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Final report

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1 Acknowledgments

We wish to thank Directors of PDA, Mr. Ou Bosphaon from Kampong Thom, Mr. Ngeb Srorn from Takeo, Mr. Heng Binyi from Kampong Cham and Mr. Chan Chesda from Kampot for their invitation and the subsequent support of the project. PDA officers in these Provinces contributed greatly to the project, by playing a pivotal bridging roll between CARDI scientists and farmers in their Districts. Many farmers made valuable contribution; some used their farms as ‘model farms’ and others as ‘demonstration farms’. Their knowledge and practical skills are admired by all who are privileged to work with them.

Many CARDI scientists, workers and administration specialists have worked together to enable successful completion of this project. Financial support from ACIAR is greatly appreciated. We wish to thank Dr John Dixon for his strong support of the project, his advice on several key areas to improve the project and technical input.

2 Executive summary

The aim of this four year nine month (2007-2012 including 15 month extension) project in Cambodia was to increase the range of crops grown under rainfed lowland conditions by promoting non-rice crop technologies that provide efficient water use and high financial return to growers. This can be achieved by adding a non-rice crop after the main wet season rice crop (i.e. rice/non-rice double cropping) and the key research issue was water – how to select the appropriate soil and water environment in the wet season for the following non-rice crop, particularly peanut, soybean, and mungbean, and how to ensure adequate water for the crop? The intended target group of the project was for small scale lowland rice farmers with favourable water availability on-farm. Limited amounts of water may be available from underground or on-farm ponds, as supplementary irrigation to non-rice crops. Assessment of cropping risks and economic evaluation of new technologies are two key aspects of the project.

In the first two years of research, the legume technologies were developed by the project, and have been tested widely by farmers in three Provinces in the last three years. The legume crops considered most promising are mungbean and peanuts. A good supply of supplementary irrigation water is essential, as the amount of soil stored water and rainfall are generally small. Legume cropping requires thorough land preparation and the soil should be levelled to ensure even distribution of irrigation water if land is prepared flat and flood irrigation utilized. For mungbean in particular, ridges and furrows should be used to ensure good establishment, ease of irrigation, and control of weeds. Irrigation water needs to be applied every week. Another key requirement for legume cropping is high labour productivity. The viability of growing legumes depends on, not only increasing yield with the improved technologies, but also decreasing labour inputs to reduce the cost of growing legumes. Opportunity exists for reducing the labour cost in activities associated with land preparation, planting, and application of supplementary irrigation. The project was successful in developing labour-efficient supplementary irrigation methods for legume cropping in rice-based cropping systems to address the two key issues.

Legume growing in the lowlands was new but was accepted by farmers with appropriate resources in areas near the project activities. The legume cultivation in lowlands is likely to be adopted in areas with supplementary irrigation availability, but also possibly areas where full irrigation is available. Major impact of the project may be seen through the improvement in scientists' capacity to conduct research. In particular, there has been improved understanding of water requirements to grow a legume crop (water productivity). The scientists are now capable of measuring water input to the field and also soil water content during the crop growth. The ability to measure water input greatly improves the opportunity to make gains in developing efficient water productivity systems. Similarly, there has been capacity development for estimation of labour productivity.

This project has demonstrated the value of supplementary irrigation in introducing mungbean and peanuts in what is otherwise a rice mono-cropping system. With increasing land areas with access to irrigation supply, options for intensification also improve, with water management as part of the agronomic package a key to achieving higher farm profitability. Based on the improved livelihoods of farmers using diversification and intensification in the model farm demonstrations conducted within this project, the potential for improved and diversified household nutrition, the improved capacity of scientists and PDA staff, in combination with the increasing land area and consequently landholders who have access to full or supplementary irrigation, further work on diversification and intensification in which a more holistic approach is adopted (which was beyond the scope of the current project) in rice-based lowlands in Cambodia should be considered. This new systems approach will widen the project area beyond legumes to any crops/farming activities that are suitable in rainfed lowland with some supplementary water availability.

This suggestion is in accordance with the recommendation of reviewers; the following is taken from the review report. ‘The reviewers support the concept of developing a new ACIAR project proposal to capitalize on the progress made during CSE/2006/040 and on CARDI’s expertise and experience in the rainfed lowlands. A new project will also provide continuity to the current research, thereby ensuring the plant breeding and other outputs in CSE/2006/040 will gain further strength. Any new project should continue to foster the solid relationships existing between CARDI and the PDAs. Because of the nature of the rainfed lowlands, the proposal should be developed with a 10 year research horizon with the first phase possibly being 5 years in length. It should:

a) Target the rainfed lowland ecosystem where a majority of farmers reside and where the need for farm income improvement is the greatest

b) Target the Prateah Lang and possibly the Prey Khmer soil types. CARDI has experience on these soils which are wide spread in the Cambodian rainfed lowlands.

c) Target areas with potential on-farm reservoirs of good quality water

d) Use a multidisciplinary approach and work through the PDAs

e) Include model farms to develop a full understanding of the interactions and synergies of a diversified farm approach

f) Include studies on minimizing pest incidence through farming practices ie drying soil after rice to reduce insects and disease loads, keeping plants sufficiently healthy etc

g) Include studies on processing, packaging and general value added marketing of upland crop products

h) Include studies on the linkages between private sector and farmers

i) Conduct further research on the mechanization of non-rice crops, particularly in the dry season

j) Expand varietal evaluation of non-rice dry season crops to other food and fodder crops

k) Diversify to high value crops ie sugar cane, water melon and other vegetables

A potential project title is “Improving farming systems on the rainfed lowlands of Cambodia”.’

3 Background

The following (2 pages) is taken from the project proposal, and provides the project justification. The key issues to be addressed are stated at the end of this 3 Background section.

'SECTION 2: Project Justification

Partner country and Australian research and development issues and priority

Rice is, and will remain, the most important crop in terms of area. However one of the priority issues for agriculture development is diversification of rice-based systems to increase farmer income. The ACIAR Annual Operational Plan for Cambodia promotes such agricultural diversification, particularly through non-rice crops, and increased productivity of rice-based farming systems. This project focuses on the diversification and intensification of the lowland rice-based systems.

Over 90 % of rice in Cambodia is produced in the lowlands (under paddy conditions with bunds to store free water) and over 80% of this is grown under rainfed conditions in the wet season. Increasingly, as farmers meet their subsistence rice requirements, they explore new avenues to increase family/ farm income, including intensification, sometimes with supplementary irrigation, and diversification with higher value crops. The recently completed project (CIM/1999/048) demonstrated the profitability of a short season early maturing rice variety before the main wet season rice crop. Many farmers now grow two crops of rice and are increasing family income by 37 and 25% in two provinces (Chea et al. 2004). However there is little diversification to other crops even though the duration of the wet season in Cambodia provides more opportunity than in Laos or NE Thailand to develop double cropping. CIM/1999/048 demonstrated that planting a crop of mungbean after the main long season rice crop is risky because of the lack of moisture. It also showed that non-rice crops growing in the beginning of the wet season are exposed to flooding. This project will address those constraints to add a non-rice crop after the main rice crop to fully exploit the growing season. To do so will require changes to the rice system which are the subject of the experimentation of the project.

The area of lowland rice is much larger than upland rice, and thus the potential for diversification is also large provided that the constraints can be overcome. The issues of crop diversification in the uplands of Cambodia are being addressed in another project[1] and this new project will use the relevant outputs from that work. As discussed later, there is potential for farmers to add a non-rice crop after their main lowland rice crop on around 20% of their land. It is also estimated that farmers may now be willing to divert around 10 % of their land from rice to a high value crop. Thus in aggregate the potential for diversification of the 2 million ha of rainfed lowlands is large. The project will focus on three provinces – Takeo, Kampong Thom and Kampong Cham – which cover about 20 % of the lowlands. The options for intensification and diversification of the rice based lowland systems developed could be readily extrapolated to most of the lowlands.

Crop diversification can include forage crops (for livestock production), vegetables or broadacre crops. The main target for adding a crop after the main rice will be high value,

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[1] *ASEM/2000/109 Dr Bob Martin's project on Farming systems research for crop diversification*

short season crops such as soybean, mungbean and peanut. The researchable issues will be to determine how shorter season rice cultivars, minimum tillage and supplementary water (from shallow surface storage) extend the growing season for a follow-on crop and how best to manage that crop in terms of planting system, nutrition and water use. Intensification of the system by adding a crop after the main rice crop will provide an additional income for the normal rice farmer. It is assumed that each farm will continue to produce enough rice for home consumption while converting parts of the land to the non-rice crops.

The choice of the crops grown depends largely on markets and on their suitability to the growing environment. This project will address the latter i.e. it will examine the feasibility and profitability of growing non-rice crops as part of the rainfed lowland rice based system.

The researchable issue is to match crop needs to the local field environments and provide viable cropping options. A major driver is the available water. Variation in the position of paddies in sloping land at the farm level provides variation in the microenvironments including soil types, local drainage, water availability in the root zone, hard pans and water tables. The most suitable part of the farm will be determined and utilized for the introduction of the non-rice crop. The area on each farm that could be utilized would depend on the value of the crop and how much input per unit area is required to grow the crop. High input high output crops could be grown on small areas with access to stored water. This could be more profitable as limited water and other resources (e.g. manure) can be utilized intensively in a smaller area resulting in high quality produce that can attract a high price. In general lowland rice soils are poor in fertility and require inputs. Adequate data will be obtained to determine the optimum use of resources for various crops. It is anticipated that 10% of the lowlands will diversify to crops other than rice in the main season, as farmers become familiar with growing non-rice crops in lowlands in the wet season.

The three provinces where the work will be conducted were chosen because they are relatively close to markets (and therefore demand for higher value crops) and provide a range in rainfall distribution typical for the lowlands of Cambodia. All the work will be done on farmers' fields to obtain useful benchmark data on performance of the new systems as a whole and for use in whole farm budgets analysis to understand the economic impact from diversification. The knowledge about the diversification processes gained at these sites will be applicable to other lowland areas.'

Key issues to be addressed.

As stated in the project document 'The aim of the project is to increase the range of crops grown under rainfed lowland conditions and to develop sufficient information in order to promote non-rice crop technologies that provide efficient water use and high financial return to the growers'.

Detailed objectives and activities are stated also in the project document (see the next section on Objectives). Key issues can be summarized as the following.

To determine:

1) Whether we can grow non- rice crops, particularly legumes, in rice paddy fields after harvesting rice.

2) What would be the best crop management options that would enable the legume crops to be a financially viable option in the rice dominated lowlands?
3) Where can we grow the legume crops, particularly in relation to soil types and water availability? How much water is required, and where can we secure the quantity of water?
4) Do we have suitable varieties to grow legumes in generally difficult-to-grow lowland rice soils, and is there a scope for improvement?
5) What would be the on-farm cost, including labour cost, of introducing the legumes into otherwise rice monoculture system, and would this justify the inclusion of the legume in the cropping system?

4 Objectives

The Objectives as set out in the project proposal were as follows.

Objectives

The aim of the project is to increase the range of crops grown under rainfed lowland conditions and to develop sufficient information in order to promote non-rice crop technologies that provide efficient water use and high financial return to the growers

There are two objectives

Objective 1 is to develop profitable double cropping options for a rice/ non-rice (mungbean, soybean and peanut) system for the rainfed lowlands in three provinces.

Activity 1. Identify sites with suitable soil types and hydrological conditions for non-rice crops.

Activity 2. Develop crop, nutrient, tillage and water management options for rice/ non-rice cropping system based mainly on rainfall on two (2) farms in each of three (3) provinces.

Activity 3. Incorporate feed-back from farmers and other stake holders to identify best bet cropping options and validate these on additional farms in each province.

Activity 4. Undertake economic analysis of the rice/ non-rice systems.

Activity 5. Identify well-adapted varieties of mungbean and soybean for different locations and water availability conditions

Objective 2 is to define the water requirements for non-rice crops and model and predict the level of risk under mainly rainfed conditions of the diversified cropping systems.

Activity 1. Measure the seasonally available water on a sloping land.

Activity 2. Determine the water use of non-rice crops including the application of small amounts of stored water

Activity 3. Analyse the level of risk for adding non-rice crops using a water based crop model.

5 Methodology

The project duration was extended by 15 months, so that the total duration was 4 years and 9 months. The legume crops were planted after harvesting rice; thus in most cases from December- February. There were 4 crop seasons, 2007-08 (year 1), 2008-09 (year 2), 2009-10 (year 3), 2010-11 (year 4) and 2011-12 (year 5). In the first 2 years, most work was conducted in the three nominated provinces of Takeo (varying water supply), Kampong Thom (intermediate water availability) and Kampong Cham (good water availability), while in year 3 we concentrated in two provinces (Takeo and Kampong Thom). In year 4, we focussed again in Takeo and Kampong Thom, but further extended to Kampot, after we found potentially suitable areas for mungbean in the province. In year 5, in addition to these Provinces, Battambang Province was added.

The Table below shows the summary of all work undertaken during the project period. Groups: AE- Agricultural Engineering; AFS- Agronomy and Farming Systems; Ngoy- Cheth Kimngoy's MPhil project; PB- Plant Breeding; SE-Socio-Economics; SW- Soil and Water. Location: KPC- Kampong Cham; KPT- Kampong Thom. Objective and Activity indicate the primary Objective/Activity of each work. In the text, each work is identified by using Group-year-description combination in italics; for example AE09Mulch for the first work. Unless specified as demonstration or model farm, all work in groups AE, AFS, PB and SW are experimental work.

Group	Year	Description	Locations	Objective	Activity
AE	9	Mulch	KPC, KPT, Takeo, Preah V	1	2
	10	Mulch, planting method	CARDI, KPT, Takeo	1	2
		Machine demonstration	KPT, Takeo		
	11	Mulch, density	CARDI, KPT,	1	2
		Machine demonstration	Kampot, KPC, KPT, Takeo		
AFS	8	Model Farm	Takeo		
	9	Model Farm	Takeo, KPT		
		Bed, fertilizer	KPC,	1	2
		Time of planting, density (for PN)	KPT, Takeo (Takeo mixed up)	1	2
	10	Model Farm	KPT, Takeo		
		Bed, density	KPT, Takeo	1	2
		Demonstration	KPT, Takeo	1	3
	11	Model Farm	KPT, Takeo		
		Demonstration	Kampot, Takeo, KPT	1	3

	12	Demonstration	Kampot, Takeo, KPT, Battambang	1	3
Ngoy	9	Bed, irrigation	CARDI	1	2
	10	Glasshouse	CARDI	1	2
	10	irrigation, cow manure,	CARDI	2	2
PB	8	Screening	CARDI	1	5
	9	Screening	CARDI	1	5
	10	Screening	CARDI	1	5
	11	Screening	CARDI	1	5
		Multilocation trials	CARDI, Kampot, KPT, Takeo	1	5
	12	Multilocation trials	CARDI, Kampot, KPT, Takeo	1	5
PP	9	Pest identification	CARDI		
	10	Pest identification	CARDI		
	11	Pest identification	CARDI, Takeo, KPT		
	12	Chemical control	CARDI, Takeo, KPT		
SE	8	Background	KPT	1	1
	9	Farm Budget	CARDI trial	1	4
		Model farm analysis	Takeo, KPT	1	4
	10	Demonstration analysis	KPT, Takeo	1	3
		Field day analysis	Takeo	1	3
	11	Demonstration analysis	Kampot, Takeo, KPT	1	3
	12	Demonstration analysis	Kaopot, Takeo, KPT, Battambang	1	3
SW	8	Soils	CARDI, KPC, KPT, Takeo	1	1
	9	Irrigation, Planting time, Fertilizer	CARDI, KPC, KPT, Takeo	2	2
	10	Irrigation, bed, Fertilizer	CARDI, KPT, Takeo	2	2
	11	Fertilizer	CARDI	1	2
	12	Fertilizer	CARDI	1	2

Types of activities

There were different types of activities; experiments, demonstration and farmers initiatives, model farms, and survey and economic analysis.

All experiments, other than at CARDI, were conducted on farmers' fields. For each of these experiments, a CARDI scientist was assigned responsibility, and developed an experimental protocol. The protocol was discussed with Provincial and District Agriculture officers for the District selected, for each experiment. A farmer interested in the experiment was selected and the farmer looked after day to day operation of the experiment. PDA officers inspected the experiment frequently, often every week or more frequently, and informed the CARDI scientist if any action needed to be taken. The CARDI scientist commonly visited the experiment before the planting, and then after crop establishment a few times to inspect the experiment. Most measurements were conducted by the PDA under the instruction from the CARDI scientist, and the results were provided to the CARDI scientist within a month of completing the experiment.

Demonstration activities were undertaken with farmers who were interested in participating in our project. The best-bet cropping options were developed for mungbean and peanuts after 2 years of field activities. The best-bet technologies were then discussed with farmers, and the demonstration activity took place on their farm. Some farmers who were not selected as demonstration farmers but were interested in the dry season cropping were given seed, and some planted seed (Farmer initiatives).

Model farms were established in each of three original Provinces, but the one in Kampong Cham did not proceed, as we decided to concentrate on two provinces (Kampong Thom and Takeo) only. These farms were used to demonstrate the usefulness of supplementary irrigation in farms based on rainfed lowland rice. The activity included legume growing after rice among other activities. Detailed descriptions of time spent to grow these crops were monitored as well as any inputs and outputs. They were discussed with PDA officers and CARDI scientists in terms of major issues, such as type of activities, but the actual running of the farm to optimize the farm operation was done by the farmers.

Survey and economic analysis was conducted by CARDI scientists. Various surveys were conducted at farms in relevant areas and then group meetings were held to discuss key issues of agricultural activities. Surveys were also conducted at field days when a number of farmers gathered together. Economic analysis was conducted based on the record of model farm activities, a field experiment (SW 09 Irrigation, fertilizer), and demonstration farms in year 3.

Standard experimental protocol

The methods and measurements were similar in all experiments, except treatments differed. Therefore a standard protocol was used for most experiments. An example of the protocol is shown below using the case of SW 10 Irrigation fertilizer experiment.

Materials and methods

Three pairs of experiments were conducted in 2010 dry season in Cambodia. The three experiments were CARDI furrow, CARDI flat bed and Takeo furrows. In each experiment, there were two trials, one for mungbean and the other for peanuts. CARDI experiments were conducted at Cambodian Agricultural Research and Development Institute, Phnom

Penh while the Takeo experiment was conducted on farm at Yea Thaer village (Angkor Borei District), Takeo Province.

Experimental design and treatments.

Each trial used a split plot design with irrigation method as main treatments, while subplots were high and low fertilizer (High fertilizer 46-120-30 kg/ha; low fertilizer 23-60-30 kg/ha). Half of the fertiliser amount was broadcast prior to planting and incorporated with harrowing to a depth of about 5 cm. The other half was applied at 20 days after sowing (DAS) at the commencement of irrigation treatments.

In furrow (30 cm deep) trials, there were 4 main treatments; irrigation with furrows filled fully with water every 3 days (3d-f), every 6 days (6d-f) and every 9 days (9d-f) and with furrows filled only half full every 3 days (3d-h). In the fully filled furrow (f) treatments, irrigation water was applied to the furrows to about 5 cm below the top of bed level, while in 3d-h, furrows were filled to the level of 15 cm below the top of bed level.

In flat bed trials, there were only three timing of irrigation treatments, every 3 days (d), 6 d and 9 d. Water was applied from hoses with spray roses attached until soil surface in each plot was thoroughly wet and water started to runoff from the surface.

There were 3 replications in all trials.

Cultural details

The lowland sites were selected for each experiment, and after rice was harvested in late 2009, the land was ploughed a few times and levelled. Appropriate furrows/beds were then constructed for the furrow trials. Row spacing was 30 cm for both crops in all trials, and a few seeds were dibbled with spacing of 25 cm for mungbean and 30 cm for peanuts. In furrow trials, 2 rows were planted on a 60 cm wide bed, and each furrow was about 30 cm deep and 30 cm wide at the top. Plot size was 42 m2 and each trial area was 554 m2 for the furrow trial and 778 m2 for the flat bed trial.

In addition to the fertilizer application, gypsum was applied at 1000 kg/ha to peanut trials prior to planting. After planting, rice straw was spread to protect the soil surface. At both locations (CARDI and Takeo) the CMB2 mungbean and Rough peanut varieties were used. Planting dates were 26/02/2010 for mungbean at CARDI, 24 and 25/02/2010 for Peanut at CARDI for Furrow and Flatbed, and 27/01/2010 for both Takeo trials, respectively.

