. In lower fields, land was prepared in June; seedlings are transplanted from June to July; and rice was harvested from late November (i.e. CMS) to late December (Bei Kor). On the other hand, in upper fields, land was prepared later from July to August; transplanting time was from August to September depending on the availability of field water while harvesting was earlier than lower fields, from early to mid November (i.e. TM). Draft animal power was still popular used for land preparation (two white cows for plowing) in the both villages (63% of the surveyed households). Seedlings were often randomly transplanted with rate of 3 or 4 seedlings per hills with high density (Table 5.9: 38 - 42 hill m^{-2}). Seedlings age was often from 30 to 45 DAS depending on water condition. Due to less holding water capacity of sandy soil in upper fields in both TY and NT village, old seedlings were commonly transplanted without the presence of standing water (dry condition).

Cow manure mixed with straw and leaves was often applied before transplanting. There were 87% and 70% of household used farmyard manure with rate of 1.7 and 0.8 t ha^{-1} according to farmers' survey or 1.7 and 0.5 t ha^{-1} according to the field monitoring (Table 5.7) in TY and NT village, respectively. However, households using the manure might not apply it to all their fields. For example, according to our field monitoring, there are two farmers owning 7 fields in NT village, but only lower fields were applied the manure. Farmers often rotate fields yearly with the manure. Lower fields were applied the manure in 2008 but they were not in 2009 while the manure was not applied for upper fields in 2008 but in 2009. This was perhaps because farmers did not have enough manure to apply for all of their fields.

Urea and DAP were the only two types of inorganic fertilizer used in both villages in WSR 2008 and farmers more often used urea than DAP. There were 87% of households using urea while only 52% of them used DAP in WSR 2008 in the two villages. All of farmers used inorganic fertilizer in NT village but only 67% of the household used it in TY village in WSR 2008. The same as cow manure, farmers only applied inorganic fertilizer for a certain number of their fields. Only 27% of the area was applied at very small rate of inorganic fertilizer (32 kg ha^{-1}) in TY village in WSR 2008 (Table 5.7). However, the area increased to 100% with much higher rate of 81 kg ha^{-1} in this village in WSR 2009.

Pesticide was not used in the both villages in WSR 2008 although weed infestation, damages by insects and rats were reported to be relatively high. In terms of water constraint, 60 and 50% of the farmers in TY and NT village respectively reported that the occurrence of drought was more often than that of water exceeding in both of the villages.

Yield and yield components: Average grain yield was low for both upper and lower fields in the both villages in WSR 2008. According to our field monitoring of 9 fields in TY village and 7 fields in NT village, the average yield in WSR 2008 ranged only from 141 g m^{-2} (upper fields in TY village) to 160 g m^{-2} (upper in NT village) (Table 5.8). In upper fields in WSR 2008, low yield in TY village was perhaps due to low yield of both Dam Neub and TM, particularly for TM which low yield was observed by both field monitoring (134 g m^{-2}) and farmers' survey (122 g m^{-2}) while a relatively higher yield in NT village was mainly due to the contribution from high yielding ability of PRD (192 g m^{-2}). There was no significant difference between WSR 2008 and 2009 for each field location, but we can observe the consistence of higher yield performance of PRD in upper fields in the both years in NT village and new appearance in WSR 2009 in TY village (283 g m^{-2}). Average rice plant height and shoot dry matter at maturity for 2 years in the two villages in upper fields were significantly lower than those of lower fields (Table 5.9). However, rice harvest index of upper fields was significantly higher than that of lower fields. In general, number of panicle per m^2 and spikelets per panicle were very low in both upper and lower fields. The value of former yield component was only 183 and 172 for upper and lower fields, respective

Table 5.6. Household (hh) and area percentage of varieties planting in WSR 2008 in TY and NT village

Village	Location	distance from home (km)	var. name (local name)		Planting area hh no.	%hh	area (ha)	% area
TY	upper	0.7±0.6	early					
				Thmar Rormeal	9	60	3.8	43
				Dam neub	1	7	0.3	3
				Total	10	67	4.1	46
	lower	1.1±0.5	Medium					
				Neang Phall	2	13	0.3	3
				Chhmar Sar	6	40	2.4	27
				Total	8	53	2.6	30
			Late					
				Neang Sar	1	7	0.5	6
				Bei Kor	1	7	0.6	7
				Neang Minh	1	7	1.0	11
				Total	3	20	2.1	24
	Total	1.0±0.6			15	100	8.8	100
NT	upper	0.5±0.5	early					
				Phka Malis	1	8	0.3	3
				Cham reak Pdao	2	15	1.5	16
				Srauv Krahom	1	8	2.0	21
				Total	4	31	3.8	40
	lower	1.4±0.9	Medium					
				Neang Phall	6	46	2.1	22
				Neang Chol	1	8	0.9	10
				Total	7	54	3.0	31
			late					
				Kpo Daung	5	38	2.7	29
				Total	5	38	2.7	29
	Total	1.0±0.7			13	100	9.4	100

		May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Field water condition									
2008	Upper			NF	NF	SA-F	SA-F	NF-SA	
	Lower			SA-F	F	F	F	F	
2009	Upper		NF	NF	NF-SA	SA-F	SA-F	NF-SA	
	Lower		SA-F	SA-F	SA-F	F	F	SA-F	
2010*	Upper			NF	NF	NF	6 cm	NF	
	Lower			4 cm	3 cm	3 cm	24 cm	13 cm	

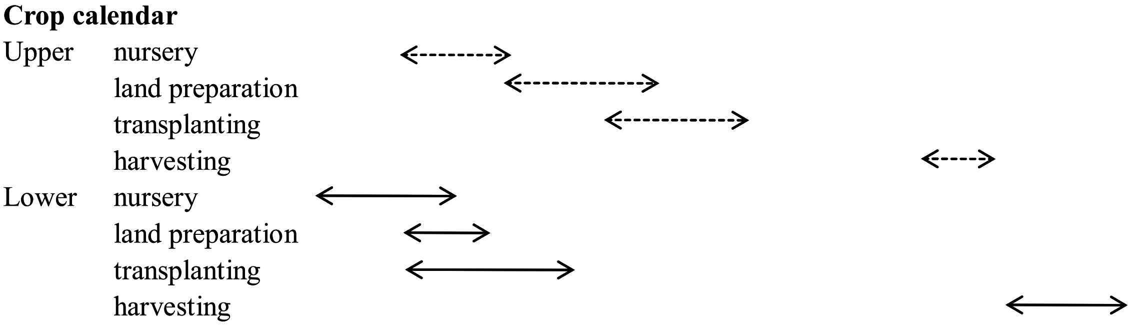

Fig. 5.2. Field water condition (non-flooded (NF), saturated (SA), and flooded (F)) and crop calendar in upper and lower fields on average of both TY and NT village (* maximum water depth in each month in upper and lower fields in TY village only).

Table 5.7. Field and area percentage and amount of organic and inorganic fertilizer used in upper and lower fields in TY and NT village in WSR 2008 and 2009.

						Organic fertilizer				Inorganic fertilizer			
Vill.	Year	Loc.	N	total area (ha)	field size (ha)	% fields fertilized	% area fertilized	rate for all field (kg ha^{-1})	rate for only fertilized field (kg ha^{-1})	% fields fertilized	% area fertilized	rate for all field (kg ha^{-1})	rate for only fertilized field (kg ha^{-1})
TY	2008	upper	6	0.31	0.05±0.02	33	29	595±922	1786	67	71	22±20	32±15
		lower	3	0.51	0.17±0.12	33	12	556±962	1666	0	0	0	0
		total	9	0.82	0.09±0.08	33	18	582±874	1746±69	44	27	14±19	32±15
	2009	upper	6	0.31	0.05±0.02	67	52	1063±973	1595±669	100	100	100±73	100±73
		lower	3	0.51	0.17±0.12	100	100	1931±1095	1931±1095	100	100	44±21	44±21
		total	9	0.82	0.09±0.08	78	82	1352±1039	1739±810	100	100	81±65	81±65
NT	2008	upper	4	0.20	0.05±0.01	0	0	0	0	0	0	0	0
		lower	3	0.41	0.14±0.01	100	100	513	513	100	100	103	103
		total	7	0.61	0.09±0.04	43	67	220±274	513	43	67	44±55	103
	2009	upper	4	0.20	0.05±0.01	75	67	2604±1875	3472±867	75	80	35±30	47±24
		lower	3	0.41	0.14±0.01	0	0	0	0	100	100	62	62
		total	7	0.61	0.09±0.04	43	22	1488±1922	3472±867	86	93	47±26	54±17

Table 5.8. Field survey grain yield (sampled) in WSR 2008 and 2009 in upper and lower fields and farmer survey grain yield in WSR 2008 in TY and NT villages.

				Field survey		Farmer survey	
Village		Year/ location	Variety name	N	Grain yield (g m^{-2})	N	Grain yield (g m-2)
TY	upper						
		2008	TM	4	134±38	14	122±56
			Dam Neub	2	157±23	1	33
			Total	6	141±33	15	117±59
		2009	TM	4	146±40		
			PRD	1	283		
			Dam Neub	1	132		
			Total	6	166±65		
	lower						
		2008	CMS	3	146±12	13	191±157
		2009	CMS	3	125±42		
NT	upper						
		2008	PKRD	2	192		
			Dam Neub	1	117		
			unknown	1	140		
			Total	4	160		
		2009	PKRD	2	181±82		
			unknown	2	151±11		
			Total	4	166±51		
	lower						
		2008	Kpo Daung	3	148±50	6	118±67
		2009	Kpo Daung	3	185±45		

Table 5.9. Average yield components in upper and lower fields for both TY and NT village and both WSR 2008 and 2009.

Yield components	Field location	N	Mean		Minimum	Maximum	CV (%)
Yield (g m^{-2})	Upper	20	151		87	283	31
	Lower	12	151		92	218	27
Plant height (cm)	Upper	20	99	*	72	128	15
	Lower	12	111		85	135	13
Shoot dry matter (g m^{-2})	Upper	20	377	*	245	804	36
	Lower	12	497		325	662	23
Harvest index (%)	Upper	20	35	**	28	47	16
	Lower	12	26		21	32	13
Hill number per m^2	Upper	20	42		26	64	21
	Lower	11	38		33	51	15
No of panicle per m^2	Upper	20	183		95	333	37
	Lower	12	172		122	214	16
No of spikelets per panicle	Upper	20	48		19	86	33
	Lower	12	51		25	76	30
No of spikelets per m^2	Upper	20	7,954		5,709	11,473	20
	Lower	12	8,596		5,175	12,557	26
Percentage of ripened grains	Upper	20	82		62	95	8
	Lower	12	79		64	87	8
1000-grain weight (g)	Upper	20	23		19	29	12
	Lower	12	23		21	26	7

*P<0.5 and **P<0.01

5.3.2 On-station participatory experiments in WSR 2009 and 2010

5.3.2.1 Experiment in WSR 2009

Grain yield of PRD was significantly higher than that of TM regardless of field location (Table 5.10). The average yield in lower field was higher than that in upper field. There was an interaction effect of variety and inorganic fertilizer on grain yield in upper field but only fertilizer effect was observed in lower field. In upper field, among the 4 treatments, yield of PRD with fertilizer was highest (252 g m^{-2}) and the next was TM with fertilizer (158 g m^{-2}). There was no significant different between yields of PRD and TM without inorganic fertilizer although yield of PRD tended to be higher than that of TM (112 vs. 82 g m^{-2}). There was also interaction effect of variety and inorganic fertilizer on shoot dry weight in both upper and lower field and on number of spikelet per m^2 in lower field. Highest shoot dry weight was again observed for PRD with fertilizer, and next highest with TM with fertilizer (though no significant in lower field). In lower field, number of spikelet per m^2 was highest for PRD with fertilizer while there was no significant difference between the three left treatments. In upper field, number of panicle per m^2, number of spikelet per panicle, number of spiketlet per m^2, and percentage of ripened grains in plot with fertilizer were significantly higher than those in plot without fertilizer. Number of panicle per m^2 of PRD was lower than that of TM in upper field, but number of spikelet per panicle and 1000-grain weight of PRD were higher than those of TM in only upper field for the former and both upper and lower field for the latter. In comparison with upper field, lower field owned larger shoot dry weight, number of spikelet per panicle and number of spikelet per m^2.

According to farmers' assessment when visiting the experiment, 100% of farmers reported that PRD with fertilizer application was the best for both upper and lower fields (Table 5.11). Farmers did not recognize the effect of fertilizer on yield of TM in upper field as most of them supposed that yield of TM for both without and with fertilizer application was at medium level (73% vs. 82%). However, the difference was recognized in lower fields. There were 61% of farmers voting for TM with fertilizer as good yield while only 24% of them voted for TM without fertilizer application.

The results of the economic evaluation of all treatments in WSR 2009 are shown in Table 5.12. The analysis shows that compared with growing TM without applying inorganic fertilizer, the fertilizer application, with the exception of the use of fertilizer for TM in the lower field, resulted in positive returns to the investment made in fertilizer (benefit ratio over TM without fertilizer >1). The negative return (benefit ratio over TM without fertilizer <1) of the use fertilizer for TM in lower field was due to the less yield response to fertilizer for TM in favorable water condition. The highest return was observed in PRD with fertilizer in upper field (3.4) and the second was in PRD with fertilizer in lower field (1.8).

Table 5.10. Yield and yield components in the upper and lower field, across variety (TM & PRD) and inorganic fertilizer (without and with fertilizer) in the on-station WSR 2009.

Variety	Fert.	Grain yield (g m^{-2})		Shoot dry weight (g m^{-2})		Harvest index (%)		No. of panicle per m^2		No. of spikelet per panicle		No. of spikelet per m^2		Percentage of ripened grains		1000-grain weight (g)	
		U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L
TM	no	82	161	198	342	36	40	161	154	30	62	4,881	9,388	78	77	22	22
	yes	158	185	364	384	38	41	199	145	42	68	8,302	9,657	87	87	22	22
PRD	no	112	146	248	316	39	40	118	104	44	65	5,172	6,621	78	80	28	28
	yes	252	262	548	542	40	42	158	131	70	84	11,094	10,927	83	88	27	27
Total	no	97	154	223	329	37	40	139	137	37	63	5,026	8,005	78	79	25	25
	yes	205	224	456	463	39	41	179	138	56	76	9,698	10,292	85	88	25	24
Var. (V)		**	ns	**	ns	ns	ns	*	ns	**	ns	ns	ns	ns	ns	**	***
Fertilizer (F)		***	*	***	*	ns	ns	*	ns	**	ns	**	*	**	ns	ns	ns
V x F		*	ns	*	*	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns
LSD$_{0.05}$ (VxF)		39		85	129								2,699				
Location (L)		*		*		ns		ns		***		**		ns		ns	
V		***		***		ns		*		***		ns		ns		***	
F		***		***		ns		ns		***		***		***		ns	
V x F		*		***		ns		ns		*		*		ns		ns	
L x V		ns		ns		ns		ns		ns		ns		ns		ns	
L x F		ns		*		ns		ns		ns		*		ns		ns	
L x V x F		ns		ns		ns		ns		ns		ns		ns		ns	

*P<0.05; **P<0.01; and ***P<0.001.LSD$_{0.05}$ means least significant difference at 5%. ns means no significant difference at 5%. U and L mean upper and lower field, respectively

Table 5.11. Visual yield level (good, medium and bad) in the on-station experiment WSR 2009 assessed by farmers (% of farmers; N=33)

Variety	Inorganic fertilizer	Upper			Lower		
		good	medium	bad	good	medium	bad
TM	no	0	73	27	24	76	0
	yes	0	82	18	61	39	0
PRD	no	21	73	6	21	79	0
	yes	100	0	0	100	0	0

Table 5.12. Grain yield (GY), cost, rice selling, benefit and benefit ratio over Thmar Rormeal (TM) without inorganic fertilizer (IF) for all treatments and the two field location in the on-station experiment WSR 2009

Field location	Variety	IF	GY (kg ha^{-1})	Cost[a,b] (000 Riel)	Rice selling[c] (000 Riel)	Benefit[d] (000 Riel)	Benefit ratio over TM without IF
Upper	TM	no	818	0	818	818	1.0
		yes	1,583	515	1,583	1,068	1.3
	PRD	no	1,115	0	1,450	1,450	1.8
		yes	2,520	515	3,277	2,761	3.4
Lower	TM	no	1,609	0	1,609	1,609	1.0
		yes	1,848	515	1,848	1,333	0.8
	PRD	no	1,463	0	1,901	1,901	1.2
		yes	2,623	515	3,409	2,894	1.8

[a] the exchange rate was 4000 Riel = 1 US$

[b] treatment costs were calculated based on IF input (urea = 2,800 Riel kg^{-1}; DAP = 3,400 Riel kg^{-1} and potassium = 4,000 Riel kg^{-1}) and labor costs (2 labor days ha^{-1} for application of IF; 12,000 Riel per day)

[c] money obtained from rice selling were calculated based on GY and farm gate paddy prices of TM (1,000 R kg^{-1}) and PRD (1,300 R kg^{-1}) in 2009 and 2010

[d] benefit was calculated as a balance between money obtained from rice selling and treatment costs

5.3.2.2 *Experiment in WSR 2010*

There was no significant interaction effect of variety, potassium and other fertilizer on grain yield in both upper and lower field (Table 5.13). On average, yield of improved variety was not significantly different from that of local variety in upper field but it was in lower field. Potassium did not significantly affect grain yield in both upper and lower field, but other fertilizers had significant impact on grain yield regardless of variety in both upper and lower field.

Because CAR4 and CMS growing in lower fields matured later than PRD and TM growing in upper fields, we could invite farmers to vote for fields with good yield in only upper location. Farmers generally thought that plots applied both urea and DAP were better than other plots (Table 5.14). Within PRD plots for each type of other fertilizers (no, urea, urea & DAP), plots with potassium application was always assessed to be better (60%, 40% and 61%, respectively). However, this result was not applicable for TM.

Table 5.15 shows results of the economic evaluation of all treatments in upper field in WSR 2010. If compared with growing TM without applying IF, returns to the investment made in fertilizer were either low (benefit ratio = 1.0 - 1.2) or negative (0.8), except for the treatment of PRD with urea and DAP (benefit ratio = 1.5 (without potassium) and 1.4 (with potassium)).

Table 5.13. Grain yield (g m^{-2}) in upper and lower field, across variety and inorganic fertilizer in WSR 2010.

Other inorganic fertilizer	Variety[1]	Potassium	Upper	Lower
No fertilizer	local	no	171	134
		yes	170	146
	improved	no	137	145
		yes	149	140
Urea	local	no	208	89
		yes	187	100
	improved	no	143	172
		yes	188	232
Urea and DAP	local	no	206	222
		yes	230	254
	improved	no	211	337
		yes	223	335
Var. (V)			ns	*
Potassium (P)			ns	ns
Other fertilizer (OF)			*	**
P x OF			ns	ns
V x P			ns	ns
V x OF			ns	ns
V x P x OF			ns	ns

*P<0.01; **P<0.001; ns means no significant difference at 5%.

[1] for local variety: TM for upper field and CMS for lower field; for improved variety: PRD for upper field and CAR4 for lower field

Table 5.14. Percentage of farmers voting for the best plots according to variety, potassium and other inorganic fertilizers (no, urea, and urea & DAP) for upper field in WSR 2010 (N=52)

Variety	Potassium	Other inorganic fertilizer		
		no	urea	urea & DAP
TM	no	23	44	14
TM	yes	17	15	25
PRD	no	0	0	0
PRD	yes	60	40	61
Overall assessment		bad	medium	good

Table 5.15. Grain yield (GY), cost, rice selling, benefit and benefit ratio over Thmar Rormeal (TM) without inorganic fertilizer (IF) for all treatments of upper field location in the on-station experiment WSR 2010

Other IF	Variety	Potassium	GY (kg ha^{-1})	Cost[a,b] (000 Riel)	Rice selling[c] (000 Riel)	Benefit[d] (000 Riel)	Benefit ratio over TM without IF
No	TM	no	1,709	0	1,709	1,709	1.0
		yes	1,702	280	1,702	1,422	0.8
	PRD	no	1,365	0	1,775	1,775	1.0
		yes	1,495	280	1,943	1,663	1.0
Urea	TM	no	2,076	172	2,076	1,904	1.1
		yes	1,872	440	1,872	1,432	0.8
	PRD	no	1,427	172	1,856	1,683	1.0
		yes	1,883	440	2,448	2,008	1.2
Urea and DAP	TM	no	2,062	247	2,062	1,814	1.1
		yes	2,304	515	2,304	1,789	1.0
	PRD	no	2,113	247	2,748	2,500	1.5
		yes	2,228	515	2,897	2,381	1.4

[a] the exchange rate was 4000 Riel = 1 US$

[b] treatment costs were calculated based on IF input (urea = 2,800 Riel kg^{-1}; DAP = 3,400 Riel kg^{-1} and potassium = 4,000 Riel kg^{-1}) and labor costs (2 labor days ha^{-1} for application of IF; 12,000 Riel per day)

[c] money obtained from rice selling were calculated based on GY and rice price of TM (1,000 Riel kg^{-1}) and PRD (1,300 Riel kg^{-1})

[d] benefit was calculated as a balance between money obtained from rice selling and treatment costs

5.3.3 Adoption survey in WSR 2010 in TY village

5.3.3.1 PRD adoption

PRD was adopted by 80% of the surveyed household but it occupied only 25% of the WSR area in WSR 2010 (Table 5.16). Surprisingly, PRD was not only planted by farmers who receive PRD seeds in WSR 2009 but also the ones who only received fertilizer (54% of household with 13% of WSR area) and did not receive any resources (79% of household with 29% of WSR area). Many household did not plant PRD in all of their fields in WSR 2010 and it was shown clearly in Fig. 5.3. Among the PRD adopters, up to 53% of the household planted PRD in less than 20% of their WSR area while only 9% of them planted it in 80-100% of their WSR area.

Most farmers (72%) planted both PRD and local variety while only 5% of household planted only PRD (Fig. 5.4). Reasons that farmers did not grow PRD at all or in all their fields were mainly due to seedling damage because of drought (56%) and lack of PRD seeds (42%) (Fig. 5.5). Lack of suitable fields for PRD and the scare of losing risk if growing only PRD were other reasons affecting on the adoption level of PRD.

Table 5.16. Percentage of household adopting and area planted PRD in WSR 2010 in TY village.

Resource provision in 2009	No of household	WSR area (ha)	PRD adoption in 2010	
			% household	% area
Seed and fertilizer	15	7.3	100	31
Seed	14	5.4	86	27
Fertilizer	13	6.5	54	13
No provided resource	14	5.5	79	29
Total	56	24.7	80	30

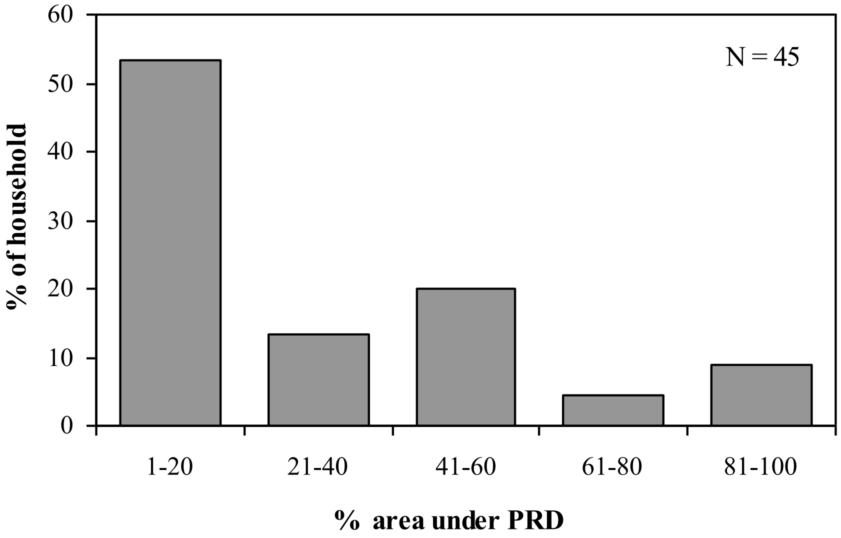

Fig. 5.3. Distribution of area percentage under PRD among the PRD adopter in WSR 2010 in TY village.

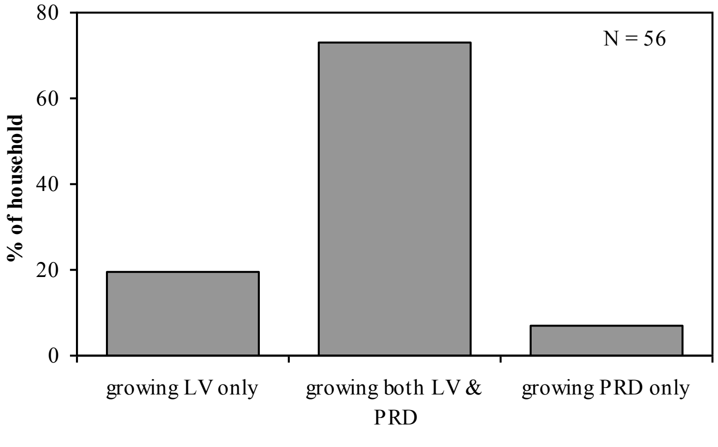

Fig. 5.4. Percentage of household planting only local variety (LV), both LV & PRD and only PRD in WSR 2010 in TY village

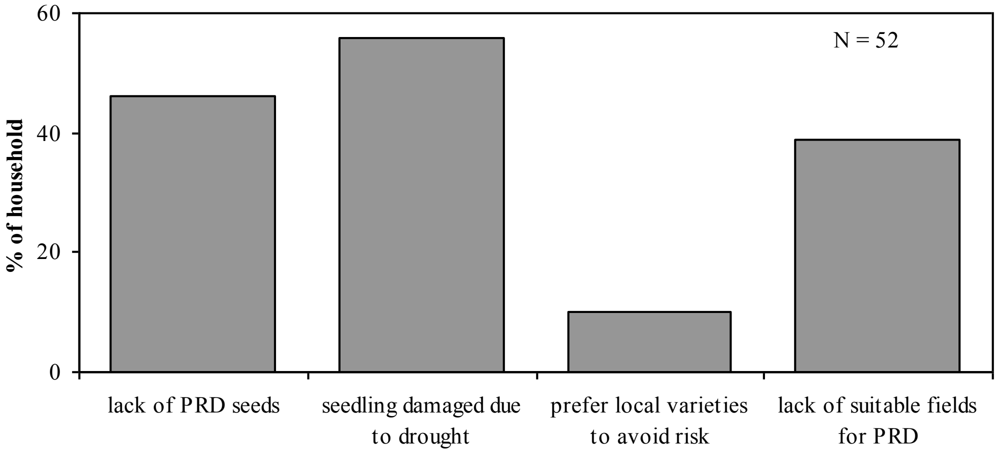

Fig. 5.5. Reasons for not adopting PRD in WSR 2010 in TY village

5.3.3.2 Fertilizer adoption

The proportion of household using inorganic fertilizer was only 30%, while 22% of their WSR rice area was fertilized in WSR 2010 (Table 5.17). Among the fertilizer adopters, 65% of them only applied fertilizer in main fields while only 35% applied in both nursery and main fields. Farmers' decision on where to apply fertilizer also depended on their variety planted. The adopters often applied fertilizer on both PRD and local variety (65%) although 29% of them still applied in only local variety. The average application rate for all surveyed household was only 21 kg ha^{-1} while the rate for only fertilizer users was 70 kg ha^{-1}. Differently from PRD adopters, 47% of fertilizer adopters applied inorganic fertilizer on most of their fields (80-100% area) while only 6% of them applied on less than 20% of their field area in WSR 2010 (Fig. 5.6). Main reasons for farmers not to use inorganic fertilizer were lack of money (64%) or water shortage (36%) (Fig. 5.7). Farmers also did not apply inorganic fertilizer because they thought it was enough to apply only farmyard fertilizer (23%) or their fields were already fertile (10%). Beside this, some farmers (10%) concerned that the application of inorganic fertilizer would degrade their soil.