Irrigation was applied manually to saturate the whole experimental field and then drained almost every day during the first 20 days before irrigation treatments commenced. Weeds were removed by hand, while insects were controlled by frequent applications of insecticides and pesticides such as Chlopirifos, BT (BioBit), and Superman depending on types of insect (eg. BT was used to control pod borers).

Measurements

Shoot emergence was determined 21 DAS by counting the number of hills with plants in the whole area of each plot. At 50% flowering (when 50% of plants started flowering) in each treatment, 5 plants were randomly selected from each subplot, and dry weight determined. Mungbean was harvested 3-5 times as pods matured, while peanuts were harvested only once when most nuts showed the sign of maturity. The area harvested in each plot was 5m of centre 6 rows (9 m2). The number of hills that produced grains was counted from the harvest area, and recorded as productive hills (%). Grain yield was determined after hand threshing and reported as dry weight. The number of pods per hill was counted on harvested plants from 3 hills, and then 100 grain weight was determined.

Plant height was also determined from the same plants. After the above ground materials were removed, roots were recovered from 4-8 plants per plot. Soils were carefully dug to determine maximum root depth at flowering time from soil surface, and dry weight recorded.

Amount of water supplied for furrow trials was determined using a flow meter connected to the electrical pump which had an output of 250 litres/min with a 3 cm diameter pipe, and the quantity of water applied to each plot was recorded based on the meter reading. For the flat bed trials, the same tool was used, but with a spray head connected at the end of the pipe, and the meter reading was recorded for each plot. In each case, the time taken to complete application of water for each plot was also recorded for estimation of irrigation amount.

Experimental treatments and other activities

Experimental treatments and key measurements, and methodologies of survey and other activities are described for each Objective/Activity.

The methodology as appears in the project proposal is shown in black. The blue writing is how we actually conducted research.

Objective 1 Activity 1.

Objective 1 is to develop profitable double cropping options for a rice/ non-rice (mungbean, soybean and peanut) system for the rainfed lowlands in three provinces.

Activity 1. Identify sites with suitable soil types and hydrological conditions for non-rice cropping.

Initially, a survey will be conducted of the current practice on any double cropping in the wet season to determine likely crop and yield levels required to make double cropping economically viable.

The non-rice crops (peanut, mungbean and soybean) will be grown on a range of soil types in each province to determine the most suitable soil type for each crop.

This information will be used to select two (2) farms in each province for the main experiments.

Two of the most probable non-rice crops will be selected for further experimentation at each site

Initial survey (SE 08 Background) was conducted in Kampong Thom, where three villages were selected. These villages were thought to have favourable growing environments for legumes after harvesting rice in lowland paddies. The survey was done in two ways; one was interview with individuals (total of 123 farmers) where a relevant questionnaire was used to obtain information. This was accompanied by 4 focus group workshops where several knowledgeable leaders met with the project scientists to provide their views on general information on farming activities as well as more specific information on potential legume cropping after rice in lowland paddies.

Most suitable soil types (SW 08 Soils) and crops were identified by growing 2 varieties of each of mungbean, soybean and peanuts in 11 locations with 4 different major lowland paddy soil types. At maturity, crops were harvested and yield determined for identification of suitable soil types and crops. The soil types were as follow (Table 1).

Table 1. Soil types tested in Activity 1 in the three provinces and at CARDI (Phnom Penh).

Province / Soil	Prateah Lang	Prey Khmer	Bakan	Toul Samroung
Kampong Cham	X		X	X
Kampong Thom	X	X	X	
Takeo	XX	X	X	
CARDI	X			
Total	5	2	3	1

Experimental design was randomized complete block design with 3 species (peanut, mungbean and soybean) x 2 varieties with 3 replications. Plot size was 5m x 5m.

Activity 2.

Activity 2. Develop crop, nutrient, tillage and water management options for rice/ non-rice cropping system based mainly on rainfall on two (2) farms in each of three (3) provinces.

The rice crop management may need to be modified for the addition of non-rice crops. For example the length of the time of the rice crop grown in the wet season may need to be adjusted to increase the growing window for the non-rice crop. This may be achieved by the use of early maturing rice varieties.

The experiments will be conducted to explore:

a) Effect of seedbed manipulation

b) Effect of planting time on yield of non-rice crop following rice harvesting

c) Effect of no tillage on yield of non-rice crops

d) Effect of rice residue on water conservation and growth of non-rice crops

e) Effect of fertilizers, particularly phosphorus on growth of non-rice crops

Supplementary water may need to be added from shallow tanks (used for capturing water for establishing rice seedlings in the main season and or fish tank). The area of these trials will vary – the area for lower value crops may be larger than that for higher value crops in order to compare options with somewhat similar inputs (labour, fertiliser, water etc).

The experiments will be conducted for 2 years.

This activity was carried out mostly in year 2 and 3 in the three project provinces (Kampong Cham in year 2 only).

The effect of bed manipulation was mostly comparison of flat bed planting against raised bed planting. In some cases the bed manipulation was also related to irrigation method (Objective 2 Activity 2), as furrows/ridge bed system used furrow irrigation, while flat planting used flood irrigation. This was the case in the work of AFS 10 Bed Density and also SW 10 Irrigation Bed.

The time of legume planting (AFS 09 Time of planting, Density) was examined by planting at different times in January through to February in Kampong Thom and Takeo. In this experiment, irrigation was supplied throughout crop growth, so that the effect of time of planting examined factors other than water availability. The irrigation work (SW 09 Irrigation, plant density) also included the time of planting (5 or 15 days after rice harvesting). In this experiment, irrigation was not applied at crop establishment, so the effect of time of planting examined mostly the effect of time of planting in relation to soil water availability at the time of crop establishment.

The effect of no tillage was examined as one of treatment factors in AE 09 Mulch planting method at four locations. In the No-till treatment, seed was sown in the soils which were not cultivated after rice harvesting, and this was compared with the tilled treatment.

The effect of use of rice residue was examined by adding rice straw mulch at the rate of 1.5 t/ha in AE 09 Mulch planting method at 4 locations, and also in AE 10 Mulch plant density at 3 locations.

The effect of fertilizer rate was examined by comparing the legume performance at two rates- high N and P rate and low N and P rate in a few experiments AFS 09 Bed, fertilizer and also SW 10 Irrigation experiments at several locations, while the effect of N and P rate was examined in SW 11 Fertilizer and SW 12 Fertilizer.

An additional activity was conducted to determine legume agronomy within a context of farming activities. This was achieved by the establishment of two ‘model farms’ one in Kampong Thom and the other in Takeo (third one was established but abandoned in early stage as was not appropriate for the project objective). Irrigation and drainage systems and fences were established on the model farms. The model farms were developed using best-bet technologies. The model farms were run by the owner farmer with inputs from the project scientists and PDA collaborators. The main attribute considered here was the use of pond water to irrigate legume crops in the lowland paddy after rice was harvested, while other associated agronomic practices such as use of furrows and beds for some soil types for sound crop establishment and irrigation purposes, fertilizer type and amount, and different crop combination were incorporated. The model farms had other on-farm activities such as sale of fish from the pond. All the model farm activities including cropping and other activities were evaluated in relation to inputs, outputs and profitability (economic analysis is for Objective 1 Activity 4).

Activity 3

Activity 3. Incorporate feed back from farmers and other stake holders to identify “best bet” cropping options; provincial officers validate these in additional farms in each province.

The provincial staff will facilitate regular feed back from farmer focal group to collectively decide which components (crops and practice) will provide the best bet options

Open field days will be conducted.

In year 3 best bet options will be tested by additional farmers.

A demonstration activity was undertaken in year 3 (for mungbean and peanuts, and tomato as a comparison) and year 4 and 5 (for mungbean). In year 3, 10 farmers were selected in each of Takeo and Kampong Thom, and they grew the three crops under instruction from PDA officers. In year 4, 18 farmers were selected from 3 Provinces (Takeo, Kampong Thom and Kampot) and again were asked to grow with PDA officers as per the guide. In each Province, a workshop was held and mungbean planting demonstrated by PDA and CARDI officers at the beginning of dry season. Some farmers who were not selected as demonstration farmers but were interested in the dry season cropping were given seed, and some planted seed (Farmer initiatives). In year 5, 29 farmers participated in demonstration trials in Takeo, Kampong Thom, Kampot and Battambang. A field day was conducted at different locations and farmers feedback was recorded. They were used to refine best-bet technologies.

Activity 4

Activity 4. Undertake economic analysis of the rice/ non-rice systems including returns to labour.

The physical inputs (labour, land, nutrients and water) and outputs of yield and income measured for each season .

Farmer family incomes (FFI) determined.

Information from farmer assessment, from FFI and from risk assessment (see below) combined and made available in the appropriate format for policy makers.

Economic analysis of the effect of irrigation frequency on mungbean was conducted using the results of irrigation frequency experiments conducted in year 2 (SW 09 Irrigation, fertilizer). During the experiment, all input costs including labour cost were recorded. As irrigation was applied manually, the time taken to irrigate the field was recorded throughout the experiment. The grain yield recorded at different irrigation frequencies was then converted to the monetary gain using the price of mungbean at the time.

In another analysis, demonstration trials were utilized. All inputs and output were recorded by interviewing all farmers participating in the trials in year 3. Use of pumps for irrigation was timed and the total amount of water used for irrigation as well as the fuel cost was estimated for each farm.

Similar analysis was conducted for model farms. Here also detailed descriptions of time spent to grow these crops were monitored as well as any inputs and outputs. In the model farms, all activities were recorded, including legume cropping, but also other crops, tree crops, fish culture and animal husbandry. Price of each commodity was determined from local markets.

Activity 5.

Activity 5. Identify well adapted varieties of mungbean and soybean for different locations and water availability conditions.

● A number of existing quick maturing varieties and landraces are tested for their suitability

● New materials will be imported from Thailand and tested

● Several promising genotypes are examined at different locations to determine their general adaptation to rainfed lowlands in wet season

All available mungbean, soybean and peanuts varieties were collected after the commencement of the project in year 1. They included 28 varieties/lines for mungbean (5 from Australia and some from AVRDC), 29 Varieties/lines for soybean (6 from Vietnam, 21 from AVRDC and 2 from Cambodia) and 2 varieties for peanuts (Cambodia). They were planted in January 2008 at CARDI for evaluation of their general adaptation.

The screening of mungbean lines (28 lines in year 1 and 27 lines in year 2) was conducted at CARDI for 2 years. Several lines (VC4152, VC3541B, ATF3944, CARDI Chey & farmer's variety) that performed well in year 1 were then tested in on-farm adaptive trials (OFAT) in Kandal Province where 10 farmers participated in the trials.

After year 2, 13 lines were selected for their high grain yield and grain quality, and tested at CARDI in year 3. A total of 10 lines were then selected, and multilocation yield trials conducted at 7 locations (2 each in Kampong Thom, Takeo, and Kampot, as well as CARDI) in year 4, and 6 locations (Kampong Thom was reduced to only 1 location) in year 5.

Soybean screening trial with 26 entries was repeated at CARDI in year 2 as it failed in year 1. Thirteen soybean lines were selected and seed multiplied for future use.

Pure line selection was conducted for peanuts using two local varieties. In year 2, 55 selected lines were grown as hills to rows and 45 peanut lines introduced originally from ICRISAT were also tested at CARDI. In year 3, the best 14 lines were tested at CARDI. Seed was multiplied in year 4, and 12 selected lines were tested at CARDI and Kampong Thom in year 5.

Objective 2 Activity 1

Objective 2 is to define the water requirements for non-rice crops and model and predict the level of risk under mainly rainfed conditions of the diversified cropping systems.

Activity 1. Measure the seasonal available water on a sloping land.

Free water level will be determined using PVC tubes placed in lowland rice areas surrounding non-rice fields and will be used as an indicator of water availability in the non-rice crop field.

Free water level was determined in several experiments (eg Ngoy 10 Bed irrigation) using a 1.4m long PVC tube inserted into the lowland fields. The lower part of the PVC tubes were perforated and the free water level down to 1m depth was determined every week during the legume growing period.

Activity 2.

Activity 2. Determine the water availability and use of non-rice crops.

Soil water content will be determined for the main experiments during the growth of non-rice crops.

The water holding capacity of the soils and effective root depth of different crops will be determined to identify water availability for different crops during late wet season-early dry season

From these measurements, success/failure of non-rice crops will be examined in relation to water availability, and then probability of crop success will be determined in relation to rainfall, soil type and paddy position in a sloping land.

Soil water content was determined for the duration of several experiments (eg SW 09 Irrigation, Ngoy 09 Bed irrigation) at rather shallow depth (mostly 10 and 30 cm as no roots were found below this depth) using ECHO soil probes. In some other experiments (eg AE 10 Mulch, planting method, AFS 10 Bed density) soil samples were taken gravimetrically at particular times during the crop growth where treatments were expected to show differences.

The amount of irrigation water applied and legume response to irrigation was determined in a number of experiments at different locations (eg. Ngoy 09 Bed irrigation, SW 09 Irrigation fertilizer, SW 10 Irrigation fertilizer). In some other experiments (eg AE 10 Mulch density) the amount of irrigation water was determined although irrigation frequency or amount was not a treatment factor. The amount was determined in different manners. In some experiments, the bucket was used to hand water, and the number of buckets used to irrigate each plot was recorded throughout the experimental period (eg SW 09 Irrigation fertilizer). Another method used was to determine flow rate from a pump and the time the pump was run to irrigate the field or plot was recorded each time (eg SW 10 Irrigation fertilizer, AE 10 Mulch density), and then the total amount was recorded. In some others (eg Ngoy 09 Bed irrigation) a large water tank was filled with water, and then the fraction of tank water used for irrigation at a time was determined and then the amount of irrigation water estimated.

These water quantity measurements were used in conjunction with the grain yield achieved, and optimum water requirement estimated. As the stored soil water content was generally small, the irrigation water was almost the same as the total water that the crop utilized. In some rare cases rainfall was significant, and then this information was also used to determine water productivity.

Activity 3

Activity 3. Analyse the level of risk for adding non-rice crops using a lowland water model.

Incorporate measurements of available water into the recently developed UQ lowland water balance model (Tsubo et al. 2006) and use the model to predict water balance at different positions of toposequence in lowlands.

Quantify risk assessment for different cropping options.

All soils information available in Cambodia was assembled, and also a number of weather station data were collected from the Meteorology Department. The model was examined and was considered as suitable for the purpose, but the risk of crop failure is too high without irrigation water. Hence we concentrated on the amount of irrigation water required, rather than to estimate the risk without the irrigation water.

6 Achievements against activities and outputs/milestones

Objective 1: To …

no.	activity	outputs/ milestones	completion date	comments
1.1				
1.2				
1.3				

PC = partner country, A = Australia

Objective 2: To …

no.	activity	outputs/ milestones	completion date	comments
2.1				
2.2				
2.3				

PC = partner country, A = Australia

The following is the original Output table and Schedule table. Outputs are numbered (1-13) for the ease of reference. Achievement is described for each output after the Schedule table under the heading of Achievement against expected outputs.

3.2 Outputs

Objectives & Activities	Outputs	Risks / Assumptions	Applications
6.1.1 Objective 1. To develop profitable double cropping options for a rice/ non rice (mungbean, soybean and peanut) system for the rainfed lowlands in three provinces			
Activity 1 Identify sites with suitable soil types and hydrological conditions for non-rice crop(s)	Suitable soil types identified for growing non rice crops (Output 1)		The suitable soil types and hydrological positions identified will be used as criterion for

	Soil constraints for non rice crops determined (Output 2)		selection of sites for adding non- rice crops.
Activity 2. Develop crop, nutrient, tillage and water management options for rice/ non-rice cropping system based mainly on rainfall on two (2) farms in each of three (3) provinces.	Performance data for the various rice / non-rice cropping systems using different agronomic practices. (Output 3). Medium term information on the nutrient needs of the system determined. (Output 4).	Experiments fail because of water shortage	Suitable crops and appropriate agronomic practices for mung bean, soybean or peanut are available from which to select 'best bet' options by farmers. Crop performance data used to assess economic viability
Activity 3. Incorporate farmers feed back and other stakeholders to identify best bet-cropping options and validate these on additional farms.	Best bet options for growing mungbean, soybean and peanut determined by focal small group farmer meetings facilitated by the provincial staff. (Output 5). Validation of the best bet options by additional farmers (Output 6). Provincial offices gain new knowledge on agronomy of non-rice crops (Output 7)	Sufficient farmer interest in exploring new cropping options.	Best bet options available for further out -scaling to additional farmers in each province. Provisional officers use new knowledge on agronomy of mungbean, soybean and peanut for out scaling. Some innovative farmers use new information to diversify their rice systems.
Activity 4. Undertake economic analysis of the rice/ non-rice systems	Productivity and profitability of the rice / non rice system assessed (Output 8) Labour availability and productivity assessed.(Output 9).		Information on economic viability in combination with information on risk analysis (see objective 2 below) used by policy makers on the potential for diversification of the rainfed lowland rice

			systems
Activity 5. Identify well adapted varieties of mungbean and soybean for different locations and water availability conditions	A number of existing and introduced genotypes are tested for their suitability to lowlands in wet season (Output 10)		A few varieties of soybean and mungbean are identified to be widely adapted to lowland in wet season and are promoted for their inclusion in the cropping system
Objective 2. To define the water requirements for non-rice crops and model and predict the level of risk under mainly rain fed conditions.			
Activity 1. Measure the seasonal available water on a sloping land	Available water measured for different crops under different growing conditions (Output 11)	Sample variability is too large for the water data to be useful	Information used to refine the agronomic practices for the non-rice crops.
Activity 2 Determine the water availability and use for non-rice crops.	Water use of different crops measured including quantities of supplemental irrigation from local storage. (Output 12)	Sample variability is too large for the water data to be useful	Information used to refine agronomic practices for non rice crops and to assess the quantity of local water storage needed for high value crops
Activity 3. Analyse the level of risk for adding non- rice crops using a lowland water model.	Prediction of the probability of success of introduction of non-rice crops, (Output 13)	Useful weather data available at the province and district level	Regional assessment of the risk to diversification for use by policy makers. for use by policy makers.

5.2 Schedule

In the following table year 1=2007, year 2=2008 etc, and month1 (m1)=January, m2=February etc.

Objectives & Activities	Tasks	Time line (Yr and m)	Milestones
6.1.2 Objective 1 To develop profitable cropping options for a rice/ non rice (mungbean, soybean and peanut) system for the rainfed lowlands in three provinces			
Activity 1 Identify sites with suitable soil types and hydrological conditions for non-rice crop(s)	•Fields with different soil types are selected and used to grow different non-rice crops	Yr 1, m6-12	Two sites in each province selected
Activity 2. Develop crop, nutrient, tillage and water management options for rice/ non-rice cropping system based mainly on rainfall on two (2) farms in each of three (3) provinces.	•Several treatments are tested in the main experiment. •Experiments are repeated with some modification.	Yr 2, m6-12 Yr3, m6-12	Data collected from trials at each of two sites in each province Experiments modified and repeated at each site
Activity 3. Incorporate farmers feed back and other stakeholders to identify best bet-cropping options and validate these on additional farms	• Farmer focal groups established; discuss treatments and crop performance with farmers • Provincial staff identify new sites to validate the best bet options and establish observation plots	Yr2, m6-12 Yr3, m6-12	Farmer focal groups at each site Two best bet options identified and validated by additional farmers
Activity 4. Undertake economic analysis of the rice/ non-rice systems including returns to labour	•Collection of initial data •Economic analysis of	Yr1, m4-12 Yr2, m1-3	Current practice of non-rice crops in lowlands in wet season documented. Economic analysis of the current

	the initial data •Economic analysis of the main experiments •Economic analysis of the main experiments and farmers trials	Yr3, m1-6 Yr4, m1-3	practice completed. Preliminary economic analysis of new system available. Economic assessment report available for policy makers
Activity 5. Identify well adapted varieties of mungbean and soybean for different locations and water availability conditions	●Testing existing varieties and landraces ●New materials are introduced from Thailand and tested ●Genotype by environment interaction is identified	Yr1, m6-12 Yr1, m6-12 Yr2, m6-12 Yr2, m6-12 Yr3, m6-12	Several promising genotypes are identified Several promising genotypes are identified A few genotypes are identified to have wide adaptation to lowlands in wet season
Objective 2. To define the water requirements for non-rice crops and model and predict the level of risk under mainly rain fed conditions.			
Activity 1. Measure the seasonal available water on a sloping land.	• PVC tubing placed in the selected sites and monitored	Yr1, m6-12 Yr2, m1-12 Yr3, m1-12 Yr4, m1-3	Soil water data collected and analysed each year for 2 sites in each province
Activity 2 Determine the water use of non-rice crops including the application of small amounts of stored water	•Soil water content determined for field experiments and estimation for farmer trials	Yr1, m6-12 Yr2, m1-12 Yr3, m1-12 Yr4, m1-3	Soil water data collected and analysed each year
Activity 3. Analyse the level of risk for adding non- rice crops.	• Incorporate water balance information into the UQ water balance model * Couple to DSSAT models * Determine level of risks at provincial level	Yr1, m4-12 Yr2, m1-6 Yr3, m1-6 Yr4, m1-3	UQ and DSSAT model adapted for analysis of risk Risk of growing non rice crops available for policy makers

Achievement against expected outputs.

Output 1. Suitable soil types identified for growing no- rice crops.

From year 1 experiments conducted at 11 locations on 4 soil types, Prey Khmer soil was found to be the best for legumes followed by Prateah Lang soil. These are important lowland soils that occupy some 30% of the total lowland rice fields in Cambodia. They are rather coarse soils, and Prey Khmer soils are generally deeper than Prateah Lang. Grain yield of crops grown in Prateah Lang soils differed greatly from location to location, indicating large variation in legume yield due to physical or chemical attributes within the Prateah Lang soil type, and/or other factors, such as management and water availability, were important in determining crop performance. It should be pointed out that soil type is only a factor among many other factors determining legume yield, and there may well be soil type interactions with other factors. Thus, while we identified the two soil types to be most suitable, legumes may perform well in other soil types under different crop management.

Output 2. Soil constraints for non-rice crops determined.

Lowland rice soils are commonly compacted due to cultivation to grow rice under wet conditions. Legume growth was found to be limited in the lowland rice soils, possibly due to the problem of poor root elongation in compacted soils with high soil strength. Earlier work on Prateah Lang and Prey Khmer soils showed that the values of soil strength in the top 0-30 cm depth ranged 3.6-4.4 MPa, well above the critical value for root growth (CARF5-CARDI87 Project, 2008). Root growth has been confined in most cases to within 20 cm of soil surface. Thus, legumes would have limited water and nutrient uptake, and efficiency of irrigation is often reduced.

Another problem associated with compacted soil is poor infiltration of supplied water. Irrigation water often ponds at the soil surface, and slow water movement with limited air space would cause soil saturation, affecting legume plants severely. Legumes are known for their susceptibility to soil saturation. Land preparation to make the planting bed flat and level, or use of furrows with a slight slope is required to minimize the surface ponding problem.

Surface crusting is another common soil problem which can reduce crop establishment. This is particularly a problem with the flat bed and surface irrigation method that is often practised by farmers growing a non-rice crop after rice harvest.

Other soil-related constraints for achieving high yield included low pH and low organic matter in the soil, which are not readily amended in the agricultural system practised in Cambodian lowlands. The lowland rice soils were also low in total N and extractable P and K, and the poor soil chemical fertility is a general constraint. The results of our experiments are supported by an earlier ACIAR funded project (SMCN/2001/051, 2008) in which a detailed assessment of these identified soil constraints were studied.

Output 3. Performance data for the various rice / non-rice cropping systems using different agronomic practices.

A number of agronomic trials have been conducted to produce performance data of various rice/non-rice cropping systems. These trials were related to soil management or crop management. The soils should be managed to ensure good crop establishment and even water availability within the field. Making ridges and water on furrows can minimize the soil surface crusting problem and improve crop establishment. It also allows uniform water supply over the field with an appropriate slope. In some fields making ridges/furrows may not be necessary; in this case the land needs to be well levelled for good crop establishment, reduced water logging, and uniform legume growth.

The following crop management is likely to contribute to better legume performance.

Use of rice straw mulch. This has increased mean mungbean yield by 50% in 4 experiments we conducted in 2008/09DS and the general usefulness of straw mulch has been demonstrated in later work.

Early planting of legume. Legume performance was found to be better when planted soon after rice harvesting. Early planting provides a better growing environment including more soil moisture availability for better establishment. However, it was also noted that land may not be prepared well without spending time after the first ploughing. Often poor crop establishment was noted when legume seed was planted without full land preparation. Similarly short time period after rice harvesting may not be sufficient to kill rice completely and regrowth may cause a weed problem.

Higher planting density. Established hill density of 300,000 hills per ha for mungbean and 200,000 hills per ha for peanuts is likely to produce higher yield than the crop with lower density.

Fertilizer application. Yield levels in the Prey Khmer and Prateah Lang soils are commonly up to 1000 kg/ha for mungbean and 2500 kg/ha for peanuts, and at these levels legume response to fertilizer has been rather limited. Hence the rate of fertiliser application at 23-60-30 N-P2O5-K2O kg/ha would be sufficient for these yield levels. Gypsum may be effective in securing high quality peanut grain.

Output 4. Medium term information on the nutrient needs of the system determined.

As shown above, the fertilizer requirement for legumes appears rather small at the grain yield level commonly achieved in the dry season in Cambodia. While there are some field observations that rice growth is assisted by rotation with the legume, and hence possibly fertilizer requirement of rice following the legume is reduced, no quantitative assessment of this has been made during the project.

Output 5. Best bet options for growing mungbean, soybean and peanut determined by focal small group farmer meetings facilitated by the provincial staff.

Several small group meetings were held early in the project period in areas where the project has worked. This provided useful information but also encouraged networking of farmers and PDA officers with the project staff.

The best-bet options were developed from the experimental work conducted in the first 2 years, and this was written up in Khmer and discussed in the field days and other occasions with farmers and PDA staff members from year 2 onwards. We developed best-bet options for only mungbean and peanuts, as soybean was considered to be least adapted to the lowland growing environments in Cambodia. The best-bet options for mungbean and peanuts were used by 20 farmers (demonstration farms) in Kampong Thom and Takeo in 2009/10 dry season to grow mungbean and peanuts. Grain yield and the amount of irrigation water used were recorded. During the season and subsequently, project staff discussed with farmers crop performance and the various factors determining performance, and the best-bet options were further modified (such as the importance of land levelling before planting).

Output 6. Validation of the best-bet options by additional farmers.

The modified best-bet options for mungbean were validated by 18 farmers in Kampong Thom, Takeo and Kampot provinces in year 4 and 29 farmers in Kampong Thom, Takeo, Kampot and Battambang provinces in year 5. Most farmers were able to harvest their crops with reasonable yield, although some 20% failed mostly at crop establishment phase.

Output 7 Provincial offices gain new knowledge on agronomy of non-rice crops

The offices have been provided with technical notes on growing mungbean and peanuts, and they were fully discussed with CARDI scientists. PDA officers communicated well with participating farmers resulting in successful experiments and demonstration trials.

PDA officers in Takeo, Kampong Thom and Kampong Cham participated well in the conduct of experiments from the first year, and frequent discussions with the CARDI/UQ research team have resulted in them gaining new knowledge on agronomy of legume crops. It should be pointed out that the number of PDA officers that participated and gained knowledge is limited to a few in each Province. In year 4 and 5, Kampot PDA and in year 5 Battambang PDA were also included in our project activities.

Output 8 Productivity and profitability of the rice / non rice system assessed

The productivity and profitability of the rice/ non-rice system has been assessed quite comprehensively using information obtained from two sources.

The first source is the use of results of 20 demonstration farms in year 3. Peanut productivity was higher than mungbean (mean of 1,658 vs. 665 kg/ha) and this resulted in slightly higher gross income in peanuts ($1161 vs. 998 per ha). However cash expenditure was higher in peanuts, mainly because of the higher fuel cost for pumping of irrigation (given it is a longer duration crop) water. Labour cost was higher in mungbean

($380 vs. 361 per ha) because at maturity several harvests were required. When the labour cost is included at full cost (i.e., costed at the prevailing wage rate), with no discount for family labour, both crops produced marginal profit ($54 vs. 102 per ha). Without costing family labour, the profit would be around $400-500/ha in both crops. It should be noted that this was the result of demonstration farms where legumes were grown on a rather small scale (of 5m x 10m), and the production cost per ha may be different on a commercial basis using a larger area. Similarly this legume growing on lowland rice field was the first time for most farmers, and the productivity is likely to improve with experience. Also note the market price of these crops varies within a year, particularly mungbean price rising towards Khmer New Year (in April).

The second source is the model farms where detailed inputs and outputs were recorded and profitability of the rice/ non rice system determined. Compared with traditional mono-cropping of rice, the profit was higher in rice/legume double crop farming. The profit was even higher where triple cropping of rice (early wet season)/rice (wet season)/legume (dry season) was successfully managed. The use of pond water for fish and other non-crop activity further increased profitability.

Output 9. Labour availability and productivity assessed.

The farmer survey conducted at different stages of the project has shown that in some cases labour availability becomes a bottleneck for the double cropping systems that were being considered. The initial survey conducted in year 1 quantified labour availability in the dry season, and also identified some opportunity to work on-farm or off-farm. This suggests that introduction of legumes into farm activity will compete with on-farm and off-farm activities for available labour and, in some cases, the legume cropping will not be successful due to shortage of cheap labour. Thus, legume cropping after rice is unlikely to be successful if growing the legume requires a large labour input. This was well illustrated with the economic analysis for the case of hand watering, which was shown to reduce labour productivity severely. The farmer survey conducted in year 3 also highlighted the concern of farmers on high labour requirements. Labour productivity was shown to increase when furrow and flood irrigation systems were introduced to replace hand watering using watering cans. Similarly, bed making and legume planting by hand are time consuming operations which can be mechanized using a power tiller with appropriate implements attached. The cost of mechanization however still needs to be assessed.

Output 10. Introduced genotypes are tested for their suitability to lowlands in wet season

A number of genotypes, existing and introduced, have been tested in mungbean, soybean and peanuts, and genotypes suitable for post-rice cropping have been selected. However, the first season was found to be too hostile for selection, and hence the first season genotypes were tested again in the second season. In years 2 and 3 screening of mungbean peanuts and soybean lines was successful. Some ICRISAT peanut lines appear promising, while a mungbean variety released recently (CMB3) appears well suited to the cropping system because of its quick maturing nature. From mungbean multi-location trials conducted in year 4 and 5, two more lines were identified to be higher yielding than CMB3. Compared to mungbean and peanuts, soybean was less adapted to Cambodian lowland soils. Soybeans had greater disease and pest problems, and we have reduced work on soybean and increased peanut work. Nevertheless 13 soybean lines were identified as promising, and could be utilized after further testing.

Output 11. Available water measured for different crops under different growing conditions

While the soil water stored at the end of the rice cycle may be available to the non-rice crops, the amount is generally small because of the low water holding capacity of the soils tested and also limited soil depth that the legume crops can explore. Therefore the project spent limited time in exploring stored soil water availability to legumes.

Output 12. Water use of different crops measured including quantities of supplemental irrigation from local storage.

During the course of research, we have realized the importance of water availability for legume growth in lowlands. This is because the amount of soil stored water at the end of the rice cycle is generally small. Thus, it is essential that the farms have access to a supplementary irrigation source. We have found that the use of tube wells and on-farm storage ponds can provide sufficient supplementary irrigation to grow legumes successfully.

Hand watering is too time consuming and hence the amount of water provided is often less than adequate, causing plant water deficit. We have successfully developed furrow and flood irrigation systems using underground or stored pond water, and this has ensured good water supply and crop growth.

The potential problem of poor water supply of supplementary irrigation was largely resolved with the use of pumps and a gravity fed system. These and other improvement made the legume cropping system more economically feasible.

Two major irrigation systems were considered - furrow irrigation and flat land- flood irrigation. The latter can utilize a no-till option, while the former requires a tillage system which can form beds and furrows and hence requires more resources.

The quantity of water required to grow mungbean and peanuts has been obtained in a number of experiments and also in 20 demonstration farms in year 3. Water use efficiency is within the range expected for the legume crops.

Output 13. Prediction of the probability of success of introduction of non-rice crops.

Our estimation indicates that the contribution of soil stored water is small relative to the amount from supplementary irrigation source. Thus, the expected Output 13 has become somewhat irrelevant to the project, as the risk of water running out would be much smaller with the availability of supplementary irrigation. We have conducted economic input and output analyses and the probability of success of legume crops is being estimated.

7 Key results and discussion

Key results are described below for each Objective-Activity.

Objective 1 is to develop profitable double cropping options for a rice/ non-rice (mungbean, soybean and peanut) system for the rainfed lowlands in three provinces.

Objective 1 Activity 1. Identify sites with suitable soil types and hydrological conditions for non-rice cropping.

Initial survey of farms with potential for legume growing after rice.

The farm survey in the Kampong Thom has provided useful information and key points are listed here. A family with five workers and two dependants was the most common case. Some 77% of total family income is earned through agricultural activities. Average paddy size is just over 2 ha; on average 3145 kg of paddy rice is produced (yield of 1.6 t/ha) and 44% of the rice is sold (in addition 13% used as seed and 11 % as feed). Thus almost 40% of farmers considered rice as a main trading commodity, while the rest considered it more for home consumption. There are some work activities other than the main activity of growing rice, the percentage of those engaged in a second job being about 40% for men and 30% for women. The main non-rice crop is cashew, particularly in one village. Most families own cattle (average of 5 cattle) and use them for cultivating land (less than 20% of families own a tractor) and also for some cash income. Family labour for farming is required for almost the whole year round if dry season crops are also cultivated. Around 30% of the farms is accessible to some form of supplementary irrigation, which is mostly used for garden land or vegetable production; water melon is common currently but it can be a risky operation. Most farmers do not have experience of growing legumes in lowlands, but consider legumes not suitable for lowlands because of lack of irrigation water, flood, unsuitable soil type, and lack of labour. Among the three legume crops of the project, peanuts and mungbean are more favoured than soybean.

The focus group workshop suggests the following; it would be useful to grow legumes in paddies adjacent to village or housing areas because they tend to be more accessible for supplementary irrigation and inputs of organic materials and also the crops can be protected from free grazing cattle and perhaps thief. Cultivating method especially land preparation should be selected to maintain soil moisture, and no tillage and mulching technique based on existing rice stubble may be useful. Farm or non-farm job opportunity and hence availability of family labour should be considered for successful adoption of the legume crops in lowlands.

Soil types.

The soil analysis results shows organic carbon, N, P and K to be in the range of low to very low in all 4 soil types tested (Table 1).

The results of 11 experiments in year 1 (1 experiment failed to produce crop yield) shows that Prey Khmer soil was most suitable for legume crops after rice in lowlands (eg, 1075-1244 kg/ha for peanuts). Crop yield varied greatly in Prateah Lang soil (eg, 47-1160 kg/ha for mungbean), which is the most common soil type in lowlands of Cambodia (Table 2). Peanuts is most suitable in terms of crop vigour and yield among the three crops examined followed by mungbean.

Table 1. Main properties of the soils used for the soil type experiment in year 1.

a) Analysis

Soil	Texture class	pH (water)	Org. C (%)	Total N (%)	Avail. P (mg/kg)	K (mg/kg)	K (cM+/kg)
TS	Silty clay	5.88	0.97	0.10	3.18	40.02	0.10
PL	Loamy	5.30	0.28	0.04	1.83	5.96	0.02
PK	Loamy sand	5.66	0.41	0.05	4.88	11.32	0.03
BK	Silt loam	5.35	0.29	0.05	11.30	37.50	0.10
b) Interpretation							
TS		mod. acid	very low	Low	very low		low
PL		strong. acid	very low	very low	very low		very low
PK		mod. acid	very low	very low	very low		very low
BK		strong. acid	very low	very low	Low		low

TS = Toul Samroung, Kompong Cham; PL = Prateah Lang, Kompong Thom; PK = Prey Khmer, Takeo; BK = Bakan, Kompong Cham.

Table 2. Grain yields of mungbean, soybean and peanut (kg/ha) in soil type experiment in year 1.

Environment	Soil type	Date of sowing	Mungbean V1	Mungbean V2	Mungbean Mean	Soybean V1	Soybean V2	Soybean Mean	Peanut V1	Peanut V2	Peanut Mean
CARDI	PL	7-Feb-08	340	538	439	122	102	112	404	258	331
KT1	PL	4-Jan-08	73	47	60	120	67	93	760	773	767
TK2	PL	28-Jan-08	147	153	150	39	25	32	284	205	244
TK3	PL	17-Jan-08	1033	1160	1097	793	150	472	273	152	212
KT3	BK	3-Jan-08	43	73	58	80	60	70	400	400	400
TK1	BK	1-Feb-08	207	288	247	87	88	87	723	408	566
KC1	BK	27-Dec-07	47	81	64	42	18	30	140	207	174
KT2	PK	19-Jan-08	216	279	247	451	403	427	951	850	900
TK4	PK	10-Feb-08	773	1340	1057	140		140	1537	1300	1418
KC2	TS	25-Feb-08	173	173	173	114	111	112	251	249	250
Means	PL (4)		398	475	437	268	86	177	430	347	389
	BK (3)		99	147	123	70	55	62	421	338	380
	PK (2)		495	809	652	295	403	283	1244	1075	1159

	TS (1)	173	173	173	114	111	112	251	249	250
	Overall	305	413	359	199	114		572	480	526
Environment (E)			71**			36**			177**	
Genotype (G)			25**			13**			92*	
G x E			80**			41**			ns	

Soil type: PL = Prateah Lang, BK = Bakan, PK = Prey Khmer, TS = Toul Samroung.

Environment: KT= Kampong Thom, KC= Kampong Cham; TK= Takeo

Variety: Mungbean V1= VC3541B, V2= ATF3946; Soybean V1= DT84, V2= B3039; Peanut V1= Rough, V2=Smooth

Objective 1 Activity 2. Develop crop, nutrient, tillage and water management options for rice/ non-rice cropping system based mainly on rainfall on two (2) farms in each of three (3) provinces.

Agronomy - mulch.

Use of rice straw mulch and various crop establishment methods were examined in two series of mungbean experiments in year 2 and 3 in Kampong Thom, Takeo, Kampong Cham and CARDI where soils were coarse and compacted strongly. In one set of experiments conducted at four locations in year 2 the effect of straw mulch (together with some other treatments) were examined. In order to determine the quantity of mulch required, another set of experiments were conducted in year 3 at three locations with four levels of mulch under two planting densities. On average in year 1, mulching of rice straw at 1.5 t/ha increased mungbean crop establishment from 72 to 83%, reduced weed biomass from 164 to 123 kg/ha and increased yield from 228 to 332 kg/ha (Table 3). Mulch was effective in conserving soil moisture, and even at maturity the mulched area had on average 1 % higher soil moisture content. The amount of mulch between 1 and 2 t/ha did not show consistent effects in year 2, partly because some mulch treatments resulted in excessive soil moisture content and were not effective. Rice straw mulch had significant effect on mungbean yield in 6 out of the 7 experiments conducted in two years, and mean yield increase was 35%. This yield advantage was attributed to better crop establishment, improved growth and reduced weed pressure, but in some cases only one or two of these was effective. In weedy areas, mungbean yield was negatively associated with weed biomass measured during the growth (Figure 1). Maximum root depth varied little by mulch or planting density, and was shallow (< 20 cm) in all three locations where this character was determined.

Thus, it can be concluded that straw mulch had positive effect on mungbean yield through various pathways. In some cases, weeds were not a major problem (eg Kampong Thom in year 1), yet yield was improved with mulch application. In others (eg Kampong Thom in year 2), crop emergence was not improved, yet yield was improved. In some others, there was contribution of all these factors.

While the amount of straw mulch required was not conclusive in these experiments, 1-2 t/ha of straw mulch had rather a large effect. It is expected that the area planted to mungbean after rice is much smaller than the rice area on a farm, and it is likely that the amount of straw would be available for use for the purpose. Reduced use of animal for drought power with increased use of tractors would reduce straw requirement on a farm. If mulch is required after mungbean planting, they could be removed and utilized for other purposes. The work of Rahman et al. (2005) showed that the removal of rice straw after 20 days of planting of wheat had only minor effect on crop yield; this would be so particularly if crop establishment without mulch was so poor and is limiting crop yield.

Peanuts were tested only in year 3 at the 3 locations where mungbean was tested, and the results were similar in the two crops. There was a good response to rice straw mulch at Kampong Thom (1362 kg/ha without mulch and 1857-2035 kg/ha with mulch) and CARDI (1137 kg/ha without mulch and 1359-1428 kg/ha with mulch). At Takeo, 1 t/ha of mulch produced the highest yield (1060 kg/ha) while the other 3 treatments (0, 1.5 and 2 t/ha) mulch produced similar yields (750-780 kg/ha).

Table 3. Effect of mulch on weed biomass and grain yield of mungbean at four locations in dry season 2008-09 in Cambodia.