More than 70% of farmers think that the best rate of inorganic fertilizer to apply for their rice fields is from 51 to 100 kg ha^{-1} but their actual applied rate in WSR 2010 was mainly less than 50 kg ha^{-1} (more than 60% of the household) (Fig. 5.8). Sixty three percent of farmers also think that fertilizer should be split into 3 times during rice growing season (basal, tillering and booting stage) while also that similar value of farmer percentage actually applied only one time at basal time in WSR 2010 (Fig. 5.9). The main reason for applying small amount of inorganic fertilizer was lack of money while lack of inorganic fertilizer and water were reasons for not split fertilizer into 3 times (Table 5.18)

Table 5.17. Features of inorganic fertilizer used in WSR 2010 in TY village

Items	
% of farmers using fertilizer (N=56)	30
% of area fertilized (N=56)	22
Location (% hh; N=17)	
only in main fields	65
both nursery and main fields	35
On variety type (% hh; N=17)	
only PRD fields	7
only traditional variety fields	29
both PRD and traditional variety fields	65
Number of times (% hh; N=17)	
one time	76
two times	24
Applying time (% hh; N=17)	
only at basal time	65
only at tillering stage	12
at basal and tillering stages	12
at basal and booting stages	12
Fertilizer type (% hh; N=17)	
Urea	88
DAP	71
Fertilizer rate (kg ha^{-1})	
Fertilizer users only (N=17)	70
All farmers (N=56)	21

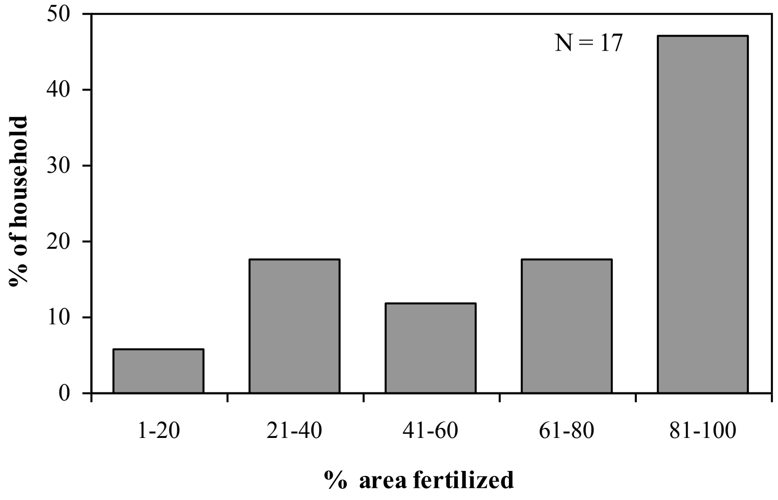

Fig. 5.6. Distribution of area percentage with fertilizer among the fertilizer adopters in WSR 2010 in TY village

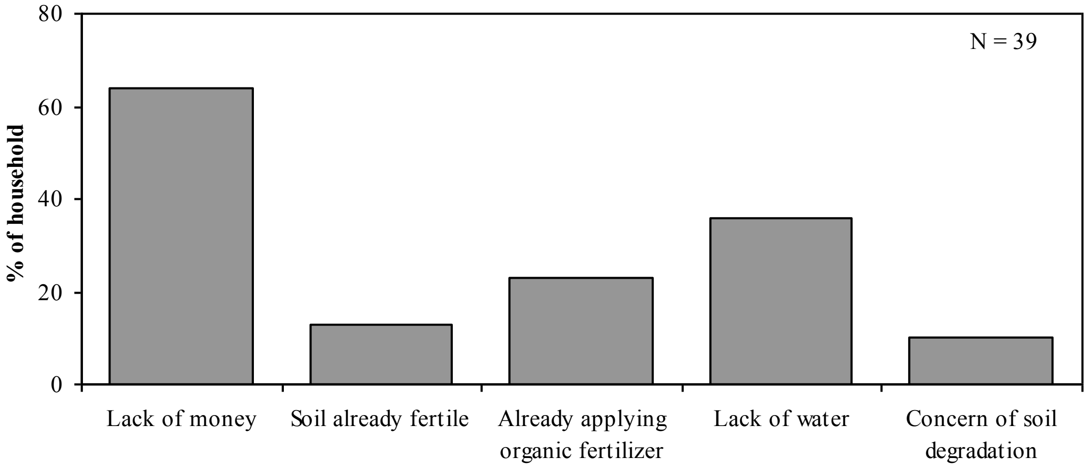

Fig. 5.7. Reasons for not adopting fertilizer in WSR 2010 in TY village

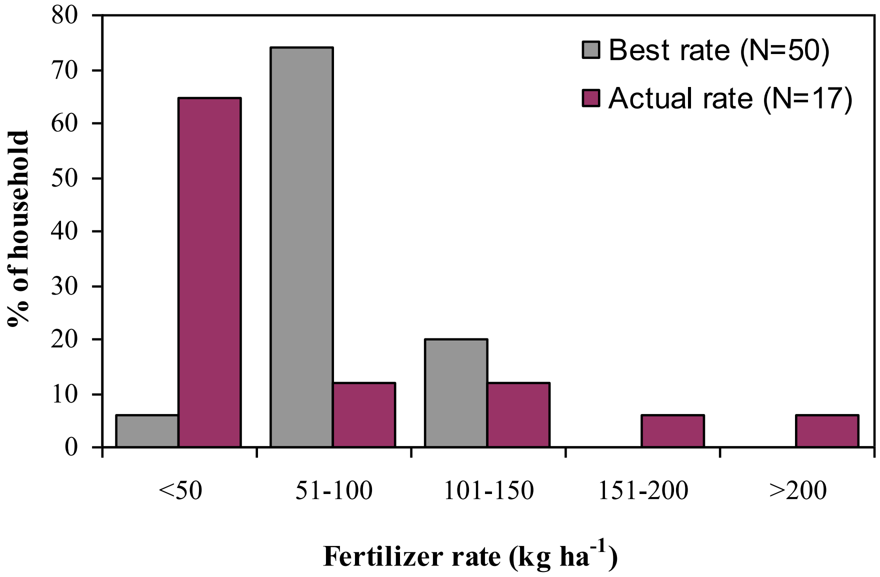

Fig. 5.8. Distribution of fertilizer best rate according farmer perception and actual rate used in WSR 2010 in TY village

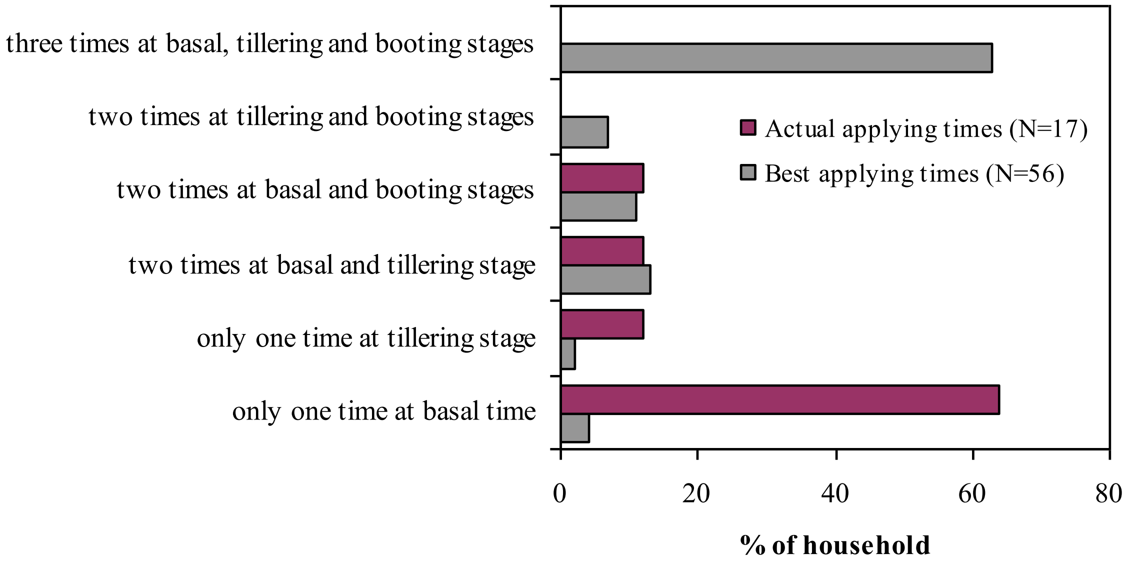

Fig. 5.9. The best applying times according farmer perception and the actual times applied by farmers in WSR 2010 in TY village

Table 5.18. Reasons for applying inorganic fertilizer less than 3 times and small amount in WSR 2010 in TY village.

Items	% of household (N=17)
Reasons for applying less than 3 times	
lack of fertilizer	59
lack of water	53
enough	6
Reasons for applying less than 50 kg ha^{-1}	
lack of money	63
concerning of grain quality	25
just for trial	13
enough	13

5.3.3.3 Farmers' estimated yield in WSR 2009 and WSR 2010 in TY village

Yield of PRD (187 g m^{-2}) was significantly higher than that of local variety (125 g m^{-2}) in WSR 2009 (Fig. 5.10). Yield in fields with fertilizer was also higher than that in fields without fertilizer (103 vs 107 g m^{-2}) in WSR 2009. There was significant difference in yield in field with and without fertilizer for local variety but not for PRD.

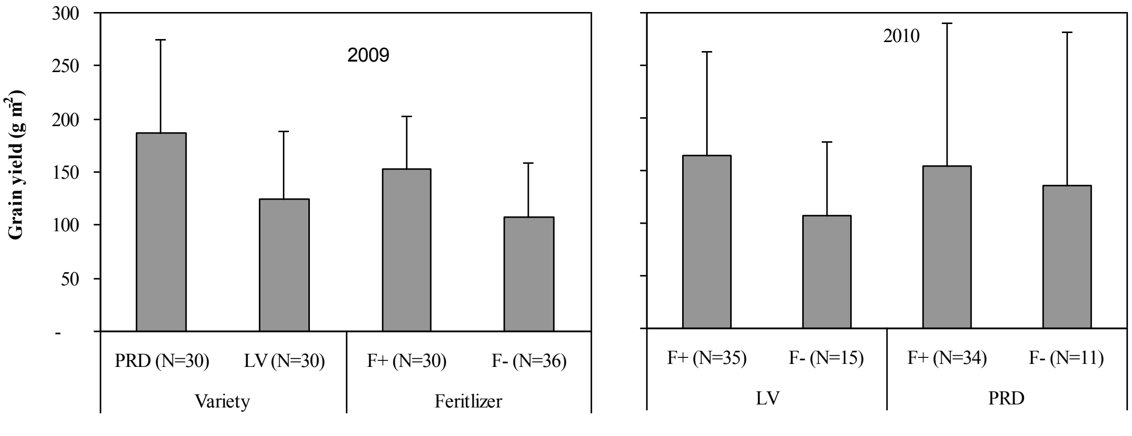

Fig. 5.10. Farmers' estimated grain yield of fields with fertilizer (F+) and without fertilizer (F-); and of local variety (LV) and PRD in WSR 2009 and 2010 in TY village.

5.4 Discussion

5.4.1 Characterization of rainfed lowland target sites for water conditions and resource input

RLR upper fields in NT and TY village can be classified as rainfed shallow, drought-prone as defined by Wade et al.(1999). Farmers in the two villages reported that drought occurs frequently during wet season rice. Drought may occur at planting time from June to August (e.g. in WSR 2010; Table 5.1) and this may lead to the delay in transplanting time or the use of old seedlings for transplanting. Drought also may occur at late stage, especially, for medium and late maturity (e.g. 2009).

This study showed that there was micro-scale variation in water environments in RLR in the two villages (Fig. 5.2). Field water depth of lower fields is deeper than that of upper fields and flood duration of lower fields is longer than that of upper fields, and farmers planted different variety type with different maturity for lower and upper fields. This confirms the results of toposequence variation in water in RLR from the previous study (e.g. Miyagawa and Kuroda, 1988; Tsubo et al., 2006; Boling et al., 2008; Homma et al., 2007).

Improved rice variety has not yet been introduced to either TY or NT villages (Table 5.6). According to ACI (2002), about 19% of farmers and 14% of area was planted with improved variety in WSR 2002 in Cambodia. USDA (2010) reported that the level of improved variety adoption in Cambodia increased sharply from 15% of farmers in 2003 to 40% of farmers in 2008. This indicates that although improved variety of rice has been promoted to grow widely in the country, there are still more than 50% of farmers without access to modern varieties such as in TY or NT village in Cambodia.

Fertility of Prey Khmer soil is low (White et al., 1997) while fertilizer application is very limited in the area. For instance, there was only 27% of area applied inorganic fertilizer with the rate of 32 kg $ha^{-1}$for only fertilized area and 14 kg ha^{-1} for all cultivated area in TY village in 2008 (Table 5.7) These area percentage and rate of inorganic fertilizer were far below the national average values in wet season 2004 with 77% of area fertilized with rate of 72 kg ha^{-1} (Yu and Diao, 2011). Furthermore, the national average value of fertilizer rate was estimated still below from recommendation rate (Blair and Blair, 2010).

As a consequence of using only local variety and low rate of inorganic fertilizer, average grain yield in the two villages in WSR 2008 was low, only around 1.5 t ha^{-1} (Table 5.8) while the average value at national level also in WSR 2008 was 2.3 t ha^{-1} (Yu and Diao, 2011).

5.4.2 The effect of improved variety and fertilizer on grain yield

Although the maximum yield of PRD, an improved variety released in 1999, with recommended fertilizer in our experiment (252 g m^{-2} in upper field) did not reach its yield potential (5.5 t ha^{-1}; ACI 2002) and lower than the experimental yield in Prateah Lang soil (347 to 487 g m^{-2}; Ikeda et al. 2008; Seng et al., 2001), which is probably due to the less advantage of soil fertility and field water condition), the yield advantage (i.e., about 60% higher) of PRD over TM, a popular traditional variety in the target village, was demonstrated as well as the good response of this variety to fertilizer (Table 5.10). This was supported in the farmers' assessment of each treatment in the experiment (Table 5.11), and the similar results were observed on farmers' fields; yield of PRD was greater than that of LV variety in 2009 only and yield with F+ is generally better than F- in both 2009 and 2010 (Fig. 5.10).

Based on our farmers' survey in 2008, it was revealed that farmers have used only urea and DAP but not potassium on their rice fields. They seemed to be very interested in the information of the potassium when we provided it to them in WSR 2009 while we have learnt from literature that potassium is deficient in Prey Khmer soil (White at al. 1997; Seng et al., 2001). Linquist and Sangxua (2001) also reported that the common practice of applying only nitrogen and phosphorus may lead to yield limitation by potassium deficiency. Therefore, we conducted an experiment to examine the effectiveness of potassium and other fertilizers (urea and DAP) on yield in WSR 2010. Beside the two varieties used in experiment WSR 2009 (PRD and TM), two medium maturity varieties (local and improved variety) were also planted in lower field in order to examine the possibility of introducing the improved variety into lower fields in the two villages.

Response to potassium fertilizer is expected to occur in Prey Khmer soil (Seng et al., 2001) while it was detected to only minor degree only for PRD in our experiment in WSR 2010 (Table 5.13 and Table 5.14). This is perhaps due to the features of deep sandy soil with the multiple nutrient deficiencies, which balanced nutrient supply is essential to achieve positive response in this soil (White et al. 1997; Bell and Seng, 2004). Furthermore, leaching of nutrient included potassium after basal fertilizer application due to the light sandy texture characteristic of Prey Khmer soil may be another reason preventing response of the fertilizer. Pracilio et al. (2006) also found no K response in some areas with Prey Khmer soil in the northwest of Takeo.

No significant difference in yield between PRD and TM was found in upper field in WSR 2010, probably because of very low rainfall experienced in this WSR. Farmers also reported that the advantage of PRD yield over local varieties was not found in their fields in WSR 2010 (Fig. 5.10). However, high yield of CAR4 in comparison to that of CMS in lower field shows the possibility of using it in lower fields for increasing rice productivity in the area.

Generally, inorganic fertilizer had consistent positive effects on grain yield in both year WSR 2009 and 2010. However, benefit return from the use of inorganic fertilizer in WSR 2010 was generally lower than that in WSR 2009 due to the occurrence of drought (Table 5.12 and Table 5.15)

5.4.3 Technology adoption: availability and popularity of inorganic fertilizer and improved variety

This study revealed that technology adoption level in RLR in Kompong Chhnang province depends on the effectiveness of the introduced technologies, the availability of resources (e.g. seed amounts, economical strength of farmers for purchasing fertilizer) and also the popularity of resources (e.g. farmers' choices may be related with policy government, market price and cost of the resources)

Farmers quickly recognized the advantage of PRD over TM, the popular local variety in WSR 2009, after self-planting on their fields and visiting our demonstration experimental fields, leading to 80% of the households in TY village (Table 5.16) adopting PRD variety in WSR 2010. This high adoption level of PRD is due to its popularity among farmers.