Locations	Weed biomass (kg/ha)		Grain yield (kg/ha)	
	Mulch	No-mulch	Mulch	No-mulch
Takeo	115.5	232.4	460	421
Kampong Cham	318.7	370.8	302	169
Kampong Thom	21.7	40.7	361	203
Preah Vihea	37.2	11.3	209	118
Mean	123.3	163.8	332	227
Interaction LSD at 5%	27.7(**)		77.6(**)	

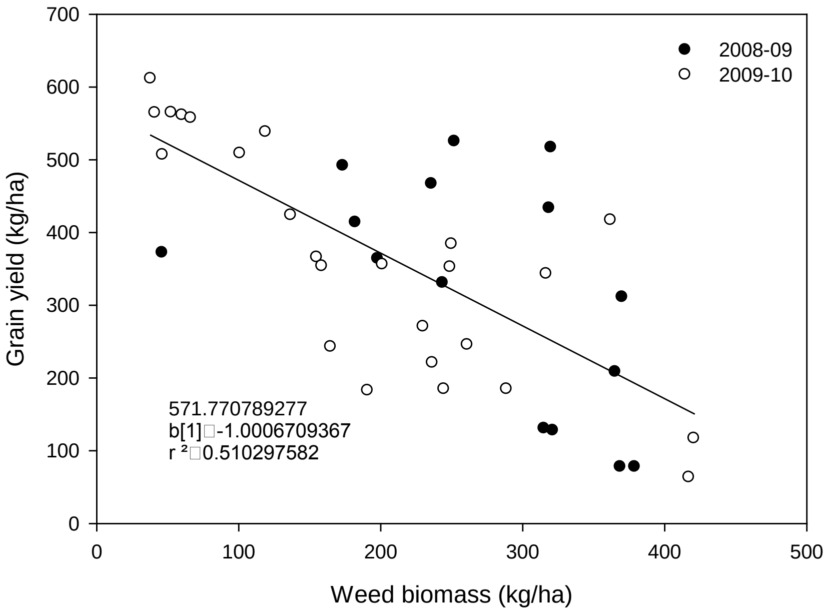
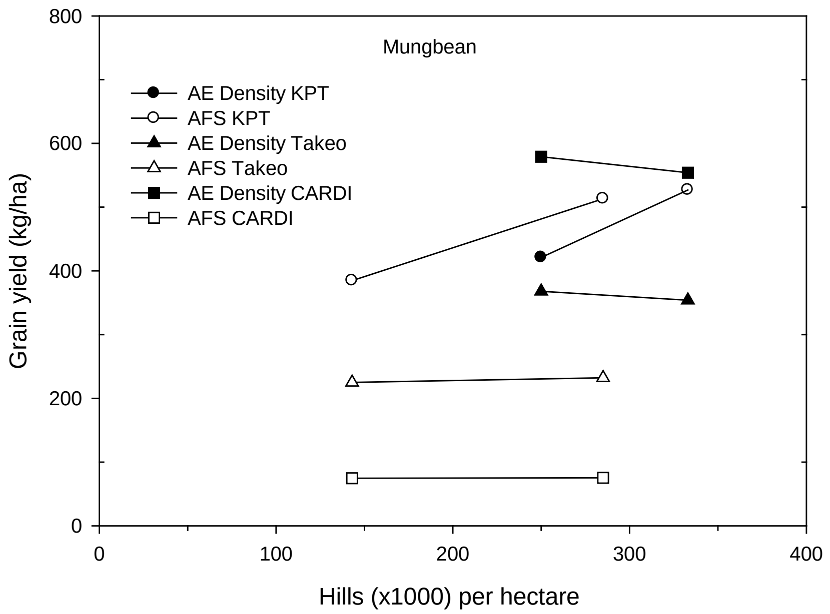


Figure 1. The relationship between grain yield of mungbean and weed biomass when experiment average for weeds biomass was greater than 50 kg/ha (i.e. 2 loc with 24 g and 31 g weed biomass avgerage in 2008-09 removed) dry seasons in Cambodia.

Planting density (hill density)

Two sets of mungbean trials (one led by Agricultural Engineering-AE, and the other by Agronomy and Farming Systems-AFS) at three locations that involved two hill density show that in two cases there were significant yield increases of around 25%. The yield increase occurred only at Kampong Thom (KPT) where yield level was moderate at around 400-500 kg/ha (Figure 2). At the same location, peanuts also responded to planting density in year 2 (2009) when the yield level was high (2500-3500 kg/ha). However the result was not repeated at the same location in the following year. Five out of 7 peanuts experiments responded significantly to increased hill density by mean increase of about 32%. These results suggest the target hill density should be around 300,000 hills/ha (20 cm rows with 15 cm hill spacing) for mungbean and 200,000 hills/ha (25 cm rows with 20 cm hill spacing) for peanut.



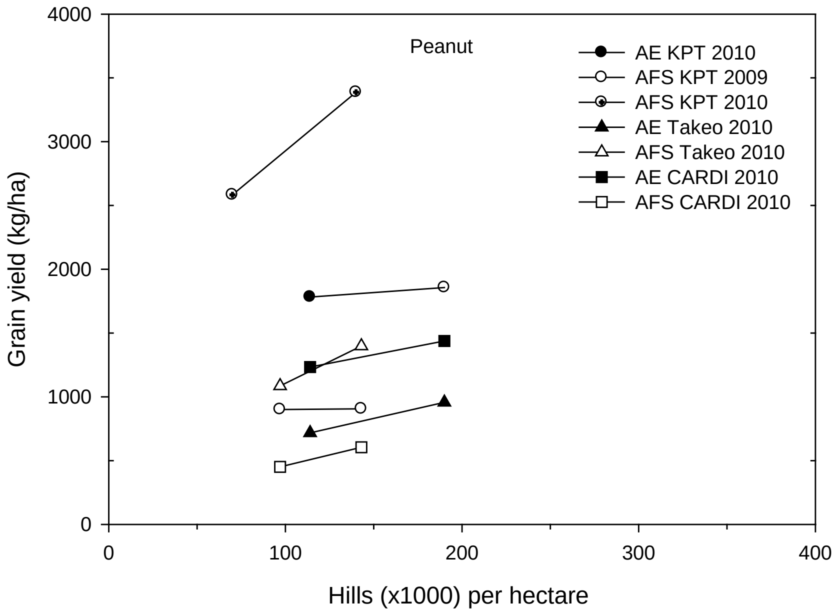


Figure 2. Effect of planting density (hill density) on yield of mungbean and peanuts grown after rice.

Time of planting.

In several experiments in year 2, the effects of time of planting were examined for mungbean and peanuts. The early time of planting generally produced higher yield, and in an experiment in Kampong Thom, mungbean yield decreased from 810 to 291 kg/ha as planting was delayed from immediately after rice harvesting (on 18 December 2008) to 6 weeks after rice harvesting (1 February 2009). This experiment was conducted under irrigated conditions, indicating factor(s) other than water availability becomes more limiting with delay in mungbean planting after rice planting. On the other hand, peanut yield was not significantly affected by the time of planting, yield ranging from 3460 to 4220 kg/ha.

In another set of experiments conducted in year 2, where irrigation was withheld during establishment period, the delay in planting of peanuts from 5 to 15 days after rice harvesting reduced crop establishment, and in Takeo subsequent yield (Table 4). In Takeo, without rainfalls around rice harvesting to legume establishment, delayed peanuts sowing resulted in about 20 % lower establishment, which could not be compensated with some increase in growth of individual plants. This resulted in reduction in the yield by 24 %. The number of pods per plant was also reduced.

Table 4. Effect of time of planting after rice harvesting on growth and yield of peanuts (Takeo).

Sowing time	Establishment (%)	Plant height (cm)	Pod number per hill	Good grain (%)	Pod yield (kg/ha)	Grain yield (kg/ha)	Weight of 100 grains (g)
5DAH	95	27	49	87	5479	3957	34
15DAH	74	25	44	84	4252	3015	30
5% LSD	10.9 *	ns	0.3*	2.0 *	800*	593*	2.6*

DAH; days after rice harvesting

At CARDI where the effect on mungbean crop establishment was small reducing from 90 to 87% (the crop was subsequently destroyed by un-seasonally heavy rainfalls). A larger effect on mungbean establishment was found in Kampong Thom where establishment was reduced from 97 to 59%, but crop failed to produce yield in both cases.

It thus can be concluded that earlier legume planting after rice harvesting is generally advantageous. This is particularly the case where supplementary irrigation may run out later in the dry season. Late planting tends to encounter excessively high temperature. Late planted crops in farmer demonstration trials tended to produce lower yield. On the other hand, too early planting would cause potential problem with rainfalls at the time of legume planting, and also possibly land preparation may not be done properly causing potential problem of reduced establishment.

Fertilizer and soil amendments

In one experiment at Kampong Thom, Takeo, and Kampong Cham in year 2, the effect of doubling fertilizer rate (23-60-30 vs. 46-120-30 N-P2O5-K2O kg/ha) was examined with both mungbean and peanuts, but no significant effects were found in either of the crops.

Another fertilizer rate experiment (18-46-30 vs. 36-92-30 N-P2O5-K2O kg/ha) was conducted with both mungbean and peanuts in year 3 at Takeo and CARDI in relation to irrigation water requirement. In CARDI, the crops were grown in flat bed and raised bed/furrow. A half of the fertilizer amount was broadcast prior to the planting and incorporated with harrowing to a depth of about 5 cm. The other half was applied at 20 days after sowing (DAS) at the commencement of irrigation treatments.

In this series of experiments, the effect of doubling N and P was often seen during the early stage but it was rather small by maturity, although positive effects persisted to maturity in some cases. For example, peanuts in the CARDI furrow experiment (Table 5) showed a large fertilizer rate effect at flowering with 60% increase in plant dry weight. High fertilizer rate produced 22% higher yield than low rate, and this was mostly due to higher pod number per plant. While root length (15.9-16.9 cm) was not affected by fertilizer rate, root weight was increased greatly by higher fertilizer application rate. In the CARDI flatbed experiment with mungbean showed that fertilizer treatment tended to increase plant production at flowering and grain yield, and WUE was promoted by high fertilizer application (p=0.06). Root depth was not affected by fertilizer level (17.4-18.3 cm).

Table 5. Effect of fertilizer rate (kg/ha) on peanut dry weight at flowering (PLDWT, kg/ha), grain yield (GY, kg/ha), water use efficiency (WUE, kg/ha/mm), pod number per plant and 100 grain weight (g), plant height (cm), root length (cm) and weight (g/plant) in the CARDI furrow experiment.

N-P2O5-K2O	PLD WT	GY	WUE	Pod number	100 Grain Weight	Plant height	Root Length	Root weight
36-92-30 (High)	175	824	3.36	31	34.19	33.5	16.9	1.04
18-46-30 (Low)	109	675	2.77	23	33.19	29.8	15.9	0.66
5%LSD	26	80	0.34	5.1	ns	1.5	ns	0.28

The rather small response to increased fertilizer in these experiments where soil fertility was low was probably related to other constraints that limited plant growth. In some cases these constraints were expressed more towards maturity. In other cases where the effect was not seen in early stages, which tended to occur in flatbed planting may be related to poor fertilizer extraction.

Application of cow manure in mungbean in year 2 at CARDI showed more than 30% increase in yield. Gypsum application on peanuts in Kampong Thom had rather small effect on total yield but pod quality was improved (good grains increased from 78 to 92%).

In year 5, the effect of N and P on mungbean yield was examined in an experiment at CARDI and in 4 demonstration trials in Kampot and Takeo. In the demonstration trials responses to 18-46-30, 18-23-30, 46-46-30 N-P2O5-K2O kg/ha were rather small with mean yield 780-890 kg/ha with fertilizer application compared with 707 kg/ha without fertilizer application (Table 6). The CARDI experiment was affected by heavy rains and water logging during growth, resulting in low yield of 200-400 kg/ha, and no consistent effect of fertilizer rate was observed (Data not presented). These results suggest high fertilizer rate, especially N may not be required for mungbean crops grown after rice in lowland paddies.

Table 6. Effect of NPK application on mungbean (cv. CMB03) grown on rainfed rice soil after wet season rice. Means of 4 sites. The growing period was from January to March 2012.

NPK rate (kg/ha)	Duration (days)	Days to 50% flowering (days)	Plant dry weight (g/m2)	Pods (no./hill)	Grains (no./pod)	Weight of 100 grains (g)	Grain yield (kg/ha)
0-0-0	69	38	72.61	8.6	9.5	7.6	707.78
18-46-30			72.96	9.6	10.4	7.7	894.67
18-23-30			68.39	10.0	10.1	7.1	870.33
46-46-30			61.56	11.0	9.8	7.1	784.11
Mean			68.88	9.79	9.94	7.39	814.22
SE (N= 4)			6.304	1.005	0.283	0.297	80.697
LSD (5%)			20.167	3.214	0.906	0.951	258.153
p-Value			0.574	0.463	0.194	0.373	0.393
cv			18.30	20.50	5.70	8.10	19.80

Bed arrangement

The use of beds and furrows appeared to be beneficial for crop establishment and irrigation purposes, particularly for mungbean. However a wide bed exceeding 2 m had problems with uniform water availability and resulted in reduced yield. Grain yield of mungbean was greater in the single row beds in Takeo and CARDI, however flat bed was significantly better in Kampong Thom (Table 7). At all three locations there was a tendency for peanuts to grow better with flatbed configuration.

Table 7. The effect of bed preparation (Flat bed, Single or double row beds) on grain yield (kg/ha) of mungbean and peanut, grown at Takeo, Kampong Thom and CARDI in year 3.

	Takeo		Kampong Thom		CARDI	
Bed preparation	Mungbean	Peanut	Mungbean	Peanut	Mungbean	Peanut
Flat Bed	204	1404	517	1050	600	863
Single row furrow	312	1042	375	944	899	749
Double row bed	138	1271	410	745		
LSD (5%)	135*	ns	80*	ns		

Root depth was slightly deeper in raised bed/furrow than flatbed in mungbean (21.6 vs. 17.9 cm), but this was not observed for peanuts (16.4 vs. 16.6cm).

Use of furrow/bed system is essential particularly for mungbean in areas where ponding of water causes a major adverse effect on crop growth. The bed/furrow system has improved crop establishment and facilitated development of a furrow irrigation system. There are prototypes of a bedmaker available that will produce furrows/beds, and this will greatly improve labour productivity. The use of such implement needs to be tested with farmers for possible further improvement and assessing the likelihood of adoption of the furrow/bedmaker. This system needs to be compared with the no-till flood irrigation systems where operational costs will be small but requires careful management of the land from the rice cropping phase.

No-till.

No-till was examined as one of the treatment factors in a series of experiments described under the effect of mulch. There was no significant effect in 3 locations, but in 1 location (Kampong Cham) No-till produced higher yield. In these experiments, crop establishment was not affected by the No-till treatment. Subsequently we tested No-till option at other locations, but often crop establishment was poor. This appeared to be related to the compacted top soils that are quite common in the lowland soils used to grow rice in the wet season. Aeration appears limited in these cases, particularly when watered to promote germination/emergence process. It is therefore concluded that No-till for legumes in lowland rice soils is not recommended until the establishment difficulty is better understood and method to reduce the problem is developed.

Glasshouse experiment examining the effect of soil amendments and soil structure on minimizing constraints of lowland soils

There are numerous agronomic constraints to the production of dry season legumes after rice. The puddled soil, with associated soil compaction, soil surface crusting, and a hard plough pan, is a major cause of low crop establishment and poor early growth (Seng et al 2008). In addition, the inherent low soil fertility and acidity of most Cambodian lowland rice soils also contributes to the low grain yield of legumes (White et al 2008). High soil strength is closely related to soil compaction and increased soil bulk density, and also to reduction of soil water content and low organic matter within the soil. A glasshouse omission pot experiment was conducted in year 3 at CARDI to investigate the effect of soil structure, soil fertility, soil pH, lime, and straw mulching on growth of mungbean and peanut. Results showed that at flowering time, the omissions of rice straw mulching and chemical fertilizer application had the largest effect followed by omission of cow manure application on growth of mungbean and peanut, while omission of either lime or disturbed soil structure reduced growth, but the effect was small and not significant (Table 8). At final harvest stage, the omission of chemical fertilizer application still had the largest effect on the total dry matter of mungbean and peanut, followed by lime application and straw mulching.

Table 8. Mean total dry matter (g/plant) at flowering and final harvest and root dry weight (g/plant) at final harvest of mungbean and peanut for eight treatments (All+Whole mixing, and All are standards; All-disturbed soil (All-DS); All-organic matter (All-OM); All-rice straw (All-ST); All-lime (All-L) and All-chemical fertiliser (All-CF) in 2010 glasshouse pot omission experiment at CARDI.

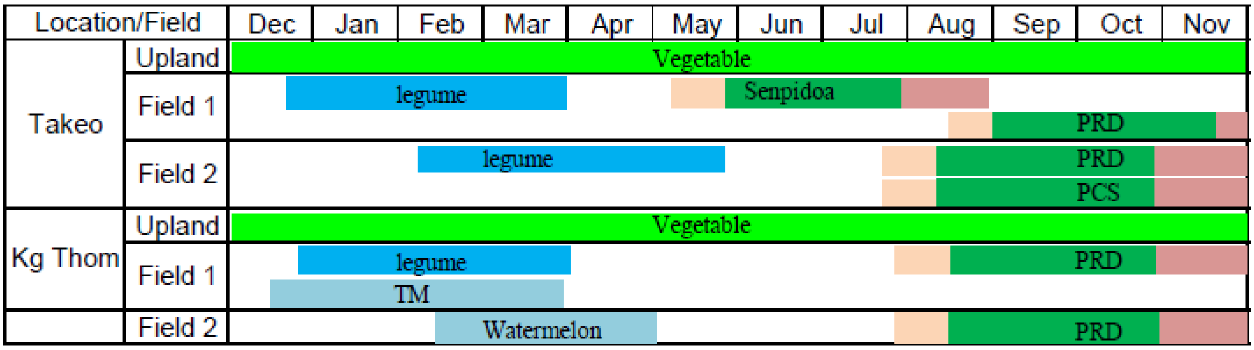
Treatments	Total Dry Matter (g/plant)		Root dry weight
	Flowering	Final harvest	Final harvest
All+Whole mixing	4.02a	10.34a	0.45
All	4.27a	10.39a	0.44
All – DS	3.11b	12.21a	0.55
All – OM	2.65bc	11.37a	0.49
All – ST	2.03c	8.37b	0.35
All – L	3.54ab	7.48bc	0.36
All – CF	1.47cd	5.22cd	0.28
Nil	0.95d	3.78d	0.28
Crop			
Mungbean	2.56	6.05	0.25
Peanut	2.94	11.24	0.55
LSD (5%) Crop	0.41*	1.32**	0.068**
Treat	0.83**	2.65**	0.023**
Crop x Treat	Ns	Ns	Ns

Model farms.

The main attribute considered in the model farming work is the use of pond water to irrigate a second crop in lowland fields after rice harvesting. It is clear from the development and operation of the model farms that a major challenge facing these lowland rice farmers who wish to intensify and diversify their cropping is to secure and apply an adequate quantity of water required for crop production with a minimum cost (including labour cost). Thus these model farms are used to test the on-farm ponding technologies, including legumes after rice, but also other technologies suitable for lowlands such as fish culture, developed by CARDI and others. We have identified the labour cost of watering to be a major factor determining the success or otherwise of legume cropping using supplementary irrigation (with generally low price and returns for legumes, cf. vegetables).

A major achievement is the demonstration of feasibility of double cropping (rice-legume in Kampong Thom) and triple cropping (rice-rice-legume in Takeo) using only supplementary irrigation water as shown in the diagram below (See the next section Economic analysis for input-output analysis).

Activities plan for a model farm (TM=Tomato, PRD=Phka Rumdoul rice, PCS=Phka Chansensar rice):



Identification of biotic constraints

There were a number of in-crop constraints observed over the project period. Insects were a major problem, consistent with previous studies in Cambodia with dry season non-rice crops (Chan et al. 2004), especially pod borers in soybean (Etiella zinckenella, Maruca testualis) and aphids on mungbean. Beanfly was identified as a severe insect pest for mungbean, and in some experiments a high proportion of plants were lost because of this. At one experimental site, greater than 90% pod damage in soybeans was estimated.

Weeds were also a problem, mainly volunteer rice and nutgrass. Straw mulch may reduce the weed problem.

No inoculum was applied to the legume seed in any experiments, and field observations indicated that although peanut produced some effective nodules, the other two legume crops produced very few or no nodules.

A series of experiments were conducted at CARDI to identify insects and diseases that appeared at different growth stages of mungbean at different times of a year. Bean fly caused the most damage during vegetative growth whereas bean pod borer, legume aphids, green stinkbug and soybean pod bug were commonly found to damage crop from flowering to maturity. A few diseases such as sclerotia stem rot, leaf spot, and yellow mosaic occurred commonly from vegetative through to maturity stages. These insects and diseases may occur at any time of the year, but they tended to cause the most damage to crops during when hot and humid conditions prevailed.

In year 5, an experiment was conducted at CARDI where different insecticides were applied and their effectiveness compared with mungbean growth in the control plots where no chemicals were applied. The five treatments were as follows: T1, Control (No pesticide); T2, Cyperan; T3, Seed treatment with Viferan, then apply Superman and BT; T4, Superman and BT; and T5, Botanical pesticide (made of chilli mixed with water)).

The results in the table below (Table 9) show that the botanical pesticide (T5) was generally ineffective and there was no improvement in grain yield. On the other hand, the chemical application of Cyperan and Superman plus BT were similarly effective in reducing the number of different insects. This resulted in yield improvement of 50-80% over the control plots. Insect damage resulted in increased bored pods per ha, and the number of damaged seed per pod.

Table 9: The effectiveness of various treatments (T1, Control (No pesticide); T2, Cyperan; T3, Seed treatment with Viferan, then apply Superman and BT; T4, Superman and BT; and T5, Botanical pesticide (made of chili mixed with water)), on reducing insect numbers and their associated effect on grain yield and yield components of an experiment conducted at CARDI in 2011/12 DS.

Treatment	Leafminor/ha	Beanflies/ha	Armyworm/ha	Leaf beetle/ha	Aphids/ha
T1	592 a	404 a	450 a	396 a	3005 a
T2	377 cd	200 cd	275 c	356 a	1123 bc
T3	339 d	192 d	302 bc	356 a	1192 bc
T4	459 bc	320 d	365 abc	264 c	900 c
T5	530 ab	345 ab	406 a	281 bc	1506 b
LSD(5%)	105	75	90	51	549
C.V	12.2	13.8	13.3	8.2	18.9
P-value	0.003	0.000	0.011	0.001	0.000

Treatment	Flower thrip/ha	Stink bug/ha	Pod sucking bug/ha	Bean pod borer/ha	Number of bored pod/ha
T1	533 a	455 a	391 b	475 a	780 a
T2	393 c	293 d	251 cd	415 b	597 c
T3	334.88 d	335 cd	227 d	272 c	459 de
T4	463 a	369 bc	363 b	187 c	380 e
T5	522 a	405 abc	425 a	415 b	629 bc
LSD(5%)	39	73	32	53	111
C.V	4.6	10.4	17.1	8.1	10.8
P-value	0.000	0.007	0.009	0.000	0.000

Treatment	Plant height(cm)	Number of fruits/hills	Number of seeds/pod	Number of damaged seeds/pod	Grain yield (kg/ha)
T1	21 a	11.66a	11.13 a	5.66 a	833 b
T2	21 a	12.33 a	11.4 a	2.73 c	1280 a
T3	23 a	11a	11.6 a	5.53 a	1300 a
T4	22 a	11a	11.6 a	3.17 c	1450 a
T5	20 a	12.66 a	11.66 a	4.53 b	953 b
LSD(5%)	ns	ns	Ns	0.74	277
C.V	11.1	10	4.3	9.2	12.6
P-value	0.550	0.360	0.670	0.000	0.006

Similarly farmers field work in the demonstration plots showed application of insecticides 3 times during crop growth increased yield from 1062 to 1306 kg/ha in one field and from 600 to 1120 kg/ha in another field in Takeo. While yield advantage was not shown in Kampong Thom, the numbers of bean flies, pod borers and aphids were all decreased with insecticide application in both Provinces.

Objective 1 Activity 3. Incorporate feed back from farmers and other stake holders to identify “best bet” cropping options; provincial officers validate these in additional farms in each province.

After 2 year activities of experiments and economic analysis, the project developed Technical notes for 'Growing peanuts and mungbean in lowland soils'. These notes were used for PDA officers to select appropriate locations and 10 farmers were selected in each of Kampong Thom and Takeo Provinces in year 3 (2009/10DS). Four different locations of Takeo and Kampong Thom provinces were selected for field demonstration of mungbean, peanut and tomato. Five farm demonstrations for each location were identical research designs – land preparation, seed rate and fertilizer types and rates but crop management such as watering and pest control would depend on certain practical situations. The farmers grew mungbean, peanuts as well as tomatoes as per our best bet technologies. Mungbean crops were generally well established. However, some farmers had problems in establishing good stand of peanuts and tomatoes. Irrigation was applied using a water hose once a week. Some farms had insufficient supplementary irrigation in 2009/10DS, which was an unusually hot and dry season. Another problem was insects such as termites and white grubs damaged peanuts and aphids and pod sucking insects damaging mungbean. Some crops appeared excellent and produced yield levels exceeding 1 t/ha.

The average mungbean yield in Takeo was 970 kg/ha but location 1 produced 1,370 kg/ha, the best yield of all locations compared with 560 of location 2. The average yield in Kampong Thom was only 365 kg/ha and contributed to low total average yield 665 kg/ha because both location 1 and location 2 could harvest only 475 and 255 kg/ha respectively and moreover 3 farms harvested no grain (Figure 3). Similarly, the average peanut yield in Takeo was considerably high, 2,910 kg/ha as the two locations produced high yields with average of 2,750 and 3,070 kg/ha. Kampong Thom did not only produce very poor yield of 410 kg/ha but also 50% of demonstration farms produced no yield (Figure 4).

In year 3, we also had a field day at Takeo where our model farm, experiments on irrigation frequency and mulch levels and demonstration of drill planted legumes were inspected by some 100 people (mostly farmers). Some commune chiefs were also invited from other areas and they showed strong interest in participating in the project in the future. Another field day was held in Kampong Thom, and this was followed in second field day at Takeo.

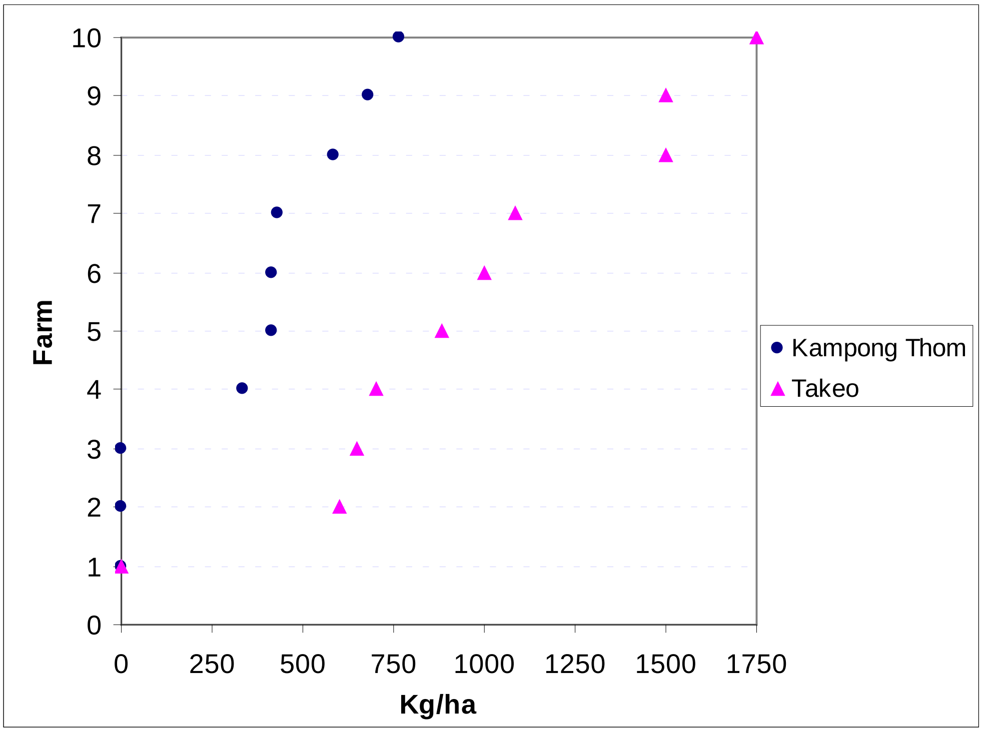


Figure 3. Mungbean yields for irrigated post-rice field crops on 20 farm experiments in four locations 2010.

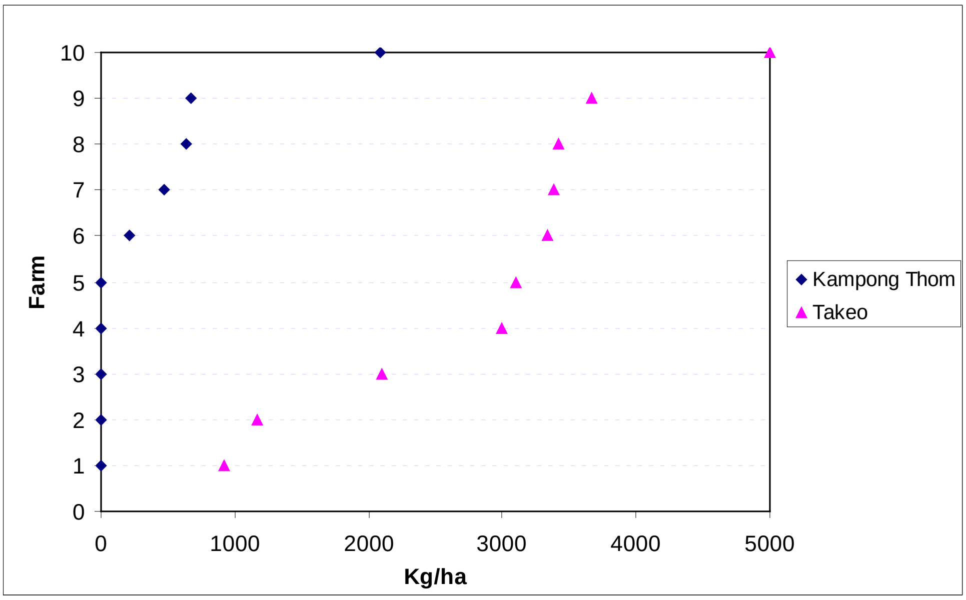


Figure 4. Peanut yields for irrigated post-rice field crops on 20 farm experiments in four locations 2010.

In year 4, we selected 18 demonstration farms (3 in each of 2 villages from each Province of Kampong Thom, Takeo and Kampot). Kampot was added for this purpose as the area has been identified as a potential area for crop intensification through diversification; that is potential to add mungbean in rice based cropping in lowlands. We decided to concentrate on mungbean only because of available technology and market prospect. At the time of planting in each village, an open day was organized for neighbouring farmers to inspect the planting activities, and they were given the opportunity of obtaining mungbean seed. Some farmers took this opportunity, and decided to grow mungbean if they felt their condition was conducive to mungbean growing after rice.

In year 5, there were 29 demonstration farms across Kampong Thom, Takeo, Kampot and Battambang. There was high variation of yield among the 29 plots ranging from 250 to 2,120 kg/ha and the average yield was 507 kg/ha. Nearly 40% of the demonstration plots yielded between 300 and 600 kg/ha and 17% of them had a yield range between 600 to 1,000 kg/ha. Greater than one tonne was also achieved by 14% but considerably large number, 21% of the total plots failed to produce any yield. The mean yield in Districts was highest in Tramkak in Takeo (866 kg/ha), but another district (Prey Kabas) in Takeo produced low yields (mean 256 kg/ha). This may be related to late planting in the District (all planted after 6 February). Chum Kiri District in Kampot also produced a high mean yield of 586 kg/ha. Crop failure and low yield from poor establishment are caused by many factors including poor land preparation with rice stubble, irrigation water not reaching to seed because of furrow irrigation, use of seed soaked in water for too long or not planting immediately after soaking, and excess water due to drainage problem. Good establishment may be obtained in some cases, but the plants were stunted perhaps because of compacted soils with low infiltration. Late planting resulted in the plants encountering high temperature and subsequently low yield. In some plots, farmers had other work to do resulting in weedy mungbean fields.

Farmers feedback

During the field day at Takeo in year 3, farmers attending the field day were interviewed for their views on legume crops grown after rice in lowlands with supplementary irrigation. Their comments were as follows.

- 66% of farmers have well and 22% have pond near the house, while 20% have well and 2% have pond at the paddy field
- Peanut and mungbean are the most interesting and preferred crops
- Narrow bed preparation was the most interest followed by broad bed, flat parcel and direct seeding
- 84% of participants like furrow irrigation more than spraying and manual watering methods
- Water sources availability is an important factor to improve diversification and productivity
- Other key constraints were insect pests and extra labour requirement

Similarly demonstration farmers in Takeo and Kampong Thom were interviewed after their crop was harvested. Their views were:

- Main water source for crop is either pond or well in Takeo while only pond in Kampong Thom
- Problems of water shortage are very important, especially in Kampong Thom province

Farmers observed that mungbean (67-100% in Kampong Thom and 64-100% in Takeo) and also peanut had grown well for all stages (63-88% in Kampong Thom and 83-100% in Takeo).

Mungbean was the most appropriate crop in Kampong Thom (82%) while 62% of farmers in Takeo thought peanut crop as the most appropriate.

More than 50% of farmers reported that insects and water shortage were the most critical constraint

Planting time management is important to avoid water shortage

Among other field days conducted by the project, the one in Kampot in year 5 also provided useful farmers' feedback. This field day was attended by 53 farmers. The paddy land title was mainly distributed in two categories, 0.01-0.5 ha and 0.6-1.0 ha with 26 and 20 households respectively and only 5 farmers owned land greater than 1.0 ha with one having 3.5 ha. This was in an irrigated lowland area, and more than 70% of farmers had a farm pond as a source of water, while canal irrigation was available to less than 20% of farmers. The pond water was harvested during the wet season and it could supply for a small plot of cultivation for a few months after the end of the wet season. The canal irrigation was supplied by a large dam source and could be used to irrigate large fields of dry season rice. Three cropping seasons, wet season, dry season and early wet season were reported. In the wet season, rice was the main crop cultivated by all participants and the secondary crops included leafy vegetables. No rice crop was cultivated in the dry season though surface irrigation was accessible for certain cases. Households cultivating non-rice crops in the dry season were more than double that of the wet season cultivation. Vegetables were cultivated by 64% of the participants and 36% grew mungbean. Other preferred crops included corn, tomato and water melon which were cultivated by between 11 and 23% of the participants. In the early wet season, some 23% of participants cultivated rice and the number of vegetable and corn productions declined to 38% and 8% respectively. The percentage of mungbean and water melon cultivations was comparable between the dry and early wet season. Mungbean cultivation was practised even before the project's mungbean demonstration, but only by a minority of the farmers who could access to canal irrigation planted mungbean on small land plot because they preferred corn to mungbean. The output was just small quantity for home consumption and they did not pay attention to the market price of mungbean. The number of households which cultivated mungbean was likely to increase after the project's mungbean demonstrations. The project assessed participants perception of five selected crops, mungbean, peanut, corn, tomato and grass (for cattle feed) which were common non-rice crops in the area. Mungbean was the best crop for suitability, preference and profitability but it was considered one of the difficult crops to be cultivated because the crop required frequent irrigation and intensive management practices from land preparation to harvesting activities. According to the mungbean demonstrations, two or three land tillages and raised bed are required before planting and weekly irrigation is necessary. These intensive activities could negatively influence farmers' assessment, and farmers may opt for less demanding grasses for feed option. Other crops including peanut, corn and tomato were assessed as medium crops for their preference, but were also more time and resource demanding than growing grasses.

Demonstration of planting drill, bed maker, and irrigation methods

The furrow irrigation method was developed by the project as an alternative to the hand watering which was common in the lowland areas. Farmers who attended field day thought that was useful method (see above). We have demonstrated simple bed makers that can be used with power tillers (2 wheel tractors) to make beds and furrows. In year 4, bed makers were then provided to interested farmers to try by themselves. Seed drill attached to two wheel tractor was also used for successful establishment of mungbean in experiments in year 2. They were then used at several locations in year 3, and several units have been assembled and used for further demonstration.

Objective 1 Activity 4. Undertake economic analysis of the rice/ non-rice systems including returns to labour.

Economic analysis of growing legumes.

For economic analysis of growing legumes, results from a mungbean experiment conducted in year 2 at CARDI were used. In this experiment, frequent irrigation every 3 days produced yield of 672 kg/ha while irrigation every 6 days produced 493 kg/ha. The frequent irrigation resulted in increased income of $US 118/ha. However, as hand watering was used in the experiment, which is the common practice by farmers, the extra watering cost was $US135/ha, and hence net returns were reduced with frequent irrigation. In fact, the estimated labour cost for hand watering was found to be too high for mungbean cropping, and all watering treatments resulted in a negative return, if farm labour is costed at market value. In this case, about a yield of 2 t/ha is required to make any positive return. This is unlikely to be achieved in the near future for most farmers in the region as national yield for upland wet season 2009 was 0.88 t/ha and for upland dry season 2009/2010 was 0.95 t/ha, and hence reducing the cost associated with watering was identified as the number one priority by the project for any viable legume cropping which relies on hired labour. Similarly in the experiment, cow manure application of 10 t/ha produced an extra mungbean yield of 164 kg/ha and increased the income by almost $US100/ha, but the return is reduced if the manure has to be purchased at the commercial rate in the area. Thus, economic analysis indicated the high input costs of labour and materials if they need to be purchased.

Economic analysis of various activities in model farms.

Another major activity in Economic analysis undertaken was input and output analysis of a model farm in Takeo. The model farm was 0.54 ha in total area with 0.30 ha of paddies and 0.07 ha of area occupied by canals and a pond. The establishment cost of the model farm was around $US720. The total income for a year was $1905 which comprised $912 from livestock, $255 from wet season rice, $176 from dry season rice, $462 from fish, $75 from peanuts and mungbean (0.07 ha each). Fruits contributed little as they were only recently planted. This compared favourably with the income from another similar size farm that the farmer also owns where only wet season rice was grown and produced $523 from 0.50 ha land. When the return was estimated, the difference is even greater, with the return from the model farm reaching $1,008 and only $131 from the rice only farm. Economic analysis was also conducted for the Kampong Thom model farm. The results indicated that this farm was not as productive as the Takeo one; for example, while the input costs for growing wet season rice were higher, outputs were lower than the Takeo farm. Similarly, the legume cropping was not successful in the Kampong Thom model farm in year 2, however the farm was in a much better condition in year 3.

Economic analysis of mungbean and peanuts growing in demonstration farms

The production factor costs of three crops can be classified into two categories, cash expenditure and labour costs. The former comprised seeds, fertilizers and fuel or hired pump for irrigation and was a form of cash but the latter could be either cash for hired labour or opportunity cost of family labour. The input costs were varied among the three crops because of different seed price, irrigation duration and fertilizer rate despite the same fertilizer types for all crops. Per hectare production of peanut required the highest outlay cost, USD 746 closely followed by tomato, USD 732 and lesser cost of mungbean, USD 515 (Table 10). The labour costs were paid for 2 times of ploughings, one harrowing, planting, weeding and harvesting. Since the demonstrations of three crops were similarly designed except the harvesting cost, so the total average labour-days were 190 days. Labour distribution indicates that weeding required most worker-days followed by comparable planting, ploughing and harvesting activities (Figure 5). The varied harvesting cost contributed to the total labour cost per hectare of each crop was USD 380, USD 361 and USD 330 for mungbean, peanut and tomato respectively. High or low total production cost was more affected by variable costs of different material inputs.

Average tomato and mungbean yields were only 510 and 665 kg/ha respectively nearly one third of peanut yield’s 1,658 kg/ha. The latter also produced the biggest gross incomes of USD 1,160 compared to mungbean of USD 998 and very low income tomato of USD 357. But mungbean crop could generate the best net return, USD 102 relative to peanut of USD 54 and even great negative return tomato of USD -705 because the mungbean grain was able to be sold at USD 1.50/kg while the market price of the latter two crops was equally USD 0.70/kg (Table 11). Further the smaller total costs as result of low seed and water costs of mungbean also contributed to the better net return.