PRD variety are preferred by farmers due to (1) its high market price compared to local variety (i.e. TM) (2) the encouragement of growing this variety from the government. PRD is one of the 10 prioritized rice varieties to be promoted and disseminated, which are recommended by CARDI in 2010, for the promotion of rice production in order to increase rice exportation, and (3) PRD seeds can be multiplied by farmers themselves for the next rice season.

However, the area planted with the variety was not very high (25% in WSR 2010), mainly due to seedlings damaged by drought and unavailability of PRD seeds. For the first reason, seedlings in the village were heavily damaged not only for PRD but also other local varieties due to the severe shortage of rainfall during early crop season (Table 5. 1) while supplementary irrigation source was not available in the village. For the second reason, farmers in both TY and NT village have never bought seeds from outside but mainly using seeds from previous season (94% of farmers, from farmer survey in 2008). Exchanging PRD seeds was popular in WSR 2010 (Table 5.16: 28 farmers or 50 % of surveyed farmers) as farmers preferred growing this variety as the discussion in the previous paragraph. However, source of PRD seeds was only from our provision and some harvest in WSR 2009 and this source seems to be not enough to meet the farmers' demand. Farmers may have enough PRD seeds for the years later just by multiplying them on their fields but the consideration of seed quality needs to be taken into account. Improving the seed production system is needed in Cambodia in order to increase the high quality seed supply. It has been known that the continuous use of rice seeds saved from the previous year's harvest not only limits crop yields but also decreases the yield due to the impurities and contaminations of these seeds (Fujisaka et al., 1993; Diaz et al, 1998). At present, the AQIP Seed Company, which is the outcome of the agricultural improvement projects, jointly funded by the Cambodian and Australian governments from 2000 to 2008, is the only rice seed company in Cambodia (AQIP, 2007). More such seed production industries are needed in order to meet the seed demand from farmers. Delivering seed production training courses to farmers is another good option to help the poor farmers to produce high quality seeds by themselves. The courses at first should be given to farmer groups, and then later they will be quickly disseminated among the famers. Managerial skills to produce seeds and to market efficiently the products as a business are also needed to be provided to farmers in order to sustain the seed production activities (Guei et al., 2011). However, there will be a need of the support of seed production specialists and funds from Cambodian government and international organizations as well as the high responsive involvement of the provincial agricultural department for organizing such activities.

Although inorganic fertilizers are available in the retailing shops and farmers showed their high appreciation on the effectiveness of using inorganic fertilizers on grain yield in their own fields (with distributed inorganic fertilizer) and in our experimental demonstration in WSR 2009, our results showed that farmers still poorly adopted the fertilizer both in terms of number of farmer and fertilizer rate in WSR 2010. Much less farmers used inorganic fertilizer in WSR 2010 than WSR 2008 in TY village (30% vs 67% of farmers) and the application rate still remain low (70 kg ha^{-1}). This is because that inorganic fertilizer is neither available to farmers due to the lack of money (Fig. 5.7) nor popular due to farmers' reasoning for low benefit returning from using fertilizer in a drought year like WSR 2010 (Table 5.15). Farmers in rainfed lowland often give up or only apply small amount of fertilizer when drought or flood occurs because they experience severe yield losses if dry spell or flood occurs at critical crop growth stages (Balasubramanian, 1999). Financial consideration is also reported as a main cause of underuse fertilizer by 79% of farmers in a recent study of EIC (MAFF and MOWRAM, 2007). Improving access to credit may help farmers to find cash source to buy fertilizer. Poor access to credit has been mentioned as a main constraint of adopting modern technologies for improving rice productivity in several studies such as Villano and Pandey (2000) and Onyenweaku et al. (2007). Subsidizing fertilzier to the poor farmers or a particular target areas with high poverty level is another solution.

Chapter 6

Multifunctionality of rice farming under three different rice ecosystems in Cambodia

6.1 Introduction

The concept of multifunctionality was originated from Western countries with industrial agricultural modes of production and officially introduced in 1992 at the Earth Summit in Rio, where the term is used to describe the potential for positive environmental benefits from ecofriendly agriculture (Groenfeldt, 2006). According to OECD (2001), apart from food and fiber (commodity), there are multiple outputs (non-commodity) from agriculture. Three aspects of non-commodity outputs, which are (1) jointness, (2) market failure and (3) public goods, are often considered among policy makers when discussing on strategies to preserve or increase these outputs (OECD, 2001; Carmel, 2001). (1) Jointness exists if the production of two or more "goods" is interlinked in such a way that a change in supply of one also affects the supply of the others (e.g. agriculture employment is jointly produced with agriculture production). (2) Most of non-commodity outputs have non-market values (e.g. landscape, biodiversity) and cause market failure. And (3) a public good is non-excludable and non-rival in consumption or simply this means that it is impossible to exclude anyone from enjoyment of the good and one person's consumption does not affect another's enjoyment of the same good. In general, multifunctionality of agriculture refers to non- commodity outputs including food security, formulation of the landscape, environmental protection such us land conservation, sustainable management of renewable natural resources and the preservation of biodiversity, and contribute to the socio-economic viability of rural community. From the point of view of rice ecosystem, rice farming and their associated components possess abundant multifunctionalities. In Japan, multiple roles of rice farming include flood control, groundwater recharge, soil erosion prevention, landslide prevention, water purification, decomposition of organic waste, climate mitigation, biodiversity conservation, landscape formation and local community formation (Matsuno et al., 2006). According to Chen (2005) and Groenfeldt (2006), farmers' livelihood should also be included in the multifunctional framework of rice farming and the roles generally can be divided into four broad categories (1) livelihood and economic functions; (2) environmental functions; (3) sociocultural and religious functions; and (4) rural development functions.

Rice is the overwhelmingly predominant staple crop and grown in diverse ecosystems which include irrigated, deepwater and rainfed lowland in Cambodia. Total cultivated rice area in 2006 was around 2.4 million ha (80% of total cultivated area), of which 2.1 ha grown in wet season and 0.3 million ha in dry season (MAFF, 2006). Rice gave more than 10 percent of the country's total export value in 2007 (IMF 2009). Only economic development, poverty reduction and food security are recognized as important roles of rice farming in national policies, while there has been little research on the multiple roles of rice farming in Cambodia from the viewpoints of local people. In order to achieve the sustainable development in agriculture and rural areas, multiple roles of rice farming should be properly recognized and appreciated. In this chapter, we attempted to assess the multifunctionality of rice farming across the 3 different rice ecosystems with the focus on only the three categories (1) livelihood and economic functions; (2) environmental functions; and (3) sociocultural and religious functions.

6.2 Materials and methods

6.2.1 Study sites

The study sites are located in 7 villages belonging to three rice ecosystems: irrigated rice (IR), deep water rice (DWR) and rainfed lowland rice (RLR) in Cambodia (Fig. 6.1). IR and DWR ecosystems are located in Battambang province and RLR ecosystem is in Kompong Chhnang province. Detail names of the villages, communes and provinces are presented in Table 6.1. Some characteristics of villages related to rice farming and farmers' livelihoods are described as below.

6.2.1.1 Irrigated rice area: Ta Nghen, Ta Kream and Poy Svay villages, Battambang province

Ta Nghen, Takream and Poy Svay villages are located in the Ta Kream commune, Banan district (Fig. 6.1). In these villages, rice farming, upland crop farming (e.g. peanuts, beans, etc) and wild fish capturing are the main income and food sources for all people in the communities. Rice fields are mostly located in the Kamping Pouy irrigation rehabilitation (KPIR) area. The characteristics and rice production of the area have been described detail in chapter 3. The average farm size of household doing rice farming is as large as 2 to 3 ha. Rice milling, rice trading and other services related to rice production (e. g. fertilizer, pesticides) are increasingly available in the villages. Kamping Pouy (KP) reservoir is not only an irrigation source for the KPIR area but also a good place for tourists to visit for its beautiful landscape and its historical incidence. Among the three villages, Ta Nghen village is situated closest to the KP reservoir, and therefore, tourism services provide another income source of many people in the village.

6.2.1.2 Deepwater rice area: Sras Keo and Pagna villages, Battambang province

Sras Keo and Pagna villages are situated in Kompong Preah commune, Sangke district (Fig. 6.1). Most of the villagers are growing both deepwater/floating rice and rainfed lowland rice for their livelihood. Although deepwater rice occupies only small proportion of the total rice cultivated area in Cambodia, it occupies up to 45% of the total rice area in Kompong Preah commune in 2009. The deepwater rice area is located near flooded forest and the Tonle Sap Lake. Rice management practices are somehow similar to those in Kompong Preah village (also located in Kompong Preah commune) described in chapter 4. Wild fish collecting from paddy fields, flooded forest and the Lake is another food source of the most habitants in the villages. There is also substantial proportion of households having members who migrate for work as agricultural wage labor in Thailand or work for industries and services trade in Phnom Penh.

6.2.1.3 Rainfed lowland rice area: Thlauk Yol and Norneam Torteung villages, Kompong Chhnang province

Thlauk Yol village is located in Taches commune, Kompong Tralach district and Norneam Torteung villages are located inTeuk Hauth commune, Roleaphiear district (Fig. 6.1). Population of these two villages is less than half of those villages in the Ta Kream and Kompong Preah commune (Table 6.1). Rainfed lowland rice, deepwater rice and recession rice are all cultivated in the villages but rainfed lowland rice occupies the greater proportion of the total rice cultivated area. Rice management practices of the two villages with focus on rainfed lowland rice ecosystem have been described in chapter 5. Villagers fish and raise livestock for consumption and earning additional income. Villagers in Norneam Torteung also often collect rattan and bamboo to making handicraft products for selling.

6.2.2 Methods

The multifunctionality of rice farming is assessed based on household interviews and Focus Group Discussion (FGD) in the seven villages in 2009. A selection of villages in the three rice ecosystems was made to capture the multifunctionality across different water environments. Number of households interviewed in each village i.e., about 15 households is presented in Table 6.1. Series of component items for assessment of multifunctionality were listed in order to develop a questionnaire after examining the previous studies (Chen 2005, Groenfeldt 2006, Matsuno et al., 2006, SCJ 2001); food security, wild plant collection, wild animal collection, changing trend of wild animals, labor force for catching animal, uses of water from rice ecosystems, land conservation and climate mitigation, tourism, rice variety diversity, landscape value, employment, workplace environmental quality, interactions between rural and city, festivals, and future vision (Table 6.2). Each of these items is grouped by the multifunctional framework of environment, livelihood and economics, and social and cultural (Chen 2005, Groenfeldt 2006). FGDs were made in each village to gather basic information on rice farming, farmers' livelihoods and some functions of rice farming including aquatic plant collection and festivals related to rice production. The village chief and about 10 farmers were invited for the FGD in each village.

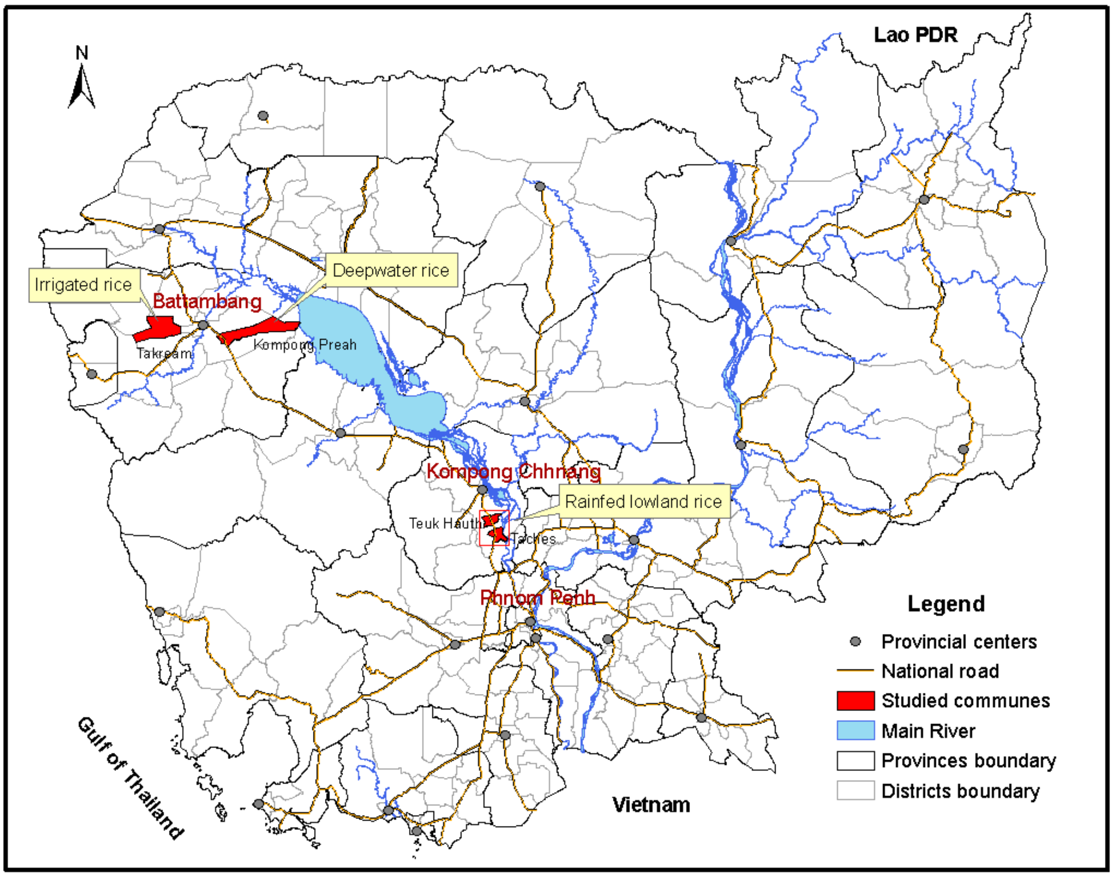

Fig. 6.1. Location of the communes in the 3 rice ecosystems which had the 7 studied villages for multifunctionality

Table 6.1. Rice cultivated area, number of households and number of household interviewed in studied villages with different rice ecosystems (irrigated rice (IR), deepwater rice (DWR) and rainfed lowland rice (RLR))

Village	Commune	Province	Main rice ecosystems	Rice cultivated area (ha)	Number of households	Number of households interviewed
Ta Kream	Ta Kream	Battambang	IR	550	385	15
Ta Nghen	Ta Kream	Battambang	IR	520	734	15
Poy Svay	Ta Kream	Battambang	IR	380	305	14
Pagna	Kompong Preah	Battambang	DWR	695	323	15
Sras Keo	Kompong Preah	Battambang	DWR	1,046	501	15
Thlauk Yol	Taches	Kompong Chhnang	RLR	168	130	16
Norneam Torteung	Teuk Hauth	Kompong Chhnang	RLR	93	68	13

Table 6.2. Selected items for assessing the three groups of multifunctionality of rice fields in Cambodia

Items	Environment	Livelihood and economic	Social and cultural
Food security		*	
Wild plant collection	*	*	
Wild animal collection	*	*	
Changing trend of wild animals	*		
Labor force for catching animal			*
Uses of water from rice ecosystems		*	
Land conservation and climate mitigation	*		
Tourism	*	*	*
Rice variety diversity	*		
Landscape value	*		*
Employment			*
Workplace environmental quality			*
Interactions between rural and city			*
Festivals			*
Future vision	*	*	*

6.3 Results

6.3.1 Food security

Rice harvested from paddy fields were used for both family consumption and selling in all the study sites. However, the shortage of rice for consumption still occurred in 2008 in all sites but with the lowest percentage (16%) in IR area (Table 6.3). When lack of rice for eating, most of RLR farmers had to buy rice from market and less RLR farmers could borrow from their relatives than IR and DW farmers. Selling rice is an income source of most of farmers (89%) in IR area while it was an income source of a fewer number of farmers (28%) in RLR.

Table 6.3. Food security from rice production aspect in different rice ecosystems

Items	IR (N=44)	DWR (N=30)	RLR (N=29)	Average (N=103)
shortage of rice for consumption (% of farmers)	16	37	31	26
shortage of rice for consumption (months/year)	3	2	3	3
solutions for rice shortage (% of farmers)				
borrowing relatives	57	64	33	52
borrowing neighbors	14	36	22	26
buying from rice miller	29	0	11	11
eating other products	0	0	11	4
buying from market	29	27	78	44
selling rice (% of farmers)	89	54	28	61

6.3.2 Wild food collection

6.3.2.1 Wild plants

More than half of interviewed farmers in all the studied sites collected different plant material from rice field ecosystems including aquatic plants, grass, straw, bamboo shoot, palm fruit and tree for home diet, animal feeding (Table 6.4). Among the listed materials, aquatic plant was the most popularly collected in all sites for mainly consumption. Grass was commonly collected for animal feeding in IR area (59%) and DWR area (91%) while palm fruit was more popular in RLR area (32%) for making sugar for home consumption. Some examples of collected wild plants from rice fields are shown in Fig. 6.2.

Farmers have listed 15 types of aquatic plants which they collected from rice fields (Table 6.5). Among the listed plants, water convolvulus (*Ipomoea aquatica*) appears to be an important role in the food security of the poor households. Water Lilly (*Nymphactareea sp.*) is another important plant which is often collected by farmers for consumption and selling.

Forage from rice field ecosystems is an important fodder for cattle in Cambodia (Table 6.6). Most of farmers who raise the cattle collect straw and weeds all around year for feeding them or let them graze freely in levee, fallow or harvested fields. In DWR area, farmers often let cows freely graze on densely direct seeded fields (around tillering stage) for suppressing the rice growth and reducing plant density, particularly in the floating rice fields and in the fields which farmers could not conduct midseason tillage.

Table 6.4. Wild plants collected from rice fields and their uses in different rice ecosystems

Type of collected wild plants	Collection (% of farmers)	Purposes of collection (% of farmers)		
		home diet	feeding animal	firewood
IR (29 out of 44 farmers (65%) collected plants in rice fields)				
aquatic plant	76	91	9	0
grass	59	0	100	0
bamboo shoot	7	100	0	0
palm fruit	3	100	0	0
Tree	10	0	0	100
DWR (23 out of 30 farmers (76%) collected plants in rive fields)				
aquatic plant	48	100	0	0
grass	91	0	100	0
bamboo shoot	9	100	0	0
Tree	13	0	0	100
RLR (19 out of 29 farmers collected (65%) plants in rive fields)				
aquatic plant	73	100	0	0
grass	16	0	100	0
bamboo shoot	16	100	0	0
palm fruit	32	100	0	0

Fig. 6.2. Photos of (a) ponded field with aquatic plants, (b) example of a type of aquatic plant collected by a farmer for home diet, (c) palm fruits collected for making sugar, and (d) grass collected for feeding cattle. The photos of (a), (b) and (c) were taken in rice fields of TY village - RLR ecosystem, and the photo of (d) was taken in rice fields of Sras Keo village - DWR ecosystem.

Table 6.5. List of aquatic plants collected by farmers from different rice ecosystems

Local name of collected herb/weed	English name	Scientific name	Site where plants collected	Major use	Collection season	Availability	Popularity of collecting
Trakuon	water morning glory, water convolvulus	*Ipomoea aquatica*	All	home diet, pig feed	May-Nov	medium	very popular
Chon Tul Phnom	water clover	*arsilea crenata*	IR	home diet	May-Nov	medium	very popular
Kan Tol Let	NA	NA	IR, DWR	home diet	May-Nov	medium	very popular
Pro let	blue water lily	*Nymphactareea sp.*	IR, DWR	home diet, ornamental, sale	May-Nov	medium	very popular
Chrach	heartleaf false pickerlweed	*Monochoria vaginalis*	IR, RLR	home diet	May-Nov	medium	very popular
Plov Kang Kep	NA	NA	IR	home diet	May-Nov	medium	very popular
Kagn Chet	water minosa	*Nuptunia olaracia*	IR, DWR	home diet	May-Nov	medium	very popular
Phka Snor	NA	NA	IR	home diet	May-Nov	medium	very popular
Slap Chang Va	greater plantain	Plantago mjor	All	home diet, medicine	May-Nov	medium	very popular
Phka Kam Plok	common water hyacinth	Eichhonia crassipes	IR	home diet	May-Nov	medium	very popular
Kamping Pouy	aquatic plant	*Jussieua repens*	IR, RLR	home diet	May-Nov	medium	very popular
Ma chul Phnom	NA	NA	DWR	home diet and sale	May-Oct	medium	very popular
Kan tinh tinh	NA	NA	DWR	home diet and sale	May-Oct	medium	popular
Ma Om	Swamp leaf	*Limnophila sp.*	DWR, RLR	home diet and sale	May-Oct	medium	very popular

Table 6.6. Feed sources for cattle production by percentage of respondents in different rice ecosystems

Feed sources	IR (n=31)	DWR (n=22)	RLR (n=23)	Average (n=76)
forage crop	3	9	0	4
maize stem	3	9	4	5
banana stem	16	13	9	13
grazing from forest	23	5	17	16
grazing from fallow fields	32	14	74	39
grazing from levee	45	45	70	47
grazing from harvested fields	61	73	17	51
straw (rainy season)	90	96	96	93
weed (rainy season)	94	100	100	97
straw (dry season)	97	73	91	88
weed (dry season)	87	78	96	87

6.3.2.2 Wild animal

Wild animal collection: There were 73% of farmers in IR and DWR area participating in catching wild animals from rice fields while there were only 45% of farmers in RLR area doing that (Table 6.7). Most of the collected wild animals are aquatic animals (i.e. fish, shrimp, crab, frog, snail and snake). Only two types of collected animals which are rat and paddy bird are not aquatic animals. Among the listed animals, fish was collected by most of the catchers across the three rice ecosystems, the next were crab and frog. About a quarter of the interviewed farmers in IR and DWR also collected snail while only a few of farmers in RLR (17%) collected this animal. Farmers collected the animals mainly for home consumption. Few farmers in IR and DWR area sold the collected animals. Examples of the collecting activities are shown in Fig. 6.3.

Changing trend of wild animals: Among those farmers who participated in collecting the wild animals from rice fields, most of them think that the amount of aquatic animals and paddy bird tend to decline recently (Table 6.8). However, rat was said to have an increase trend in amount in all the studied sites. The decrease trend of amount of the aquatic animals and paddy bird was mainly due to the use of pesticide in IR and DWR area and the use of harmful tool (e.g. electronic shock) in RL area (Fig. 6.4). High frequency of catching and the use of harmful tool were also the reasons reducing the appearance of those animals in IR and DW rice. The increase trend of rat amount is perhaps due to the decrease trend or disappearance of predators (i.e. snake).

<u>Labor force participation on catching wild animals in rice fields</u>: Mostly only male farmers participated in collecting the wild animals from rice fields in IR and DWR area while both male farmers and children participating in doing that in RLR area (Fig. 6.5). Female farmers rarely involved in this activity in all the studied sites (less than 20% of farmers).

Table 6.7. Wild animals collected from rice fields and their uses in different rice ecosystems

Wild animals	catching (% of farmers)	purposes of collected creatures (% of farmers)	
		for self-consumption	selling
IR (32 out of 44 farmers (73%) collected wild animals from rice fields)			
rat	38	92	25
bird	19	100	17
fish	97	97	16
shrimp	44	100	7
crab	75	100	0
frog	59	95	9
snail	75	100	0
snake	28	100	0
DWR (22 out of 30 farmers (73%) collected wild animals from rice fields			
rat	32	100	0
bird	27	100	0
fish	86	100	10
shrimp	38	100	0
crab	86	100	0
frog	71	94	7
snail	76	100	0
snake	19	100	0
RLR (13 out of 29 farmers (45%) collected wild animals from rice fields			
rat	15	100	0
bird	25	100	0
fish	100	100	0
shrimp	25	100	0
crab	33	100	0
frog	42	100	0
snail	17	100	0
snake	8	100	0

Fig. 6.3. Photos of (a) Children catching fish in rice in rice fields in KPIR area and (b) fish collected from DWR area in Kompong Preah commune (the woman prepared the collected fish for her family's meal)

Table 6.8. Farmers' perceptions on changing trend of wild animals in rice fields from different rice ecosystems

Sites	Wild animal	n	changing trend (% of farmers)		
			no change	decreased	increased
IR	rat	13	15	23	62
	bird	8	13	75	13
	fish	32	25	66	9
	shrimp	15	40	47	13
	crab	25	32	52	16
	frog	21	29	67	5
	snail	26	31	50	19
	snake	9	11	78	11
DWR	rat	9	22	22	56
	bird	6	0	83	17
	fish	20	25	75	0
	shrimp	8	25	75	0
	crab	17	29	53	18
	frog	17	24	65	12
	snail	16	19	63	19
	snake	2	50	50	0
RLR	rat	7	14	14	71
	bird	1	0	100	0
	fish	15	13	87	0
	shrimp	7	29	71	0
	crab	7	43	57	0
	frog	5	0	100	0
	snail	3	33	67	0
	snake	no answer			

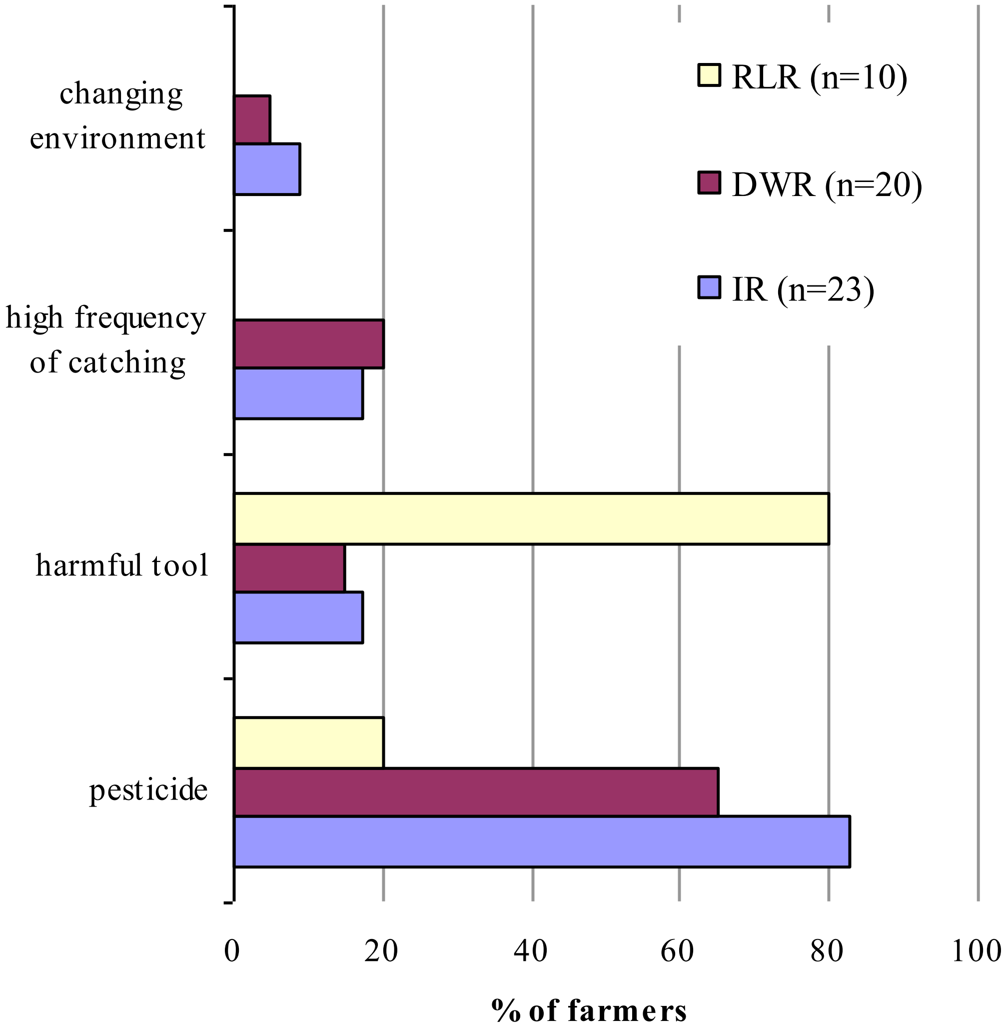

Fig. 6.4. Farmers' perceptions on reasons causing the reduction of wild animals in rice fields in different rice ecosystems.