Table 10. Production cost of irrigated post-rice field crops on farm experiments in four locations 2010

Inputs	Mungbean (USD/ha)	Peanut (USD/ha)	Tomato (USD/ha)
Cash expenditure	515	746	732
Seed	30	190	250
Fertilizers	139	139	156
Irrigation	346	417	326
Labour costs	380	361	330
Ploughing 1	39	39	39
Ploughing 2	39	39	39
Harrowing	14	14	14
Planting	79	79	79
Weeding	114	114	114
Harvesting	95	76	45
Total cost	895	1107	1062

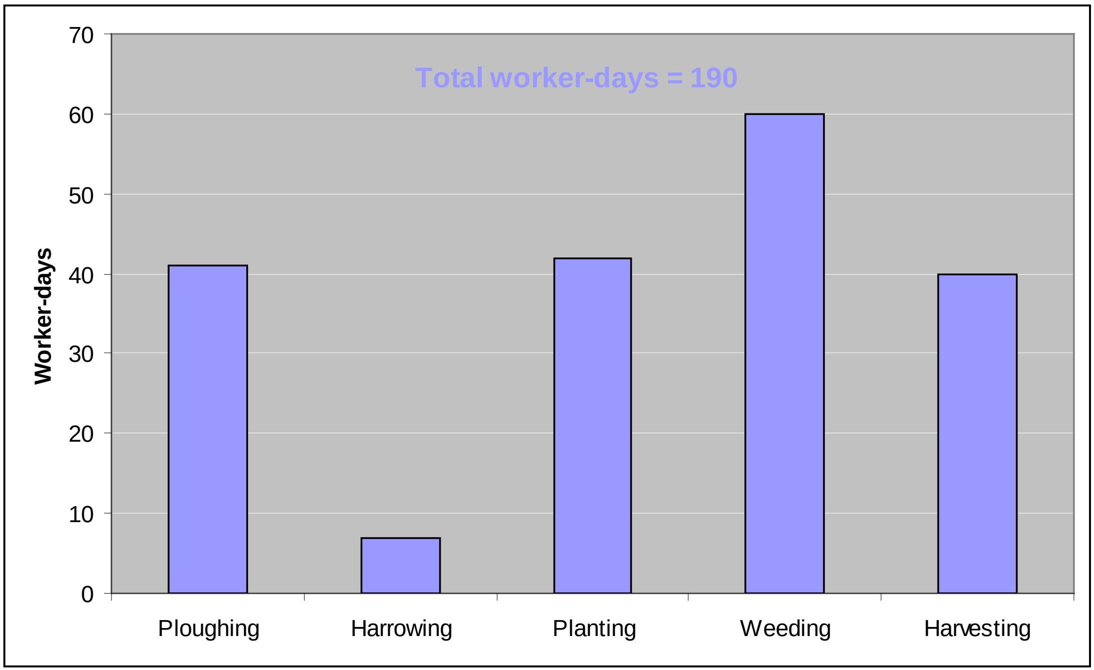


Figure 5. Labour input of irrigated post-rice field crops on farm experiments in four locations 2010

Further economic analysis was conducted using information obtained from year 4 farmer demonstration trials where detailed activities were recorded for 14 farmers. Input costs for mungbean cultivation could be classified into two types of investment, cash expenditure and labour input. The Table below (Table 12) shows overall input patterns for the dry season mungbean production. The cash expenditure was comprised of fixed costs of seed and fertilizers, and variable costs of fuel and pesticides. Seed and fertilizer rates utilized by all farmers were similar. Seed could be a farm resource but this was the first cultivation and an initial outlay was required for purchasing seed. Farmers use of insecticide and irrigation water levels varied considerably by different farmers. Family labour inputs could be a fixed cost for all demonstration plots including ploughing, harrowing, raising narrow beds, carting farm manure and planting, and also variable labour inputs such as weeding, insecticide spraying, manual watering and harvesting which were influenced by weed density, insect occurrence, irrigation levels and yield potential.

The average total labour days/ha required for mungbean production was 134 days/ha but ranged from 100 to 168 days/ha. The average labour days required for weeding and harvesting was 38 and 41 days respectively. The variation of labour days for weeding was from 15 to 75 days and for harvesting between 16 and 64 days. Other activities with large labour requirement such as planting, ploughing, bed raising and hand watering took 12 and 17 days. The tasks with less labour utility were manure carting, ploughing and pesticide spraying which on average ranged from 2 to 5 days.

The average total cost was $298/ha, and average total labour input was 134 labour days/ha. With an average yield of 671 kg/ha and farm gate price of USD 1.75/kg, the average gross income was USD 1175/ha. The net cash returns/ha were USD 877/ha after subtracting the total cash expenses. Dividing the net cash returns/ha with the total labour input, the net cash return per unit of family labour (NCRL) was an average of USD 6.5/day. With such large variation in yield among the 14 demonstrations, the highest yield of 1.5 t/ha could produce USD 2660/ha of gross income and the net cash returns of USD 2332/ha and USD 19/day. The net cash returns of the poorest yield with 278 kg/ha were only USD 188/ha and USD 1.6/day. Around 50% of the demonstration farms provided the net cash returns above USD 1000/ha and between USD 7 and 9/day.

Table 11. Costs and returns of irrigated post-rice field crops on farm experiments

Production factors	Mungbean (USD)	Peanut (USD)	Tomato (USD)
Output (kg)	665	1,658	510
Cash expenditure (C)	515	746	732
Seed	30	190	250
Fertilizers	139	139	156
Water	346	417	326
Labour cost (L)	380	361	330
Ploughing 1	39	39	39
Ploughing 2	39	39	39
Harrowing	14	14	14
Planting	79	79	79
Weedings	114	114	114
Harvesting	95	76	45
Total cost (T)	895	1,107	1,062
Total Incomes (G)	998	1,161	357
Net returns (N)	102	54	-705

T= C+L; G =Output*1.5 (Mungbean); G=Output*0.7 (Peanut and Tomato)

N=G-T

Table 12: Total input patterns for dry season mungbean production (Figures in brackets are averages of 14 farmers. Source: Chea Sareth PhD study.

Item	Unit	Quantity	Unit price (USD)	Total (USD/ha)
Cash expenditure				
Seed	kg/ha	20	1.50	30
Urea	kg/ha	145	0.50	73
DAP	kg/ha	130	0.80	104
KCl	kg/ha	50	0.80	40
Insecticide1	bottle/ha	V1	1.25	V1 x 1.25 (9)
Fuel for pumping1	litre/ha	V2	1.00	V2 x 1.00 (42)
Farm family labour				
Ploughing (2 times)	labour-day/ha	12	2.50	30
Harrowing	labour-day/ha	2	2.50	5
Bed making	labour-day/ha	10	2.50	25
Manuring	labour-day/ha	5	2.50	13
Planting	labour-day/ha	16	2.50	40
Weeding1	labour-day/ha	V3	2.50	V3 x 2.50 (38)
Spraying1	labour-day/ha	V4	4.00	V4 x 4.00 (2)
Hand watering1	labour-day/ha	V5	2.50	V5 x 2.50 (17)
Harvesting1	labour-day/ha	V6	2.50	V6 x 2.50 (41)

1Variable inputs

Objective 1 Activity 5. Identify well adapted varieties of mungbean and soybean for different locations and water availability conditions.

Mungbean

The screening of mungbean lines in year 1 at CARDI were used to select several lines to test in on-farm adaptive trials in Kandal Province. Lines such as VC4152 and VC3541B produced mean yield of 889 and 742 kg/ha in these trials when the mean yield of CARDI Chey was 604 kg/ha and local check 469kg/ha. VC 4152 won the majority of first farmers' preference and VC3541B won the second majority of first farmers' preference. They were subsequently released as cultivars (CMB1, CMB2).

The screening of mungbean lines in year 2 at CARDI indicated that yield of ATF3942, ATF3944, VC4152A VC2768A, KK2, VC6368 (46-32-2) and VC6372 (45-8-1) exceeded 450kg/ha, while the standard variety CARDI Chey produced only 390 kg/ha. A total of 13 lines including these high yielding ones were selected for replicated yield trials in year 3. The result of advanced yield trial in year 3 at CARDI indicated that ATF3942 and VC6368 (46-32-2) produced the highest yield (Table 13). Seed of the released varieties and other promising lines were multiplied for commercial use and for further testing by farmers.

Table 13. Advanced yield trial of mungbean at CARDI in year 3.

No	Genotype	Yield kg/ha	No	Genotype	Yield kg/ha
1	ATF 3942	913	6	VC6220-1	504
2	ATF 3945	537	7	VC6368(..)	865
3	VC 4152A	604	8	VC6381	564
4	VC 2768A	703	9	CARDI Chey	997
5	KK3	630			

As shown in the table below (Table 14), based on the combined results across two years (early dry season 2011 and 2012), there were significant differences among genotypes for grain yield (GY), days to maturity (DTM), plant height (PH), number of nodes per plant (NNP), number of pods per plant (NPP) and final plant stand (FPS). Based on the results, we observed that ATF 3945 with yield of 1100 kg/ha and VC 4152A with yield of 1070 kg/ha performed better than checks (CARDI Chey with 1007 kg/ha and CMB-03 with 989 kg/ha) in terms of yield. Therefore, these genotypes with consistently high yield should be selected as promising lines to move into on-farm adaptive trials for farmer evaluation in the future.

Table 14: Combined result of mungbean multi-location trials in early dry season 2011 and 2012

No	Genotypes	DTF (day)	DTM (day)	PH (cm)	NPP (pod)	NNP (node)	NBP (branch)	FPS (plant)	GY (kg/ha)
1	ATF 3942	35	54	30.93	10	6	2	259	1050.00
2	ATF 3945	35	54	33.07	10	6	2	249	1100.67
3	VC 4152 A	35	54	26.35	10	6	2	259	1070.67
4	VC 2768 A	36	54	29.09	10	6	2	254	988.67
5	KK 3	37	55	27.93	10	6	2	248	1013.00
6	VC 6220-1	37	55	26.13	11	6	2	251	1006.67
7	VC6368 (46-32-2)	35	53	30.77	9	6	2	258	935.33
8	VC 6381	35	53	30.95	10	6	2	247	979.67
9	CMB-03 (Check)	37	55	24.99	10	6	2	246	989.00
10	CARDI Chey (Check)	36	54	30.74	10	6	2	254	1007.67
	Mean	36	54	29.10	10	6	2	253	1014.13
	Min	35	53	24.99	9	6	2	246	935.33
	Max	37	55	33.07	11	6	2	259	1100.67
	Genotype (G)	0.40 **	0.25 **	1.15 **	0.63 **	0.27 **	0.22 ns	5.70 **	10.60 **
	Year (Y)	0.40 **	0.25 **	1.15 *	0.63 **	0.27 **	0.22 **	5.70 **	10.60 **
	Location (E)	0.28 **	0.18 **	0.81 **	0.45 **	0.19 **	0.16 **	4.03 **	7.50 **
	G x Y	0.56 **	0.36 **	1.62 **	0.90 **	0.38 ns	0.32 **	8.06 **	15.00 **
	G x E	0.89 **	0.58 **	2.57 **	1.42 **	0.60 **	0.50 **	12.75 **	23.72 **
	Y x E	0.40 **	0.25 **	1.15 **	0.63 **	0.27 **	0.22 **	5.70 **	10.60 **
	G x E x Y	**	**	**	**	*	ns	**	**

Soybean

Soybean screening trial with 26 entries at CARDI in year 2 showed most of these entries produced higher yield than the check variety DT84 (mean yield of 176 kg/ha), and 15 lines were selected and seed multiplied for future testing. As the experimental results of year 1 showed clearly soybean was less adapted to the growing conditions than mungbean and peanuts, soybean improvement activity was suspended, and instead the project worked on peanuts improvement.

Peanuts

Pure line selection was conducted for peanuts using two available local varieties at CARDI. Based on plant phenotype and seed quality (healthy and high number of pods per plant) 73 lines of Chrounh (smooth pod) and 35 lines of Rolong (rough pod) were selected in Year 1. In Year 2, 55 selected lines were grown as hills to rows. They were combined with 45 peanut lines introduced originally from ICRISAT and tested at CARDI. Out of the 100 lines tested, 33 lines had good establishment with no apparent segregation. A total of 9 ICRISAT lines (all foliar disease resistant lines) and 7 pure lines (5 smooth pod lines and 2 rough pod lines) were selected for their higher yield (kernel yield exceeding 0.5 t/ha). Year 3 results obtained at CARDI shows ICRISAT line FD ICGV 99033 produced the highest yield, but some other lines including Cambodian pure selection lines were promising (Table 16). Seed of all these promising lines were multiplied for testing in multi-location trials in year 4. The results of two location trials in year 5 are shown in the table (Table 15).

Table 15: Result of multi-location trials of peanut in early dry season 2012

No	Genotypes	DTF (day)	DTH (day)	NPH (plant)	NPP (seed)	DB (kg)	PY (kg/ha)	KY (kg/ha)	SP (%)
1	FD ICGV 99029	29	118	62	25	4.22	970.00	245.00	38.48
2	FD ICGV 99030	29	117	73	24	4.14	978.33	285.00	43.09
3	FD ICGV 99032	29	118	49	23	3.74	691.67	256.67	44.31
4	FD ICGV 99036	30	117	33	37	3.00	568.33	248.33	47.90
5	FD ICGV 99053	27	96	166	20	7.78	1936.67	1065.00	56.23
6	FD ICGV 99054	29	117	68	19	3.38	665.00	293.33	49.49
7	FD ICGV 03169	23	95	202	15	9.22	1975.00	933.33	50.30
8	SB 11	27	97	171	21	7.68	2046.67	1035.00	53.56
9	PS 7	24	97	151	21	5.85	1990.00	1035.00	55.36
10	PR 27	27	95	140	18	5.36	1720.00	1026.67	60.13
11	PR 41	27	96	149	19	7.95	1440.00	806.67	56.63
12	PR 12	25	95	166	17	6.67	1711.67	833.33	51.13
	Min	23	95	33	15	3.00	568.33	245.00	38.48
	Max	30	118	202	37	9.22	2046.67	1065.00	60.13
	Mean	27	105	119	22	5.75	1391.11	671.94	50.55
	Genotype (G)	0.39 **	0.97 **	2.49 **	0.99 **	0.28 **	88.39 **	44.19 **	5.12 **
	Location (E)	0.16 **	0.39 **	1.01 **	0.40 **	0.11 **	36.08 **	18.04**	2.09 **
	G x E	**	**	**	**	**	**	**	**

Note: DTF=days to flowering, DTH=days to harvest, NPH= Number of plants at harvest, NPP= Number of pod per plant, DB=Dry biomass, PY=Pod Yield, KY= Kennel Yield SP=shelling percentage. Red color = high yielding ICRISAT line and Blue color = high yielding local lines.

While some ICRISAT lines had smaller number of plants at harvest and this caused low yield, they were also late maturing and are generally not suitable. Two ICRISAT lines matured about the same time as local materials and produced high kernel yield, while all local selected materials produced consistently high yield. Shelling percentage of high yielding lines was 50-60%. Based on the combined result from CARDI and Kampong Thom trials, the best lines are 1 ICRISAT line (FD ICGV 99053, yield 1065 kg/ha), and pure line selection of 3 local materials (SB 11, yield 1035 kg/ha; PS 7, yield 1035 kg/ha and PR 27, yield 1026 kg/ha). Therefore, these high yielding genotypes will be used at a number of farms in the future.

Table 16. Preliminary yield trial of 14 peanuts lines at CARDI in year 3.

No	Genotype	Yield (kg/ha)	No	Genotype	Yield (kg/ha)
1	FD ICGV 99028	1909	9	FD ICGV 99054	1736
2	FD ICGV 99029	1389	10	PS SB 11	1857
3	FD ICGV 99030	1563	11	PS PS 7	1324
4	FD ICGV 99032	1215	12	PS PR 27	1666
5	FD ICGV 99033	2604	13	PS PR 41	1840
6	FD ICGV 99036	851	14	PS PR 12	520
7	FD ICGV 99052	972			
8	FD ICGV 99053	1736			

Objective 2 is to define the water requirements for non-rice crops and model and predict the level of risk under mainly rainfed conditions of the diversified cropping systems.

Objective 2 Activity 1 Measure the seasonal available water on a sloping land.

The maximum root depth was less than 20 cm in most cases when the measurements were made, suggesting the contribution of soil stored water prior to planting to the growing legume plants would be small, probably less than 20 mm considering the nature of sandy top soils in the Prey Khmer and Prateah Lang soils that were commonly used in the project. The depth of underground water level determined in several experiments during the project period indicated that the water table was below 100 cm soil surface (Figure 6). Thus, the contribution of this source to the growing legume plants would also be small. Generally, rainfalls in December-March are small and we cannot rely on the rainfall to provide sufficient water for legumes. These facts indicate that the crops need to be irrigated frequently to produce any commercially acceptable yield.

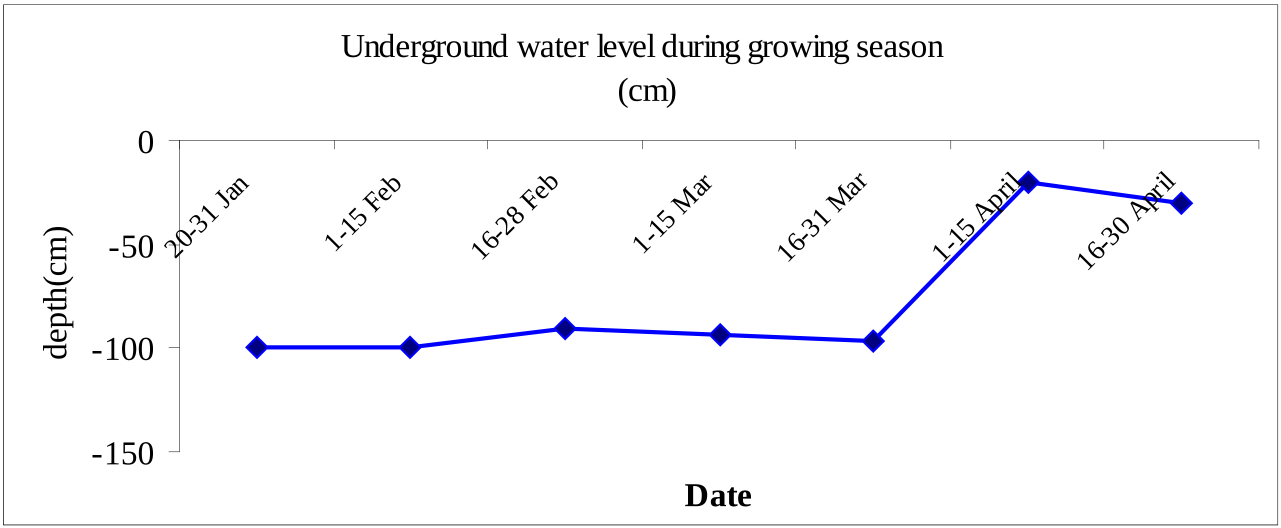


Figure 6.: Fortnightly underground water level during the growing season in 2009 at CARDI

Objective 2 Activity 2 Determine the water availability and use of non-rice crops.

Total water requirements were estimated by determining irrigation water required to grow legumes successfully.

Irrigation frequency and methods

A series of 4-6 experiments were conducted to test irrigation water requirement of mungbean and peanuts in year 2 and year 3, where water was applied at different frequencies. The mungbean results from CARDI in year 2 indicated that irrigation was required every 3 days or so when watering can was used. In one of the experiments (Table 17), water use efficiency of mungbean was found to be around 1.9-2.4 kg/ha/mm which is at the lower end of WUE commonly found in Australia.

Table 17. The effect of irrigation frequency on grain yield and water use efficiency (WUE) of mungbean in 2008-09 CARDI experiment with hand watering.

Irrigation frequency	Water use (mm)	Grain Yield (kg/ha)	WUE (kg/ha/mm)
Every 3 days	285	672	2.36
Every 6 days	262	493	1.88
EM50	281	623	2.21
9am	253	552	2.19
Mean	270	585	2.16
lsd (5%)		93.2	0.33 (p=0.05)

Table 18. The effect of furrow irrigation frequency on grain yield and water use efficiency (WUE) of a) mungbean; and b) peanut, in 2009-10 (year 3) CARDI experiment.

a) Mungbean	Water use (mm)	Grain yield (kg/ha)	WUE (kg/ha/mm)
Every 3 days	250	770	3.08
Every 6 days	216	711	3.29
Every 9 days	177	511	2.89
Mean		664	3.09
lsd (5%)		97.4	0.44 (p=0.06)
b) Peanut			
Every 3 days	285	315	1.11
Every 6 days	244	290	1.19
Every 9 days	211	307	1.46
Mean		304	1.25
lsd (5%)		ns	0.32

Hand watering was found to be labour intensive, often resulting in under-watering for mungbean and peanuts (see below), and we have successfully developed furrow and flood irrigation methods in year 3. In year 3 using furrow irrigation at CARDI, grain yield was greatest for both mungbean and peanut when irrigation was supplied every 3 days, although not significantly different from every 6 days (Table 18). At CARDI the highest WUE was achieved by irrigation every 6 days for mungbean and every 9 days for peanut. In Takeo year 3 furrow irrigation, highest grain yield was also achieved with irrigation every 3 days (Table 19). One of the key findings was that legume roots were shallow in lowlands, and water extraction was limited to the top 20 cm or so depending on the depth of the hard pan. With the rather coarse textured nature of the lowland soil used in growing legumes, accessible stored water is limited, and thus the legume crops need to be irrigated frequently.

In two of the three experiments where the irrigation interval extended to every 14 days the grain yield was reduced by 54% (mungbean) and 64% (peanut) compared to furrow irrigation once every week (Table 20). This is in part due to the fact that 14 day interval treatment received between 75-140 mm less water than furrow irrigation every week because in both instances irrigation was applied until the furrows were filled with water, and due to the poor infiltration capacity of the soil it is not possible to supply additional water in one application. The plants exposed to the 14 day interval between irrigation applications suffered from cyclical water stress. Thus, it was concluded that a 14 day interval between irrigation applications was too long to optimize grain yield.

Table 19. The effect of furrow irrigation frequency on grain yield and water use efficiency (WUE) of a) mungbean; and b) peanut, in 2009-10 (year 3) Takeo experiment. Water use data excludes rainfall.

a) Mungbean	Water use (mm)	Grain yield (kg/ha)	WUE (kg/ha/mm)
Every 3 days	232	614	2.64
Every 6 days	153	417	2.73
Every 9 days	113	385	3.41
Mean		448	2.93
lsd (5%)		169	
b) Peanut			
Every 3 days	382	673	1.76
Every 6 days	291	501	1.72
Every 9 days	182	457	2.51
Mean		498	2.00
lsd (5%)		232	

Table 20. Comparison of furrow irrigation application once every week or every 14 days in terms of total water applied (WU; mm), grain yield (GY; kg/ha) and water use efficiency (WUE; kg/ha/mm) of mungbean (two sowing times) and peanut at CARDI in 2009-10 experiments.

a) Mungbean	Sowing date	WU (mm)	GY (kg/ha)	WUE (kg/ha/mm)
Furrow once/week	18/12/2009	333	449	1.35
Furrow once/14 days	18/12/2009	193	453	2.35
Furrow once/week	17/02/2010	281	687	2.45
Furrow once/14 days	17/02/2010	206	370	1.80
b) Peanut				
Furrow once/week	18/12/2009	439	444	1.01
Furrow once/14 days	18/12/2009	299	284	0.95

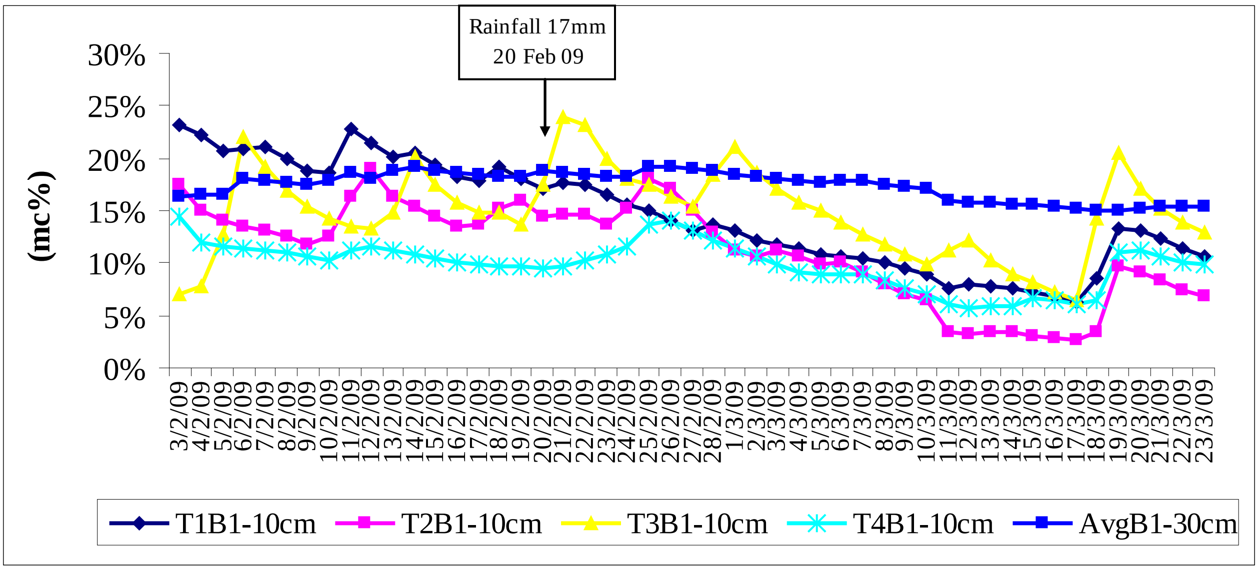


Figure 7. Soil water content at 10 cm depth in response to furrow irrigation at intervals of 4 days (T1), 8 days (T2), 12 days (T3) and 16 days (T4) and average moisture content at 30 cm depth, in the single row (B1) of mungbean and peanut sown in January 2009 at CARDI.

The water applied in furrow irrigation did not infiltrate the soil particularly well. Figure 7 indicates the soil moisture content at 10cm for each of 4 irrigation intervals and the average at the 30cm depth in single row beds. Despite treatments receiving between 14 (every 4 days) and 4 (every 16 days) irrigation applications the soil moisture content did not respond concurrently. In particular the soil water content at 30cm depth was relatively stable at 17.4 %, and did not respond to irrigation inputs at all, nor was there any evidence of extraction of water from 30 cm depth. While there was some response to irrigation at 10cm depth this was not consistent, and there was an overall decline in soil moisture as the season progressed. This is likely to be associated with poor soil conditions, with surface crusting and the walls of the furrow becoming hard with time particularly with infrequent irrigations, consequently the ability of water to infiltrate the soil appears to decline as the season progresses and irrigation intervals increase.

Irrigation methods

Comparison of furrow irrigation and flood irrigation on flatbed is shown in the section of bed arrangement.

Hand watering using can is found to be labour intensive, but also it tends to provide smaller amount of water compared with furrow irrigation or flood irrigation. Thus one experiment in year 3 at Kampong Thom shows much reduced yield with peanut compared with flood irrigation on flat bed (1800 vs 1350 kg/ha). In another experiment at CARDI with mungbean showed soil water content to 70 cm depth to be consistently lower in the watering can method compared with flood irrigation (Figure 8).

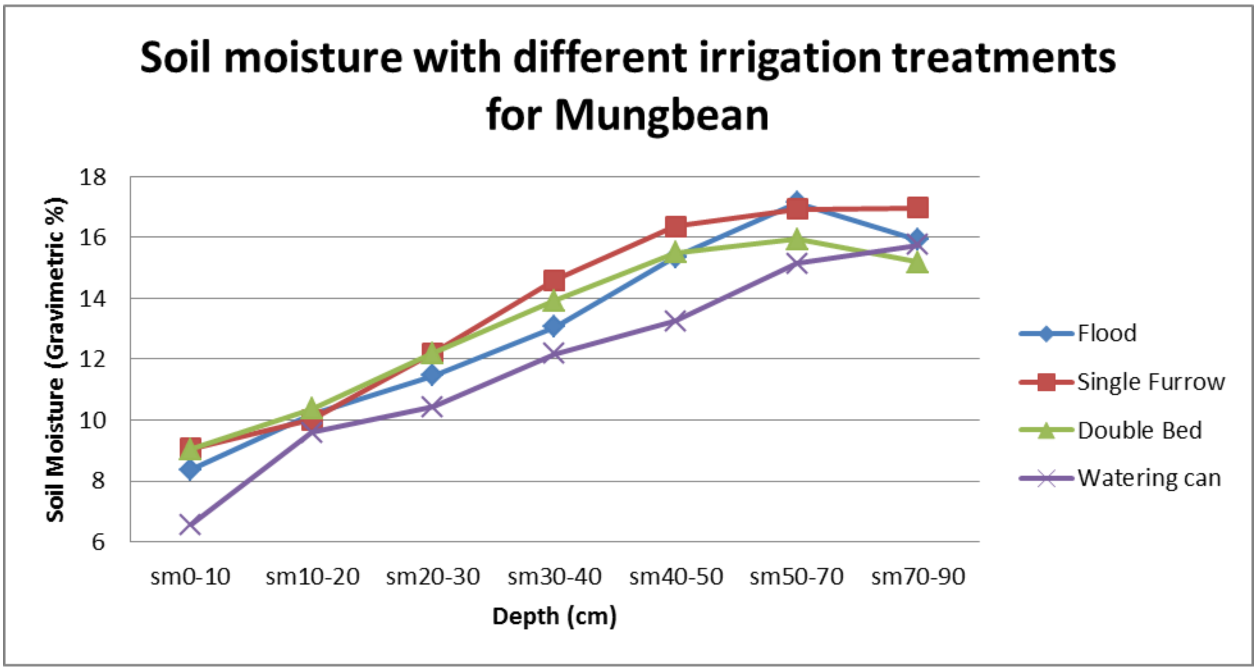


Figure 8. Soil water content under different bed arrangement and watering methods.

Another method of irrigation that was tested at CARDI was drip irrigation and this was compared to hand watering with the same water applied. Drip irrigation only yielded 37 and 60% of the grain yield of hand watering method (Table 21). This is likely due to the surface crusting nature of the Prateah Lang soil with the water unable to infiltrate and lost as either surface runoff or evaporation.

Irrigation water requirement of demonstration farms.

Irrigation duration was considerably different among the three crops in all locations in demonstration trials in year 3. Peanut was irrigated with the largest water quantity, over 1.4 million litres per ha followed by tomato crop more than 1.3 million litres and mungbean with 1.2 million litres. The variation of irrigation for peanut was between 1.2 and 1.9 million litres and 60% of the farms was closed to the average (Figure 9). Though average irrigation was smaller for mungbean, there was larger variation ranging from over 900 thousand to close to 1.9 million litres. The water quantity variation was even greater for tomato from less than 800 thousands to 2 million litres. Even though the irrigation input incurred a cash cost according to duration as per hour irrigation was almost USD 2, water amount was significantly related to pumping hour. One hour could produce over 5,000 litres for 5 cm diameter hose and slightly more than double for 10 cam diameter hose but hourly cost for the pump was not distinguished between the two diameter measurements.

Table 21. The effect of irrigation methods on water use (WU), grain yield (GY) and water use efficiency (WUE) at CARDI in 2010 (year 3).

a) Mungbean	WU	GY	WUE
drip 3 times/week	393	212	0.54
hand 3 times/week	393	575	1.46
b) Peanut			
drip 3 times/week	558.5	380.5	0.68
hand 3 times/week	558.5	626.5	1.13

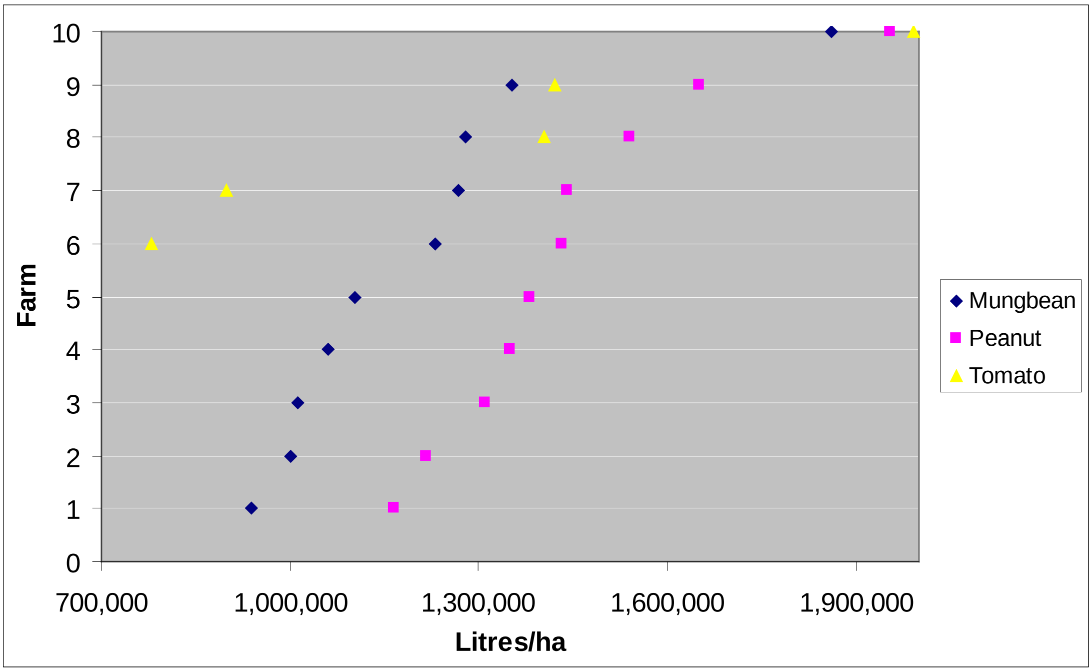


Figure 9. Irrigation water requirement for irrigated post-rice field crops on farm experiments in four locations 2010 (year 3). Note 1,000,000 Litres/ha= 100 mm of water.

Objective 2 Activity 3. Analyse the level of risk for adding non-rice crops using a lowland water model.

As the project has shown little chance of growing legumes successfully without supplementary irrigation water, the risk associated with growing legumes after rice without irrigation was not determined in the project. Instead the project determined the water requirement to grow legumes (see above sections on Activity 1 and 2).

However, necessary information to run the lowland water balance model (Inthavong et al 2011) has been assembled. Soil data that had been collected at CARDI (and CIAP) have been compiled and all available soil information in Cambodia has been collated. Collection of weather data has been made and currently we have rainfall data for 3 years (2000-2002) from 29 stations across 5 provinces (Phnom Penh, Kampong Thom, Kampong Cham, Battambang and Pailin). This will enable preliminary simulations to be conducted using the lowland water balance model to estimate length of growing period of rice and consequently the suitability for non-rice crops in the regions.

8 Impacts

8.1 Scientific impacts – now and in 5 years

The project has promoted the scientific practices of determining both water used to grow a crop and soil water content changes during the whole growing cycle. While these are not new and are routinely used in field experiments in Australia, they do not appear to be commonly practised in Cambodia. These methods are vital in estimating water productivity (water use efficiency) of the crop and how the water is used throughout crop growth. Based on water use data, the project has identified that a rather large quantity of water is required to grow mungbean and peanuts in lowland rice soils for the level of yield that is achieved (ie legumes in lowland rice soils is at the lower end of the commonly expected water productivity range). The monitoring of soil water content over the cropping season has demonstrated the difficulty of supplying water to the lowland rice soils, in which infiltration is very poor and the soil water even at 30cm depth was not utilized by the crop (also supported by the root depth measurement).

It is likely that these scientific practices will be commonly used to identify water productivity and water balance components in the future as the importance of available water in agriculture is recognized in the country (21st century is the Century of water, according to some). The water productivity values obtained for the legumes in the present project would provide a benchmark for evaluating efficiency of water use, and help improve water productivity of the crop industry in general. The improvement in water productivity and water extraction will occur largely through improved land and crop management and also through the use of improved legume varieties.

Similarly the analysis of labour productivity is successfully utilized as a tool to evaluate the agricultural practices in the project. The analysis method can have a large impact in the conduct of future research in the country (see the next section.)

8.2 Capacity impacts – now and in 5 years

Many new skills have been acquired by CARDI scientists who participated in the project. The key scientific impacts mentioned above are the results of the scientists utilizing the scientific practices during the project. Several scientists are now capable of crop-water research in the field, combined with water physiological techniques they acquired through the previous UQ-ACIAR project in Cambodia. Thus, CARDI has now excellent capacity to conduct research in the area of water productivity. It is likely that the capacity developed by the project will be used in other projects that CARDI can attract.

Another area of capacity that has been developed through the project is the way to analyse labour productivity. This was used to evaluate legume productivity based on the labour consumed in legume production. While this is also not new in some countries, the importance of the concept has now been embedded in CARDI, and the scientists will be able to utilise these methods to demonstrate the importance of labour component in determining the fate of agricultural activities. The importance of the labour productivity concept is likely to increase in the near future as Cambodia experiences labour shortage in the agriculture sector.

An agronomist employed or contracted by the University of Queensland was stationed in Cambodia for almost 3 years, and assisted with the development of research capacity of Cambodian scientists. Research and development activities were conducted jointly.

CARDI scientists have been well trained for their planning, execution and writing up of research. Scientists have learned experimental designs and statistical analysis of experimental results. In addition to the UQ scientist stationed at CARDI, UQ scientists visited CARDI regularly and meetings were held 3-5 times each year at CARDI. In these meetings, each scientist presented their plan or results of the research, followed by comments and discussion by all members. These processes have assisted scientist developing their capacity in their discipline area.

Capacity building may be also seen in the ways research activities are executed at CARDI and a gradual shift in attitude of scientists involved towards more integrated approach has been emerged. Scientists in CARDI, like those in many other institutions outside Cambodia, tended to work in isolation to focus on their own task. The project has made conscientious efforts to develop a culture of working together for the project (or any other project). We have had many meetings and joint field trips to promote communication among project members. The project, because of the nature of the topic, has involved all six scientific groups within CARDI, and this integrative approach has appeared to contribute to the concept of this project being CARDI project rather than the project belonging to the individual group as such. It is likely that this change of attitude would help individuals understanding their role and contribution within a large project, and also strengthen the capacity of CARDI in executing large projects they may attract in the future.

PDA agronomists have improved their knowledge on water requirement and crop management of various non-rice crops, particularly mungbean and peanuts in lowlands through frequent contact with the project scientists. At the beginning of the project, they had rather limited knowledge in conducting proper field experiments, but they have gained valuable experience during the project period.

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

The current project has made a number of achievements, in particular the core business of the project, which was the legume technology development. The project developed two Technical notes, one 'Growing peanuts in lowland soils' and the other 'Growing mungbean in lowland soils'. Both notes cover topics of Site selection, Time of sowing, Land preparation, Seed selection, Fertiliser and soil conditions, Spacing and sowing, Water management, Insect, weed and disease control, and Harvest. These notes were used by PDA officers to select experimental sites and farmers, and for the selected farmers to grow peanuts and mungbean in Kampong Thom, Takeo and Kampot. These together with a number of field demonstration and discussion through farmers associations, would accelerate the adoption of the technology. Farmers responses quantified in the field days and other occasions to legume cropping in lowlands are quite positive, further suggesting the likelihood of expansion of the legume growing in the target environment.

The case of economic success is demonstrated in Section 7. Year 2 Model farm economic analysis and year 3 demonstration farms analysis show the positive return to the grower who adopt the legume technology. This legume technology can provide a sufficient profit that would allow those farmers to move out of subsistence farming to some level of commercial activity. It may be that the area of legume growth may increase further when the legume technology developed can be used equally well in fully irrigated area.

The original project document estimates the future economic impacts of the project as follows “The economic impacts of this project are through the addition of non-rice crops to the rice based system and on the replacement of some rice land with a high value crop in the main wet season. The initial targets are the three provinces - Takeo, Kampong Thom and Kampong Cham- which occupy around 20% of the 2.0 million ha of rainfed lowland rice in Cambodia. Of these 400, 000 ha it is estimated that about 20% is suitable for double cropping with a non- rice crop. It is estimated that after 10 years from the end of the project, 50 % of the farmers would be growing rice / non-rice on 20 % of their land area. Thus the project impact target for adding a non- rice crop after rice is 40,000 ha after

10 years. Taking a general value for the return over paid-out costs for non-rice grain crops of US$190 per ha, and an opportunity cost of family labour of $US1 per day, the gain to farmers from the additional crop are estimated to be US$190 per ha less $US65 per ha for additional family labour, giving a net gain of US$125 per ha. This amounts to US$ 5.0 million per year after 10 years when 50 % of the farmers are using the new technology." While the project demonstrated the requirement of supplementary irrigation for the success of the legume technology, irrigated rice area (including supplementary irrigation) increased to 33.5% of the total rice lands in Cambodia recently, and in 2010, 0.911 million ha was irrigated, and this was expected to increase to 1.195 million ha in 2011. Therefore the rice area that can add legumes may not be much different from the original estimation made some 5 years ago, particularly in the three project Provinces where the water availability is good.