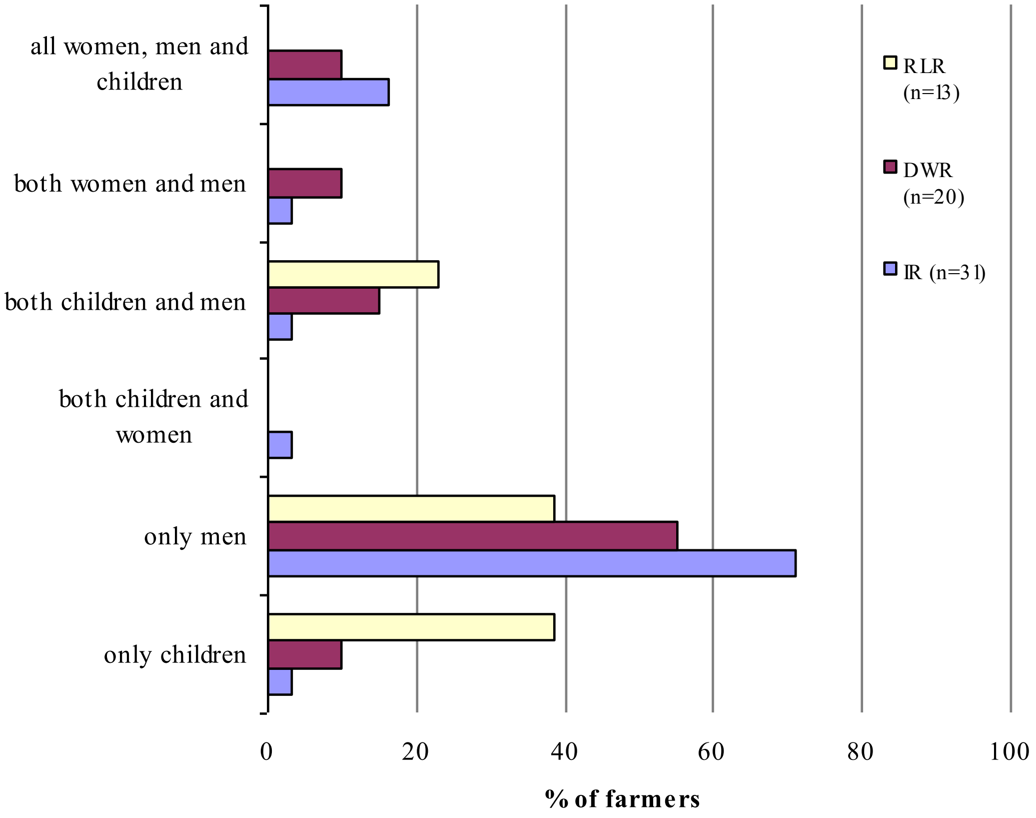

Fig. 6.5. Gender role and labor force participation in catching wide animals in different rice ecosystems.

6.3.3 Uses of water from rice field ecosystem

RLR farmers almost rely solely on well as water sources for drinking and washing while beside well, farmers in IR and DWR area also collect rain water mainly for those domestic uses. Water from rice field ecosystem such as pond, lake or canal is also used by 2 to 27% of farmers in IR and DWR area depending on the sources and activities (Table 6.9) Farmers and children can take bath and swim in canals, rice fields inside the rice ecosystems in all the sites with greater percentage in IR area (e.g., many irrigation canals, KP Lake and streams connected to the irrigation system). DWR farmers often travel through rice fields to reach the flood forestry and the Lake for fishing.

6.3.4 Land conservation and climate mitigation

It can be seen that only one third to half of the total farmers in all three sites think that rice fields provide the functions of rice ecosystems related to land conservation and climate mitigation (Table 6.10). There are still 14 to 28% of the farmers did not know or understand about the functions.

6.3.5 Tourism

Within our three studied sites, the tourism activities were observed only in the Kamping Pouy Lake and its irrigation system which is located nearby Tanghen village (one of the villages in irrigated rice ecosystem). Due to the beautiful landscape (Fig. 6. 6) of the lake and its historical massacre related to Khmer rouge, there are many domestic as well as foreign tourists, particularly Battambang city dwellers come to the area for sightseeing and swimming. Rural people living around this area can also earn significant amount of income from the services for tourism activities such as selling food, giving resting place, boating, etc.

Fig. 6. 6. The beautiful landscape of Kamping Pouy Lake (a, b) and to tourism services of swimming (c) and restaurant (d) in KPIR area in June 2010.

6.3.6 Rice variety diversity

The list of rice varieties planted in parent and recent time across the 3 rice ecosystems is presented in Table 6.11. There are total 103 varieties listed by farmers at all the 3 sites. Eighty of these varieties are justified as parent varieties while the rest are just recently planted in these sites. Among the parent varieties, 53 of them are no longer being planted in any of the 3 rice ecosystems. There are 5 glutinous varieties, 6 floating rice varieties (only grown in DWR) and 6 varieties recommended by governments (CAR4, CAR6, IR66, Phka Rumduol, Raing Chey, and Senpidao).

Although there are large differences of water conditions, variety numbers grown only at parental time (only “p” in the total column) which was recalled by farmers are similar (37, 32 and 36 in IR, DWR and RLR, respectively) among the 3 rice ecosystems.

However, the diversity of cultivars grown only at recent time (only “r” in the total column) becomes narrower in all the ecosystems, particularly in RLR. The highest number of varieties planted only at recent time is found in IR (15 varieties), the next is in DWR (9 varieties) and the last is in RLR (6 varieties). This is perhaps due to the process of agricultural intensification in IR area, where more number of improved varieties (e.g. CAR4, CAR5, CAR6, CAR9, Pkha Rumduol, Raing Chey, San CraOrb and Senpidao) is introduced and farmers are trying to find/test new varieties suitable for the new double cropping systems. It also may be because of the smaller rice cultivated area in RLR compared with IR and DWR (Table 6.1).

6.3.7 Landscape value

In average, 70% of the farmers of the 3 sites think that rice field landscape is beautiful and mainly because of it looking like a green carpet during the rice growing season and a golden carpet at maturing stage of rice (Table 6.12; Fig. 6.7). Among the 3 sites, less RLR farmers (48%) like the rice landscapes compared with IR farmers (82%) and DWR farmers (72%). It is perhaps because those RLR farmers thought of the low rice productivity obtained from their fields. However, the landscape of rice fields with the scattered sugar palm trees in RLR is quite beautiful and unique as for visitors and researchers like us (Fig. 6.7).

Table 6.9. Percentage of farmers with sources of water for daily uses in different rice ecosystems

Water supplies/sources	IR (N=44)	DWR (N=30)	RLR (N=29)	Average (N=103)
drinking				
pond	11	17	0	10
lake	9	0	0	4
canal	2	0	0	1
well	59	67	97	72
rain	61	27	10	37
washing				
stream	16	0	0	7
pond	11	27	0	13
lake	2	7	0	3
canal	9	0	0	4
well	86	73	90	83
rain	36	10	0	18
swimming				
river	2	33	0	11
stream	43	7	0	20
lake/reservoir	34	0	7	17
canal	20	13	0	13
paddy field	0	7	14	6
transportation	5	57	0	18

Table 6.10. Farmers' perception on land conservation functions of different rice ecosystems (% of farmers)

Land conservation	IR (N=44)	DWR (N=30)	RLR (N=29)	Total (N=103)
preventing from flood				
no	43	47	38	43
yes	43	43	45	44
don't know	14	10	17	14
preventing from soil erosion				
no	41	37	10	31
yes	50	47	72	55
don't know	9	17	17	14
lower temperature in summer				
no	34	37	45	38
yes	27	27	52	34
don't know	39	37	3	28

Table 6.11. List of rice varieties used at parent (p) and recent (r) time across 3 different rice ecosystems in Cambodia. Glutinous variety, floating rice, Cambodian government recommended improved variety were with underline, in italic, in bold letters, respectively. Varieties are perceived as plural variety types by farmers include early (E), medium (M) and late (L) varieties.

No	Local name of varieties	IR	DWR	RLR	Total
1	Angkung Khsach			p, L	p
2	Angkung Ov	p, L			p
3	Arith Kraham			p, L	p
4	Arith Sar			p, E, L	p
5	Cheay Sbay	p, M			p
6	Chekteuk Phnom	p, M			p
7	Chheam Angtung	p, M, L		p, L	p
8	Chong Banla	p, M	p, E, M	p, L	p
9	Chong Sanleuk			p, E	p
10	Chumtas Pluk			p, E	p
11	Chutana	p, M			p
12	Damneub Khmao	p, M		p, L	p
13	Damneub Osyang	p, M			p
14	Damneub Smach			p, L	p
15	Damneub Thnot			p, L	p
16	Kambor		p, E		p
17	Kanhol			p, L	p
18	Kaun Kmum	p, E			p
19	Kaunkat	p, L			p
20	Knear Leu	p, L			p
21	Kramuon Sar	p, E			p
22	Krapol	p, M			p
23	Kreim			p, L	p
24	Kung Ov	p, L			p
25	Neang Chek		p, E		p
26	Neang Chem			p, E	p
27	Neang Ham		p, M		p
28	Neang Kandom		p, E		p
29	Neang Lmeath		p, E, M		p
30	Neang Long		p, E		p
31	Neang Mao	p, L	p, E, M, L		p
32	Neang Pich		p, L	p, E	p
33	Neang Rith		p, M		p
34	Neang Tumne	p, L			p
35	Phka Ampil		p, E		p

Table 6.11. Continued

No	Local name of varieties	IR	DWR	RLR	Total
36	Phka Chan	p, E			p
37	Phka Phnov			p, M	p
38	Phka Popel			p, M	p
39	Phka Snol	p, L		p, L	p
40	Phka Tean		p, M		p
41	Phka Treng		p, L		p
42	Phnott Teuk			p, M	p
43	Porng Hinh			p, L	p
44	Porprum	p, L			p
45	Samrong 11	p, L			p
46	Samrong 12	p, L			p
47	Sar Champa		p, M		p
48	Sar Kantuot		p, E		p
49	Sar Kra-ob			p, M	p
50	Sersauth	p, E, M			p
51	Srauv Slap			p, E	p
52	Thhei Ouk			p, L	p
53	*Veal Kampok*		p, L		p
54	Bei Kuor			p, r, L	p, r
55	Chamreak Pdao	p, E		p, r, E	P, r
56	Changvay Pdao	p, E	p, r, E		p, r
57	Chha-ung Puos	p, E		p, r, M	p, r
58	Chhmar Sar			p, r, M	p, r
59	Damneub			p, r, E, M	p, r
60	Ith Chhmuos		p, r, L		p, r
61	Kamping Pouy	p, L	p, r, L		p, r
62	Khmorng Romeang			p, r, E	p, r
63	Kpor Daung			p, r, L	p, r
64	Krachoak Chab	p, M		p, r, E, M	p, r
65	Kung Bangkatt	p, r, L			p, r
66	Kung Khsach	p, r, M, L			p, r
67	Lorlork Cheik	p, M	p, r, M		p, r
68	Neang Khon	p, r, L	p, r, L		p, r
69	Neang Minh	p, r, L	p, r, L	p, E	p, r
70	Neang Phall			p, r, E, M, L	p, r
71	Neang Sar	p, r, L		p, r, E	p, r
72	Phka Daung	p, r, L	p, E, M	p, L	p, r
73	Phka Khnei	p, r, M	p, r, M		p, r
74	Phka Sla	p, r, E, M, L	p, r, E, M, L		p, r
75	*Sar Kranhak*		p, r, L		p, r
76	*Sar Kranhanh*		p, r, L		p, r

Table 6.11. Continued

No	Local name of varieties	IR	DWR	RLR	Total
77	Somaly	p, r, E, M	p, r, E, M	p, r, E, M	p, r
78	*Srauv Pork*			p, r, L	p, r
79	*Veal Sra*		p, r, M, L		p, r
80	*Veal Veng*		p, r, L		p, r
81	CAR 3		r, M		r
82	**CAR 4**	r, M	r, M		r
83	CAR 5	r, M		r, L	r
84	**CAR 6**	r, M			r
85	CAR 9	r, M			r
86	CAR pp		r, M		r
87	Changkorm Ampeak	r, M			r
88	Changva Prum	r, M			r
89	Dork Malis		r, E, L		r
90	Dorng Dav			r, E	r
91	**IR 66**	r, E	r, E	r, E	r
92	Kaun Cheinhcheim		r, M		r
93	Krachork Chea			r, M	r
94	Kung Changka		r, E		r
95	Lum-ong Khsach	r, E			r
96	Neang Loch	r, M			r
97	Phka Malis	r, E, L		r, E	r
98	**Phka Rumduol**	r, M	r, E, M		r
99	**Riang Chey**	r, M	r, M		r
100	Sambok Angkrong			r, E	r
101	Sdach Thai	r, M			r
102	San CraOrb	r, E	r, E		r
103	**Sen Pidao**	r, E	r, E		r

Note: 10 government recommended varieties: Short duration or early varieties; Sen Pidao, IR 66, Chul'sa. Medium varieties; Phka Rumduol, Phka Rumdeng, Phka Romeat, Phka Chan Sen Sar, and late varieties; Riang Chey, CAR 4, CAR 6. These varieties are recommended from Cambodia Government.

Table 6.12. Farmers' perceptions on landscape value of rice fields in different rice ecosystems

Items	IR (N=44)	DWR (N=30)	RLR (N=29)	Average (N=103)
Paddy fields are beautiful landscape (% of farmers)	82	72	48	70
Reasons for beautiful landscape (% of farmers)				
look like a green carpet	65	47	36	54
make air cool in summer	27	16	50	29
look like golden carpet	86	68	43	73
good smell	24	42	14	24
give rice	24	42	14	27

Fig. 6.7. The beauty of rice fields at harvesting time in TY village (RLR ecosystem), Kompong Chhnang province.

6.3.8 Employment, interactions from work and quality of work place from rice fields

In general, there are more farmers spending their time very often in rice field in WSR (June to Dec) compared to DSR (Jan to May) across 3 sites (Table 6.13). It is in November and December when the farmers visit their rice fields most frequently for harvesting. In DSR more farmers in IR area visit rice fields compared with that in DWR and RLR area. RFL farmers had longer duration not visiting rice field frequently from January to May. Working activities in rice field ecosystems may include land preparation, transplanting/sowing, nutrient and pest management (e.g. fertilizer application, weeding, spraying insecticides, etc), water management and harvesting. Farmers may work on rice field for just their own fields or/and on other farmers' fields as a hired labor or exchange labor agreement. There are more farmers in IR and DWR area hiring labor (57% for both IR and DWR area) and exchanging labor (45% for IR area and 37% for DWR area) for working in rice fields compared with RFL farmers (Table 6.14). Transplanting and harvesting are the main activities being done by hired or exchange labor across the 3 rice ecosystems.

Farmers do not work lonely in their fields but often with their family members (Table 6.14) or with other farmers (neighbor fields, hired or exchanged farmers). These give the chance for farmers to exchange and learn information from each other during working in rice fields. In average, 83% of farmers of the 3 sites answered that they often exchange or learn information related to rice production as well as other social issues with/through other farmers while working in rice fields.

Although most of farmers said that they enjoyed working and visiting their rice fields, many of them got troubles such as injury, drowning or sickness during or after working in the fields (Table 6.14). Many farmers also experienced sickness after applying pesticides, particularly farmers in IR and DWR area.

Table 6.13. Percentage of farmers often working/visiting in the rice fields (5 or more days per week) in each month of a year in different rice ecosystems

	IR (N=44)	DWR (N=30)	RLR (N=29)	Average (N=103)
Jan	63	46	35	52
Feb	74	23	31	50
Mar	81	21	38	55
Apr	67	44	0	49
May	74	71	27	65
Jun	75	90	79	81
Jul	84	90	79	85
Aug	86	90	79	86
Sep	95	93	74	90
Oct	93	93	74	89
Nov	98	100	89	97
Dec	100	100	89	98

Table 6.14. Interactions from work and quality of work place from rice fields in different rice ecosystems

Items	IR (N=44)	DWR (N=30)	RLR (N=29)	Average (N=103)
Interactions from work				
hired labor	57	57	17	46
land preparation	33	33	0	30
transplanting	54	67	50	58
weeding	4	13	0	7
harvesting	83	93	75	86
exchange labor	45	37	10	33
land preparation	47	50	0	44
transplanting	37	67	67	50
harvesting	89	67	67	79
information exchange while working on fields	82	80	86	83
rice management	89	88	28	71
rice market	55	32	40	44
child rearing	34	28	72	43
social problems	45	44	68	51
working with family members in the fields	77	83	89	82
Quality of work place				
enjoy visiting paddy	93	83	93	90
got injured in paddy	68	80	83	76
others got drowned in canals or sick	45	30	45	76
got sick after working in paddy fields	64	77	72	70
got sick after spraying pesticides	52	40	17	39

6.3.9 Interactions between rural and city

There are more people coming to visit rural area from town than farmers going to work as off-farm workers in town across the 3 sites (Fig. 6.8). There are fewer households having visitors from town in RLR area than that in IR and DWR area while there are more farmers going to do off-farm job in RLR than that in the other 2 sites. Information between rural areas and town can be exchanged through the flows of the migration from rural to town and reversely.

6.3.10 Festivals

Rice production is part of life for the farmers. A lot of cultural features, folk songs, festivals and public holidays are related to rice, in accordance with its role in the traditional identity of Cambodian people.

There are 20 kinds of festivals listed in the group discussions with the key informants in the 3 studied sites (Table 6.15). Among these, Bon Darlean and Bon Pchum Benh are the most important festivals in which farmers celebrate planting and harvesting time of rice, respectively. Most of the festivals are common in all the sites but few of them are unique. For instance, Meak Bochear and Sot Moan are only celebrated in RLR (Kompong Chhnang) area while Lehng Phom is only in DWR (Battambang).

6.3.11 Farmers' expectation of future of rice fields

In average of the 3 sites, there are 46% of farmers expecting that their rice fields are still rice fields in future while the others want them becoming fruit garden (16%) (Table 6.16). The value was higher in IR (55%) followed by DWR (47%), and lowest in RFL (31%). Forty two percent of the adult farmers in all the sites still want to do the same job as a farmer, but the ratio was lower (28%) in RFL. Eighty two percent of the farmers do not want their children to do the rice farming in the future.

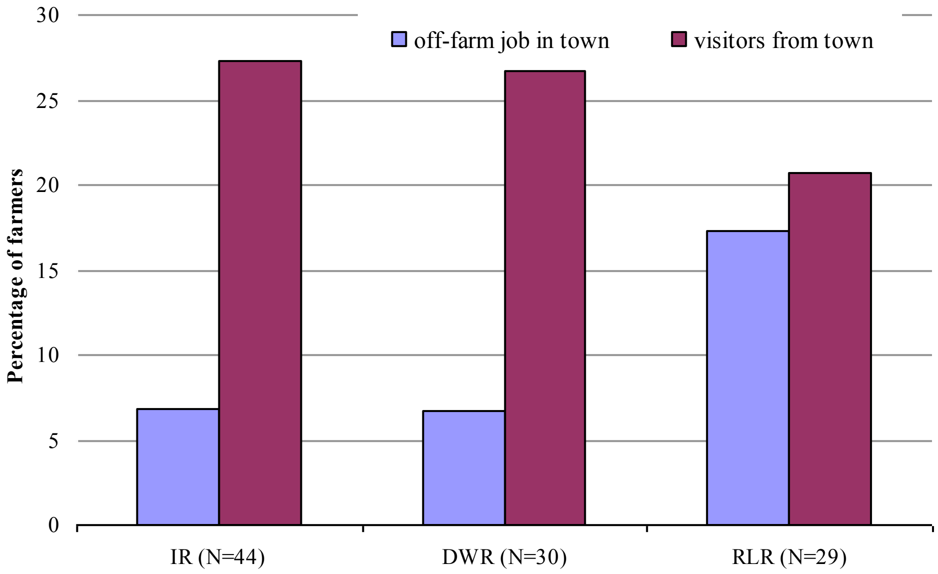

Fig. 6.8. Interactions between rural and city across different rice ecosystems

Table 6.15. List of festivals related to rice production across the three rice ecosystems in Cambodia

No	IR	DWR	RLR
1	Bon Bong Sorng		
2	Bon Phom		
3	Bon Bang Kok Phom	Bon Bang Kok Phom	
4		Bon Chenh Vosa	Bon Chenh Vosa
5		Bon Chol Vosa	Bon Chol Vosa
6	Bon Da lean	Bon Da lean	Bon Da lean
7	Bon Kathen	Bon Kathen	Bon Kathen
8	Bon Leung Lean		
9			Bon Noel
10		Bon Ork Om Bok	Bon Ork Om Bok
11	Bon Pa Chay Bon	Bon Pa Chay Bon	Bon Pa Chay Bon
12	Bon Pchum Benh	Bon Pchum Benh	Bon Pchum Benh
13	Bon Pka Prak	Bon Pka Prak	Bon Pka Prak
14	Khmer New year	Khmer new year	Khmer new year
15		Lehng Phom	
16	Meak Bochear	Meak Bo Chear	Meak Bochear
17	Pisak Bo Chear	Pisak Bo Chear	
18	Porn Phnom srov		
19	Sen Pra Kher		
20			Sot Moan

Table 6.16. Farmers' expectation (% representative) of future of rice fields in different rice ecosystems

Items	IR (N=44)	DWR (N=30)	RLR (N=29)	Average (N=103)
expecting future of paddy fields				
still to be paddy fields	55	47	31	46
to be a fruit garden	11	10	28	16
to be an industrial area	0	0	3	1
to be a city like	0	3	3	2
to be others	5	0	7	4
don't know	30	40	28	32
still like to be a farmer in future	48	47	28	42
expecting children to be a farmer in future	16	30	10	18

6.4 Discussion

6.4.1 Functions of livelihood and economic

Obviously, rice production is the primary function of rice cultivation. Our study showed that rice produced from rice farming across IR, DWR and RLR ecosystems in Cambodia is not only used for farmers' self-consumption but also for selling (Table 6.3) which contribute as an income source for farmers to carry out other activities. At national level, rice has become the most important agricultural export product in Cambodia with a contribution of 10% of the country's total export value (IFM, 2009). However, there are still a number of farmers in each of the rice ecosystems suffering from hunger, especially, those in DWR and RLR areas. Further increasing rice productivity in these areas through agricultural extension and the support of Cambodian government will help these farmers escape from the food shortage.

Beside rice production, our results also demonstrated that the richness in biodiversity of rice ecosystems, especially the aquatic plants and animals, is also very important for rural people's livelihood in Cambodia, particularly the poor farmers who do not have money to buy food from market (from Table 6.4 to Table 6.7). The important role of these aquatic resources from rice fields to farmers' livelihood in Cambodia was also supported by (Halwart et al., 2006; Shams 2007).

Another contribution of rice fields to the Cambodian farmers' livelihood is the utilization of water and tourism service from the rice ecosystems. Water from rice fields is partly used for domestic use, entertainment (swimming) and traveling in the rural area across different rice ecosystems (Table 6.9).

6.4.2 Functions of environment

Rice ecosystem has been approved to possess several positive functions related to environment such as flood control, prevention of soil erosion, groundwater recharge, water purification and climate adjustment through many studies in different countries such as Japan (Matsuno et al. 2006), Korea (Kim et al., 2006), Taiwan (Huang et al., 2006) and Indonesia (Agus et al., 2006). The monetary values of these functions were also even attempted to be assessed by these studies by using replacement cost and contingent valuation methods. We did not try to estimate the monetary values but rather tried to evaluate the farmers' perceptions on these functions. Our result indicated that most of farmers do not recognize these functions of rice fields (Table 6.10). This is understandable as farmers only think of their rice fields for production purpose. However, it is important to let farmers know the real values of their rice fields so that they can benefit the rice fields from not only the field productivity but also the payment from the government for the maintaining the rice ecosystems.

Rice ecosystems also have function of biodiversity conservation as they provide rich habitats for aquatic plants and animals (Hidaka, 1998; Yamaoka, 2005). In our study, the biodiversity of plant and animals in rice fields are not quantified in details but somehow shown the richness in biodiversity of not only aquatic creatures (Table 6.5 and Table 6.7) but also rice genetic resource (Table 6.11). Our result, however, showed that the aquatic biodiversity may be under threats of decreasing due to the over catching and the use of pesticides and harmful tools. This issue was also reported in Halwart (2006). The loss of aquatic biodiversity will negatively impact not only on environment in terms of biodiversity conservation, but also on the farmers' livelihood. Number of rice varieties grown by farmers in different rice ecosystem has also reduced overtime. Many traditional varieties during parent time are now no longer being grown in our studied sites due to the introduction of improved varieties with higher yielding potential. These imply that the government should pay attention on the enhancement the diversity of living aquatic as well as rice genetic resources when making policy decisions and management measures for increasing rice productivity in Cambodia.

6.4.3 Social and cultural functions

Our results showed several social and cultural functions of rice fields which include the provision of (1) the beautiful landscapes for farmers and visitors' entertainment, (2) employment and environment for information exchange for farmers, and (3) festivals and spirits.

The study showed that rice ecosystems in Cambodia can provide various functions belonging to three categories of (1) livelihood and economic; (2) environment; and (3) social and cultural although the value of each function has not been quantitatively estimated. Multifunctionality of rice fields has been well studied in the better developed countries such as Japan, Korea and Taiwan but the livelihood and economic functions were mostly negligible in the multifunctionality framework of these countries. Bio-resources from paddy fields are very important to farmers' livelihood, particularly poor people; therefore, this function should be put in the multifunctionality framework of the developing countries. Cambodian government recently announced rice as a white gold and wants Cambodia to become one of the major rice exporting countries in the world by increasing rice productivity through rice intensification. However, the intensification (e.g. increase in using of fertilizer and pesticide) may enhance the negative functions of rice fields (e.g. pollution, biodiversity loss). Therefore, multifunctionality of rice farming should be taken into account when making policy decisions related to rice production in order to achieve a sustainable agriculture development in Cambodia.

Chapter 7

General discussion

7.1 Micro-scale water variation within each of the 3 rice ecosystems

Rice in Cambodia is grown over diverse water environments including IR, DWR, RLR and RUR. This study shows that water environments are different not only among the rice ecosystems but also within each rice ecosystem (excluding RUR as not focused in this study) at micro-scale (landscape level as explanation in Chapter 1).

In IR ecosystem at KPIR area, field water environments largely vary along the canal as well as between the canals in WSR. Field water depth increases along the canal and water depths of the downstream canals are deeper than upstream canals (Chapter 3). Although field water condition is less different in DSR, there is still inequality in water distribution between upstream and downstream fields. The quantitative assessment of spatial distribution of water depth in both wet season rice and dry season rice is conducted for the first time in Cambodian irrigation rehabilitation areas by this study. Thun et al. (2009) also mentioned from farmer interviews about this unequal water distribution in Takeo province, Cambodia. Our study showed that the deep water at downstream fields in WSR with maximum depth of 76 cm which can be classified as medium-deep water environment (Huke and Huke, 1994) limited the expansion of improved medium maturing varieties (e.g. Raing Chey) in WSR and the water shortage at also downstream fields in DSR is a constraint factor for grain yield.

In DWR ecosystem in Kompong Preah commune, field water depth also increases along the transect line from upper fields (near Road No5) to lower fields (near the Tonle Sap Lake) (Chapter 4). This study showed that the rice fields in flood plains of Tonle Sap Lake in Kompong Preah commune can be split into 3 rice zones including (1) only DWR cultivated area with maximum water of 169 cm, (2) medium-deep RLR area where RLR varieties are grown, and (3) in-between area where both RLR and deep water rice are grown with maximum water of 40-85 cm. Identification of the in-between area has not been emphasized previously among rice researchers, but from the perspectives of farmers who have rice fields in the in-between area, it is in this region where uncertainty of water conditions affect much their choices of rice variety types (i.e., RLR or DWR).

In RLR in Kompong Chhnang, water conditions of fields in upper location are also different from lower location (Chapter 5). Field water depth of lower fields is deeper than that of upper fields and flood duration of lower fields is longer than that of upper fields. This study confirms the results of toposequence variation in water in RFL from the previous study (e.g. Miyagawa and Kuroda, 1988; Tsubo et al., 2006; Boling et al., 2008; Homma et al., 2007).

The micro-scale water variation has large influences on farming practices and yield level. Therefore, the characterization of water environments at micro-scale is important for technology development and dissemination.

7.2 The importance of technology transfer in Cambodia

Although there are available technologies which have been developed for improving rice yield in Cambodia such as irrigation development, improved varieties with high yield potential and suitable for various rice ecosystems and recommended rate of fertilizer for different soil types, rice yield in Cambodia is still low with only 2.8 t ha^{-1} in 2008 (FAOSTAT, 2011). This study emphasized the importance role of technology transfer (agricultural extension) in the enhancement of rice productivity in Cambodia.

In IR ecosystems in KPIR area, farmers' lack of knowledge on rice variety and plant protection are identified as reasons limiting rice yield in DSR (Chapter 3). Due to lack of knowledge of photo-period sensitivity and insufficient circulation of suitable varieties for dry seasons, some farmers in KPIR planted these varieties in DSR, and could not get any yield from the fields. Due to lack of knowledge of rice plant disease (i.e. *Bipolaris oryzea* and *Cercospora oryzea*) and unavailability of pesticides (i.e. fungicides) in the village shops, some farmers applied insecticide (e.g. Videci 2.5ND, Visher 25ND, Folitec 025EC) in vain instead of fungicides for controlling diseases which occurred extensively in DSR 2010. These mistakes of rice management imply that rice yield in KPIR area could not be improved by providing farmers only irrigation facilities but also rice management knowledge such as DSR varieties, efficient usage of agricultural resources for crop management and plant protection. Gaps are not only between potential yield and attainable yield, but also between attainable yield and obtained on-farm yield.

Inorganic fertilizers and seeds of improved varieties have been effective tools for rice yield improvement by way of modern agricultural research and extension systems. Our on-station experiments supported the efficiency of using an improved variety and inorganic fertilizer for attaining higher yield. However, the on-station results have not been directly translated into the farmer fields at villagessuch as TY and NT villages in Kompong Chhnang province (Chapter 5). This study showed that farmers are willing to try the new technologies, but the adoption level depends firstly on the availabilities of water; providing the farmers with inorganic fertilizer in 2009 did not result in higher yield at their fields, and in WSR 2010 when rainfall was little due to long dry spell farmers did not invest for applying more inorganic fertilizer. Secondly improved variety seeds were found to be more readily adopted by farmers than inorganic fertilizers; inorganic fertilizers need to be paid every growing season, rice seeds can be multiplied on farm for uses in plural years. However, seed renewal is needed in order to avoid seed quality degradation. The extension work to farmers such as seed production training and packets of site-specific nutrient management should be able to contribute to higher yield by improving the adoption level of improved varieties and fertilizer in RLR ecosystem in Cambodia.

However, extension services are still limited in Cambodia. According to EIC (2006), there are only 500 extension officers in the whole country with the ratio of one extension officer per 4,000 farm households. This ratio is three times less than that of Vietnam of one extension officer per 1,340 farm households. The situation has not been improved recently. For instance, in Battambang province, where agricultural land is considered as rice-bowl of the country, there are only 50 officers working in agricultural sector and responsible for agricultural production (mainly rice) for 14 districts in 2010. Among these staff, 28 of them work at district level (2 staff for one district) while the rest at provincial level. There has not been any staff responsible at commune level yet. Furthermore, the existing agricultural officers are lack of agricultural skills (personal communication with Mr. Sovanmony In, head of Agricultural office of Battambang Provincial Department of Agriculture). These imply that empowerment of human resource is crucial in order to develop a better agricultural extension system in Cambodia.

Supports from international organizations are extremely needed for establishment of extension system in Cambodia through agricultural education and agricultural development projects.

7.3 Prospects for sustainable farming for the 3 rice ecosystems in Cambodia

7.3.1 Irrigated rice ecosystem

Global rice demand is expected to continue to increase in the near future (Matriz et al., 2010), which gives a good opportunity for investing exportable rice production in Cambodia. As mentioned in the Chapter 2, in the latest policy related to the promotion of rice production and export, the Cambodian government is ambitious to increase rice production for exporting through enhancing rice productivity in the newly rehabilitated/constructed irrigation systems. The government expects to increase rice productivity by using high yield seed and modern farming techniques (i.e. fertilizer, pesticides and machinery) (RGC, 2010). Rice for export is projected to increase from 2.1 million ton in 2010 to 2.9 million ton in 2015 (Table 7.1). This increase is expected to be mainly from the expansion of DSR (from 0.38 to 0.48 million ha) and yield improvement of DSR (from 4.4 to 5.6 t ha^{-1}). However, the actual rice yield in the newly introduced DSR in KPIR area in 2009 and 2010 was only 2.9 and 2.5 t ha^{-1}, respectively (Chapter 3). Reasons for lower yield in DSR in KPIR compared with that from national statistic (e.g. 2.9 vs 4 t ha^{-1} in 2009) were probably because of variety choice (i.e. lowland yield potential of San CraOrb) and that yields obtained for the statistic was from dry recession rice (mainly IR varieties, fertile soil) as mentioned in the discussion of Chapter 3. DSR area is estimated to expand to about 100,000 ha more in 5 years from 2010 to 2015 and this area will come from the rehabilitation of the un-functional irrigation schemes like KPIR area. Many of the farmers from those projected DSR expansion area will experience growing DSR for the first time. DSR yield in this area will not automatically reach to 5.5 t ha^{-1} but there will be a need of substantial efforts to disseminate technologies (i.e. variety, water, nutrient and pest management) suitable for farmers.

Table 7.1. Projection of paddy production in Cambodia 2010-2015 (RGC, 2010)

Items		2008	2009	2010	2011	2012	2013	2014	2015
Yield (t ha^{-1})	WSR	2.54	2.62	2.70	2.78	2.86	2.95	3.04	3.04
	DSR	4.03	4.13	4.43	4.75	5.10	5.47	5.50	5.55
Cultivated area (million ha)	WSR	2.26	2.33	2.34	2.35	2.36	2.37	2.38	2.39
	DSR	0.36	0.39	0.38	0.38	0.41	0.42	0.45	0.48
Production (million ton)		7.18	7.59	7.30	7.62	8.09	8.44	8.85	9.08
Paddy for export (million ton)		3.16	3.51	3.32	3.44	3.80	4.06	4.37	4.51
Rice for export (million ton)		2.03	2.25	2.06	2.20	2.43	2.60	2.80	2.89

Results of Chapter 3 in this study indicated (1) farmers' challenges in adapting to the double cropping system (e.g. the tight schedule and shortage of labor from DSR harvest to WSR; needed improved techniques of wet seeding; and alternative weed management practice for midseason tillage) and (2) factors limiting rice yield (e.g. deep water at lower fields in WSR, weed infestation, the occurrence of diseases and low fertilizer input) in KPIR area.

Strategies to solve the farmers' challenges and yield limiting factors in KPIR area have already discussed in Chapter 3. Basically, we agree that intensification is needed in order to improve IR yield as mentioned in the national policy. However, it should be noticed that besides rice production, KPIR area also possesses others bio-resources (i.e. wild aquatic plant and animals) and other multifunctionality (i.e. domestic uses of water from irrigation canal) which are important for farmers' livelihood (Chapter 6). The manner of conducting rice management practices (i.e. fertilizer and pesticide application) will have large impact on the wild creatures and water quality of rice fields. Hence, it is important to take these externalities into account in order to obtain sustainable rice production in IR ecosystem. However, how to balance between rice production and environment conservation (or multifunctionalities) is an uneasy task, particularly, some of the functions (i.e. bioresources for livelihood or clean water in irrigation canal for swimming and domestic uses) may be only important at local level but not at national level. This study contributes to raise a voice of farmers on these locally important roles of rice fields for their livelihood to the policy makers for their consideration when making decisions on agricultural development. Based on this approach, we recommend the followings strategies for enhancing rice productivity in KPIR area:

- Using machine for harvesting in both WSR and DSR in order to solve the labor shortage problem and tight cropping schedule.

- Introduce improved techniques for wet seeding such drum seeding. This technique has been widely adopted in Vietnam when wet seeding has recently become popular in this country.

- Improve drainage system so that improved high yield potential (i.e. Raing Chey) can be extended to the lower/downstream fields in WSR

- Provide farmers training on integrated nutrient management of IR so that farmers know how to apply fertilizer in more proper manner, avoiding excessive amount causing environmental pollution

- Provide farmers training on integrated pest management (IPM), particularly, the knowledge on rice diseases and their control methods, so that rice can be protected from pest damage without the negative impacts on the other bio-resources in the ecosystem.

- Enhance the availability of agricultural inputs, particularly, fungicides and herbicide types for controlling different types of weeds in the KPIR area

- Introduce high yield varieties into DSR in order to replace the present variety of SancraOb which is low yield potential and susceptible to disease. CARDI has recommended 3 early maturing photo-period insensitive varieties for DSR namely Sen Pidao, Chul'sa and IR66. However these varieties have not been adopted by KPIR farmers. This may be because that these varieties either have not been introduced into the area yet or are not preferred by the farmers due to unfavorable taste or low market price.

7.3.2 Deepwater rice ecosystem

Result of Chapter 4 showed: (A) almost flat slope along a transect of water depth gradient and 3 groups of rice zones in the floodplain of TSL with (1) upper fields located closer to the National Road Number 5 where water depth was shallower and only LR was grown; (2) middle fields where both LR and FR were grown; and (3) lower fields located near to the Lake where water depth was deeper and only FR was grown. (B) Large yearly differences in flood from the Tonle Sap Lake were also shown. In 2008 and 2009, water came to the paddy fields from both the inundation from Tonle Sap Lake and rainfall with maximum in October of more than 100 cm, while in 2010, flood did not come from the Lake and all the 3 rice zones had less than 30 cm of maximum water depth.

Rice yield in DWR in floodplain of TSL was low with only 1.1 t ha^{-1} for FR and 1.8 t ha^{-1} for LR (Chapter 4). Low yield was caused mainly by the risky water environment in middle area where water depths were unfavorable for either LR or FR (85 cm), improper fertilizer management (none or late application) and insufficient weed management. The introduction of submergence-tolerant varieties with high yield potential (e.g. sub1-varieties now available at IRRI, according to Manzanilla et al., 2011), and nutrient and weed management techniques to farmers may help to increase rice productivity in the area. Forecasted information of flood regime both for coming WSR rice and for longer trends is also needed in order to avoid risk damage of rice farming in the middle fields.

DWR area used to be common in Cambodia in 1960s as it occupied up to 16% of rice cultivated (about 400,000 ha) (Javier, 1997; Seng et al, 1988). Most of the area near the TSL have been abandoned and become flood forest due to the discouragement of growing DWR during Pol Pot regime. Recently DWR area has an increasing trend again due to the availability of tools for clearing the abandon land. For instant, the DWR area occupied only 2.6% of the total rice cultivated area in 1999 (Ouk et al., 2001) but it was 3.9% due to deforestation of flooded forest in 2006 (MAFF, 2006). As DWR area around the TSL is flat and fertile which is suitable for rice production, the area will be potentially further expanded as the activities of clearing flooded forest near TSL are on going according to our observation from 2009 to 2011. Furthermore, price of floating rice has become higher in the rice market and easy to sell as wholesalers from Vietnam often come to buy rice with large amount at the farm gate (from our survey record and observation). Although it is understandable about high rice price and potentially good flat and large area for rice farming (expect a large mass of rice for selling), the expansion of DWR area into flooded forest could thread biodiversity and environments and need to be balanced.

Another option is to transform the DWR into recession rice (DSR planting November to March/April after flood receding). In Cambodia, most of DSR, existing before the year of 2000 when irrigation rehabilitation/construction has not been promoted by the government and international donors (e.g. ADB, JICA, FAO), is recession rice area (Ouk, 2001). High yield (more than 3 t ha^{-1}) is often observed in recession rice area due to the adoption modern varieties (i.e. IR66) and high agro-chemical inputs (Koma, 2008). DWR area in other Southeast Asia countries has also been largely converted to area where dry season rice is grown with better water management (i.e. Banladesh) or irrigated area with triple crops per year (i.e. Vietnam by building dam and irrigation system). However, it may be not easy to do the conversion in some DWR areas due to the natural conditions (i.e. unavailable large lake/pond to storage flooding water in DWR area in Kompong Preah commune) and socio-economic conditions (i.e. costly and lack of funds). Furthermore, at present the government has much concerned about the negative impacts of the intensive farming practices conducted in some existing recession rice area (increase in using of fertilizer and pesticides) on the rich biological resources of DWR area in Cambodia, particularly, the area located around Tonle Sap Lake (CDRI, 2008). Maintaining the richness of biodiversity, particularly, aquatic plants and animals, is important not only in terms of biodiversity conservation but also for poor farmers who live in the DWR area and their livelihoods are only from rice and bio-resources in the ecosystems (Chapter 6). Floating rice varieties are also very unique and valuable genetic resources, and hence it is needed to prevent from the further loss of traditional Cambodian floating rice. The conversion to recession rice from DWR will threat the disappearance of those unique floating rice varieties. In short, the conversion from DWR to recession rice will increase rice productivity but it will need high initial investment and it will also result in higher ecological costs, which could make the rice production enhancement ecologically as well as nutritionally unsustainable.

Eco-tourism development for the DWR areas around Tonle Sap Lake may be a good option for increasing farmers' income and raising the awareness of the importance of DWR ecosystem in the Tonle Sap Lake biosphere conservation. The richness of biodiversity with presence of endangered species and the uniqueness of floating rice practices will attract tourists from over the world.

7.3.3 Rainfed lowland rice ecosystem

This study showed that rice yield in RLR in Kompong Chhnang was low (1.5 t ha^{-1}) because farmers planted only local varieties on poor soil fertility with the low rate of applied inorganic fertilizer (e.g. only 14 kg ha^{-1}) (Chapter 5). The results of on-station experiments suggested that using improved variety (e.g. Phka Rumdoul) and the recommended inorganic fertilizer rate can improve rice yield in the RLR area. However the efficient level of improved variety and fertilizer still depends on field water availability/rainfall pattern. As RLR rice area occupied large proportion of rice cultivated area (80.7%) in Cambodia, only small increase in rice yield will contribute to large benefits to many farmers for their livelihood, food security, and additional income. However, farmers may not automatically adopt the introduced technologies. Our results in Chapter 5 showed that adoption level of improved variety and fertilizer depends on the availability and popularity of these resources among the farmers. Farmers preferred to grow Phka Rumduol in WSR 2010 but the adopted area was not very high due to the seed shortage. On the other hand, fertilizer was not highly adopted by farmer in WSR 2010 due to lack of money to purchase and farmers' concerns on low benefit return in the drought situation. As discussed in Chapter 5, the strategies for enhancing adoption level of the improved varieties and fertilizer are summarized and further discussed as followings:

- Improve seed production system for improved rainfed lowland varieties in Cambodia. At the present CARDI is responsible for both seed development and production. Seed production system may become more efficient if the responsibility is transferred to the commercial seed producers. The AQIP Seed Company, which is the outcome of the agricultural improvement projects, jointly funded by the Cambodian and Australian governments from 2000 to 2008, is the only rice seed company in Cambodia producing and selling large scale quality commercial rice seed in the country. In the short-term, delivering the seed production training to farmers may help to meet the demand of quality seeds in RLR area.

- Varietal development should be based on participatory approach. Conducting participatory variety selection trials by testing varieties in farmers' actual field conditions will help to identify local-specific varieties with better adaptation and traits that meet local needs (Jongdee, Pantuwan et al., 2006; Manzanilla et al., 2011).

- More flexible nutrient packets need to be developed and introduced to farmers in RLR in order to reduce the risk of crop loss and hence promote farmers' adoption of the recommended fertilizer. Dobermann and White (1999) suggested that nutrient management strategies need to be (1) aimed at specific targets; (2) flexible depending on the progress of the season and/or the outcome of the previous season; (3) able to accommodate the aims of farmers (e.g. not necessary for maximizing yields but low cost or rice flavor); and able to provide a structure for the transfer knowledge and experience between farmers and allow improving the technologies with lessons learned.
- Improve credit system and subsidize agricultural inputs (e.g. seeds and fertilizer) to farmers.

Crop diversification has been suggested as a strategy to improve land productivity and income for farmers in RLR ecosystem in the national policy. As rice is only grown in wet season, another non-rice crop can be grown in dry season. With the support from Australian government, CARDI are now trying to test different non-rice crops in different soil types in order to identify suitable crops for each soil type in Cambodia. Seng et al. (2008) found that Prey Khmer soil is the most suitable for planting legume crops (i.e. peanuts, mungbean, soybean) compared with other soil types such as Prateah Lang, Bakan and Toul Samroung. This result suggested that the legume crop can be grown in TY and NT villages as well as other area in Kompong Chhnang province where Prey Khmer is the main soil type in their agricultural land. However, supplementary irrigation is needed as there is no rainfall in dry season. Furthermore nutrient management and pest control (insect, disease and weeds) for the non-rice crops are new to farmers. Therefore, supporting farmers to create water source for supplementary irrigation (i.e. tub-well for using groundwater) and training farmers techniques on the non-rice crop management are needed in order to introduce the diversification system into RLR area. Market for the non-rice crop also needs to be developed so that farmers can sell the products for their additional income.

Off-farm job would be another option for farmers to increase their income. Rice is only grown in WSR, rainfed-farmers, who live in places closer to big cities, like Kompong Chhnang province (about 30 km from Phnom Penh: Fig. 5.1), are easy to find off-farm jobs. Result of Chapter 6 also showed the higher percentage of people doing off-farm job in Kompong Chhnang compared with the other sites in Battambang province. Government should also encourage investors building industrial areas (e.g. garment factory) nearby RLR area in order to provide off-farm job for villagers living in the area.

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