Another project achievement is the demonstration of potential uses of supplementary irrigation water to grow legumes and to also use water for other purposes (such as fish culture). Some ponds are currently not utilized or used just to raise fish, but the water can be used more widely. A farmer's note on model farming focusing on economic results in Khmer has been published and distributed to all participants during the field days at Takeo, Kampong Thom and Kampot. The use of ponds for cropping and other agriculture activities purpose needs to be investigated further. The potential for economic impact would be also high for these non-legume activities, but further research is required for estimation of economic benefit.

8.3.2 Social impacts

One issue associated with growing legumes as an additional activity to otherwise rice mono-cropping is the increased labour (and other resource) requirement. While a measure to improve labour productivity will reduce the labour requirement to grow legumes in the dry season after rice in lowland fields, increased labour resources are required to have additional crops after the rice harvest. Labour requirement is intensified particularly between the rice harvest and legume planting. The project has shown the benefit of early planting of legume after the rice harvest. However, this means that there will be a peak demand for labour in the months of December-January when rice needs to be processed after harvesting and at the same time land preparation and sowing of legumes is required. Mechanization would help reduce the intensity of the labour requirement, and this new cropping system would promote mechanization and would have social impact through mechanization.

We have already identified the intensive nature of dry season cropping, particularly if manual watering is continuously practised. A technical intervention to save labour in watering is likely to be required before the lowland legume technology could take off. We have demonstrated that irrigation water could be applied using pumps or gravity fed irrigation systems. However, this requires more thorough land preparation particularly levelling, and therefore further inputs. These points need to be considered further in estimating profitability of legume growing.

Extending the cropping season with the addition of a non-rice crop will create more opportunity for under-utilised family labour in the dry season. The additional crop will result in additional household income. The higher value crops have the potential of generating income opportunities for non-farm rural labour.

8.3.3 Environmental impacts

One potential issue that may arise is the overuse of the underground water supply. This may occur if a number of farmers within a particular region all start to use underground water to grow legumes or alternative crops and or for other purposes.

The main environmental impact will be through the misuse of pesticides on some non-rice crops. Legumes are known to be particularly prone to insect damage. We have decided to concentrate on mungbean and peanuts and avoid the soybean crop because of their particular susceptibility to insect pests. If legume cropping becomes a major activity in any area, IPM activities and training for growing these crops will be required.

8.4 Communication and dissemination activities

The majority of work was conducted in the field in the three Provinces of Kampong Thom, Takeo and Kampong Cham in the first two years, and the Kampong Thom and Takeo in the last three years (as well as in Kampot in year 4 and 5, and Battambang in year 5). These were conducted on-farm with farmers and PDA staff members. Usual communication efforts were made to inform PDA and farmers of the intent of the work, and shared any observation made in the field.

In year 3, we had 3 field days (2 in Takeo and 1 in Kampong Thom), and a number of farmers and other stake holders attended the events. Our model farm, experiments on irrigation frequency and mulch levels and demonstration of drill planted legumes were inspected by some 90 farmers (70 at Takeo and 20 at Kampong Thom) and various local Government officers. Some commune chiefs from other areas were also invited and they showed strong interest in participating in the project in the future. These field days were covered by Khmer newspapers and TV. These events and the farmers' positive responses prompted Takeo PDA to organize another field day to be held in May. The first one appeared as a newspaper article (as well as the second one) and English translated version appeared in ACIAR Newsletter (attached).

Similar field days were held in three Provinces in year 4 and in Kampot in year 5 to demonstrate the planting of legumes after the rice harvest at the beginning of dry season. Those who attended the field days were given the opportunity to grow legumes with seed freely available to them. Some of them at least have planted the seed, as the crop can be seen near the field day sites.

Model farms have acted as an agent to disseminate the project findings. Neighbouring farmers have seen the new system, and a number of them spoken with the model farmers and some use the technologies being developed by the project. The Takeo model farm, where the project utilized considerable resources, has been quite successful in improving their productivity and profitability. Other farmers consider that the model farm has made good achievements as seen by the recent appointment of the model farmer as the Head of the farmers group in the area within the District.

In addition to the community impact of adopting legumes after rice in lowlands as per the original project objective, impacts of the adoption of supplementary irrigation technologies are anticipated. The latter has potentially greater impact on the community, as this includes not only cropping activities but also others such as fish culture. We have successfully developed irrigation methods for legumes in lowlands, and farmers at the open day were interested in the irrigation methods.

We have also described project outputs in various scientific outputs such as Australian Agronomy Conference, and these are useful in disseminating information as mentioned in the last section.

9 Conclusions and recommendations

9.1 Conclusions

Growing legumes following rice harvesting in lowland rice soils can be commercially viable in some areas of Cambodia where supplementary irrigation water is available, provided the technologies developed during the project period are adopted. The legume technologies that have been developed by the project include the following. The legume crops considered most promising are mungbean and peanuts, and improved varieties are available for mungbean, and should be available for peanuts in the near future. One of the key requirements for legume cropping is that supplementary irrigation water is available and the soil types are Prey Khmer or Prateah Lang, although depending on management practises, other soil types may also be suitable for legumes. Legume cropping requires thorough land preparation and the soil should be levelled to ensure even distribution of irrigation water. For mungbean in particular, ridges and furrows should be used to ensure good establishment, ease of irrigation, and control of weeds. Irrigation needs to be applied every week.

During the course of the project, two key issues have been identified and addressed to make the legume cropping a viable option for rice-based lowland farmers in Cambodia. One is the availability of supplementary irrigation to grow legumes in lowland rice fields. In the areas studied in Cambodia, there are three options (1) Underground water applied directly from tubewell. (2) Underground water from tubewell stored in ponds. (3) No tubewell – ponds dug to access groundwater. For each of these options a pump is required unless manual watering is conducted in the third option. The amount of water required to grow legumes has been identified, and water productivity estimated. The other key requirement for legume cropping is high labour productivity. The viability of growing legumes depends on, not only increasing yield with the improved technologies, but also decreasing labour inputs to reduce the cost of growing legumes. Opportunity exists for reducing the labour cost in activities associated with land preparation, planting, and application of supplementary irrigation. The project was successful in developing labour-efficient supplementary irrigation methods for legume cropping in rice-based cropping systems to address the two key issues. Further, the project developed a bed maker to mechanise the ridge/furrow system and also successfully demonstrated the use of seed drill for planting. These implements can be attached to a power tiller. They can save labour, which is becoming increasingly scarce in areas where rice-based cropping is currently practised.

In addition to the two key issues of supplementary irrigation availability and improved labour productivity, other constraints identified for legume growing in lowland rice fields include soil physical and chemical limitations and biotic factors, particularly insects affecting legume crops. If low-cost pest management techniques can be developed legume cropping will be more viable. A long term approach is required for the soil constraint issues, particularly improved soil chemical fertility, and this would improve the productivity of both the legume and the rice crops within the system. Further improvement of legume varieties adapted to lowland soils and dry season cropping would be another way to make legume cropping more profitable.

Another major achievement was improvement in scientists' capacity to conduct research. In particular, there has been improved understanding of water requirements to grow a legume crop (water productivity). The scientists are now capable of measuring water input to the field and also soil water content during the crop growth. The ability to measure water input greatly improves the opportunity to make gains in developing efficient water productivity systems. Similarly, there has been capacity development for estimation of labour productivity. Scientists have also been trained in the conduct and presentation of research through numerous meetings conducted during the project period. In addition, two scientists have been trained for research higher degrees (one is still continuing). Perhaps the most important development is a gradual shift in scientists' attitude to working together for the common objective of achieving a project goal, rather than conducting research for the group to which they belong.

9.2 Recommendations

We wish to recommend the development of a new project building on the findings of this current project. The title of the new proposal may tentatively be "Improving farming systems on the rainfed lowlands of Cambodia". The existing project has demonstrated the value of supplementary irrigation in introducing mungbean and peanuts in what is otherwise a rice mono-cropping system. Rice/legume diversification could result in intensification of cropping to double or triple cropping (rice/rice/legume). According to the Cambodian National Strategic Development Plan (updated for 2009-2013) the Ministry of Water Resources and Meteorology (MWRAM) has made significant progress during 2006-2008 in rehabilitating and constructing irrigation infrastructure to expand capacity of the irrigation system. In 2010 the estimated irrigated area including supplementary irrigation was 33.5% of the rice lands which was about 0.911 million ha, with the area projected to increase to 1.195 million ha in 2011. With increasing land areas with access to irrigation supply, options for intensification also improve, with water management as part of the agronomic package a key to achieving higher farm profitability. The new project would take advantage of techniques developed and improved capacity for estimation of water and labour productivity. Outputs from the various options in terms of agricultural activities needs to be quantified in relation to the quantity of water required for each activity. This diversification and intensification project has the potential to improve profitability and also household nutrition of individual farmers as well as meeting the Government's policy of improving rice production.

The diversification may not necessarily be through the use of legumes. Other crops including horticultural crops such as tomatoes may be more appropriate in some case, depending on market availability and farm conditions, such as labour availability and land and water availability. One of key issues to be addressed in the new project will be the interaction between the rice phase and the non-rice phase of the cropping system. This may be related to the timing of the cropping which will become more critical with increased cropping intensity and hence reduced time available between the harvest of one crop and planting of the next. Availability of quick maturing varieties of rice and non-rice crops will be an issue here. Another issue will be the change in soil fertility with the inclusion of non-rice crops and its effect on rice productivity. It has been observed that a rice crop following a legume crop benefits from the legume, but this needs to be investigated further to determine whether the fertilizer requirement of rice may be altered with the diversification. The new project would provide information on water requirement of commonly grown or potential crops under different management conditions and to use the information to maximize the profit to farmers and maximize the efficiency of irrigation water use for irrigation associations and the irrigation authority. It is proposed to develop crop suitability maps with further collection of information on soil type and water availability. The mapping capacity has been increased recently with different projects at CARDI, and it can be utilized for the proposed project.

Additionally, diversification may not necessarily be confined to traditional crops in Cambodia. One possibility is the introduction of forage crops that can be grown after rice harvest, and be used to feed cattle or sold as feed. One benefit of forage crops is their ability to utilize all available water as no particular harvest time is required. The crops may be forage maize or improved grasses. These may be also useful in improving soil fertility, particularly increasing soil organic matter that is critically low in many lowland rice soils in

Cambodia. Integration of cattle in rice-based cropping would further enhance soil fertility. Another form of diversification that may be considered is fish using on-farm ponds. Thus importantly, the new project would require a whole-farm economic analysis including labour productivity.

CARDI has demonstrated its capacity to conduct scientific research and extend the knowledge with PDA and farmers directly in the current project. This approach should be adopted again for the proposed project. There are a number of strong farmer and irrigator associations (Farmer Water Users Communities) available in the target lowland regions in Takeo, Kampong Thom, Kampong Speu, and Kampot, and they should be partners together with PDA. Improving water productivity would be of interest to the relevant irrigators associations as well as to the Provinces. Farmer and irrigator associations with strong PDA involvement may be demonstrated as a model extension system in the new project. This may include the extension of legume technologies developed in the present project, but also new technologies that would emerge from the new project.

As well as experimenting with the agronomy, water management, and extension approaches required for the intensification and diversification of rice-based farming systems, it is recommended that in the new project attention be given to the marketing and policy constraints on the uptake of improved systems. While the current project has conducted economic analysis of best-bet options given current constraints, it will be important to develop robust models of the returns to new cropping systems under plausible future marketing and policy scenarios, in order to demonstrate the potential benefits of adjustments to these exogenous variables. For example, contract farming is a practice that is spreading in Cambodia and elsewhere and a new contract farming law has been drafted. This practice has the potential to ease constraints on input supply, credit, and market risk, and to be a conduit for technical advice. However, the experience in the Mekong region so far has been mixed. It may be that linking farmer groups (as discussed above) with accredited agribusiness firms with supervision from local agricultural staff may help to overcome some of the problems encountered so far. Thus, marketing and policy research can help to turn agronomicaly and technically feasible cropping options into economically feasible (and hence more widely adoptable) options.

This suggestion is in accordance with the recommendation of reviewers of the project (March 2011); the following is taken from the review report. ‘The reviewers support the concept of developing a new ACIAR project proposal to capitalize on the progress made during CSE/2006/040 and on CARDI’s expertise and experience in the rainfed lowlands. A new project will also provide continuity to the current research, thereby ensuring the plant breeding and other outputs in CSE/2006/040 will gain further strength. Any new project should continue to foster the solid relationships existing between CARDI and the PDAs. Because of the nature of the rainfed lowlands, the proposal should be developed with a 10 year research horizon with the first phase possibly being 5 years in length. It should:

a) Target the rainfed lowland ecosystem where a majority of farmers reside and where the need for farm income improvement is the greatest

b) Target the Prateah Lang and possibly the Prey Khmer soil types. CARDI has experience on these soils which are wide spread in the Cambodian rainfed lowlands.

c) Target areas with potential on-farm reservoirs of good quality water

d) Use a multidisciplinary approach and work through the PDAs

e) Include model farms to develop a full understanding of the interactions and synergies of a diversified farm approach

f) Include studies on minimizing pest incidence through farming practices ie drying soil after rice to reduce insects and disease loads, keeping plants sufficiently healthy etc

g) Include studies on processing, packaging and general value added marketing of upland crop products

h) Include studies on the linkages between private sector and farmers

i) Conduct further research on the mechanization of non rice crops, particularly in the dry season

j) Expand varietal evaluation of non rice dry season crops to other food and fodder crops

k) Diversify to high value crops ie sugar cane, water melon and other vegetables

A potential project title is “Improving farming systems on the rainfed lowlands of Cambodia”.’

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10.2 List of publications produced by project

Vang Seng, Rowena Eastick, Shu Fukai, Makara Ouk, Sarom Men, Sopheak Yim Chan and Sivoutha Nget. (2008). Crop diversification in lowland rice cropping systems in Cambodia: effect of soil type on legume production. In "Global Issues: Paddock Action" Proceedings of the 14th ASA Conference, 21-25 September 2008, Adelaide, South Australia. Web site www.agronomy.org.au (Appendix 11.1)

Rowena Eastick, Shu Fukai, Makara Ouk, Bunna Som, Sinath Pao (2009). Crop diversification meets conservation agriculture: a change in farming systems in Cambodia? A paper presented at International Workshop on Conservation Tillage in Dry Areas, Ningxia University, China, July 30 to August 3rd 2009. (Appendix 11.2)

Kimngoy Cheth, Jaquie Mitchell, Rowena Eastick, Seng Vang, Ouk Makara and Shu Fukai (2010). The effect of soil amendments and soil structure on minimizing constraints of lowland soils on growth of mungbean and peanut under glasshouse condition. In "Food Security from Sustainable Agriculture" Edited by H. Dove. Proceedings of 15th Agronomy Conference 2010, 15-18 November 2010, Lincoln, New Zealand. Oral presentation. Web site www.agronomy.org.au (Appendix 11.3)

Rowena Eastick, Vang Seng, Makara Ouk, Sareth Chea, Bunna Som, Vuthea Chea, Jaquie Mitchell and Shu Fukai (2010). Development of sustainable legume production in rice-based farming systems in Cambodia In "Food Security from Sustainable Agriculture" Edited by H. Dove. Proceedings of 15th Agronomy Conference 2010, 15-18 November 2010, Lincoln, New Zealand. Oral presentation. Web site www.agronomy.org.au (Appendix 11.4)

Ouk, M (2011). Improving profitability with variety improvement and the use of supplementary irrigation in Cambodia. Proceedings of 28th International Rice Research Conference, Hanoi, Vietnam. November, 2010. (Appendix 11.5)

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Chea S, Cramb R and Fukai S. (2011). Economics of growing mungbean after rice in the rainfed lowlands of Cambodia. International Conference on Conservation Agriculture. Brisbane, August 2011. (Appendix 11.7)

Bunna S, Sinath P, Ouk M, Mitchell J, Fukai S. 2011. Effects of straw mulch on mungbean yield in rice fields with strongly compacted soils. Field Crops Research 124: 295–301. (Appendix 11.8)

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Seng Vang, Veasna Touch, Jaquie Mitchell and Shu Fukai. Effects of irrigation method and frequency and fertilizer application on mungbean and peanuts after rice harvesting in lowlands in Cambodia. .

Fukai S and Ouk M. Increased productivity and profitability of rainfed rice based lowland cropping systems in the Mekong region. (in preparation for Crop and Pasture Science).

Mitchell JH, Cheth K, Ouk M, Seng V and Fukai S. Excess water problem in legumes after rice in lowland fields in the Mekong region. (in preparation for Field Crops research).

11 Appendixes

11.1 Crop diversification in lowland rice cropping systems in Cambodia: effect of soil type on legume production

Crop diversification in lowland rice cropping systems in Cambodia: effect of soil type on legume production.

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Abstract

The majority of rice production in Cambodia is based on rainfed lowland cropping systems, where rice is grown over the wet season, and fields left fallow over the dry season. Improved rice production systems in Cambodia have provided opportunities for crop diversification in rainfed lowland cropping areas. We aim to develop a system based on rice production in the wet season, followed by legume crops grown in the dry season, to provide farmer income over a greater portion of the year. In 2007-08, we evaluated peanut, soybean and mungbean production on 4 soil types commonly used for lowland rice production in Cambodia. Establishment and growth of legume crops varied between varieties and sites. Poor crop establishment and growth was attributed to soil physical constraints, and compounded by differences in crop management between sites. Inherent soil acidity and poor soil structure as a result of wet cultivation for preceding rice production, impaired nutrient availability and uptake by the crop. Insect pests, diseases and weeds also contributed to reductions in yield. Water management was also a significant issue in this rice/legume rotation system. Agronomic and management strategies need to be developed to minimise these constraints. There is potential for adoption of practices such as minimum tillage, retention of crop residues, raised bed configuration, irrigation strategies, and inoculation of legume seed, to improve production in this Cambodian system. Experiments to examine the effect of these treatments on legume crop production on lowland rice soils will be implemented in the 2008-09 dry season.

Key Words: farmer income, rural food security, intensification

Introduction

Agriculture is the basis of Cambodia's economy and society, and rainfed lowland rice is the single most important crop. It occupies about 2.24 million hectares, equivalent to 87% of the rice area , and 69% of the total cultivated area (MAFF 2008). Improving agricultural productivity has been identified as a major avenue for poverty alleviation and food security in Cambodia. There is the opportunity to increase farmer income by diversifying rice-based farming through incorporating legume crops into the system (Kirchhof et al. 2000), especially if supplementary water is available (Chan et al. 2004, Chet et al. 2008). The potential for increasing farmer income provided the impetus to examine crop diversification with lowland rice systems in Cambodia.

Traditionally, lowland rice is grown as a wet season crop, sown from May-June, and harvested in November-December, with land remaining fallow over the dry season. The modified cropping system proposes to sow legumes immediately after the rice is harvested, to maximise the use of residual soil moisture. There are a range of soil types used for rice production in Cambodia (White et al. 1997), and we aimed to identify suitable soils for peanuts, mungbean and soybean. Constraints imposed by these soils and growing conditions were also monitored. Some farming practices used in Australian may be transferable and assist in improved legume production in Cambodia. This paper presents initial results of legume crop suitability for four common rice soils in Cambodia, discussing the range of constraints, agronomic and otherwise, and suggesting future experiments to identify the best practices to address these constraints through innovative management and technologies.

Methods

Location and design

The experiments were conducted at 10 sites in Kampong Cham (KC), Kampong Thom (KT) and Takeo (TK) provinces in Cambodia. Sites were selected within these provinces on four different soil types; Prateah Lang (PL), Bakan (BK), Prey Khmer (PK) and Toul Samrong (TS). General characteristics of these soil types are provided in Table 1. An additional experiment was sown at the Cambodian Agricultural Research and Development Institute (CARDI) (11o28’35’’N, 104o48’26’’E). Experimental design was consistent between sites; randomised complete block with three replications. Variety was assessed within each site, consisting of two varieties each of; soybean (vars. DT84 and B3039), mungbean (vars. VC3541B and ATF3946) and peanut (rough and smooth shelled local varieties).

Land preparation consisted of 2-3 ploughings after the rice was harvested. Basal fertiliser of 90:30:15 kg/ha (N:P2O5:K2O) was applied prior to planting and incorporated by cultivation. A top-dressing application of 0:30:15 kg/ha (N:P2O5:K2O) was applied approximately 2-3 weeks after sowing. Plots were approximately 5m x 5m. Row spacing was 50cm and plant spacing within row was 20cm. Sowing was conducted with 2-4 seeds per hill and thinned to 1 per hill, and missing hills re-sown, approximately two weeks after seedling emergence. Planting dates were between December and February, coinciding with the end of the wet season. Hand-weeding was done 2-3 times during the crop cycle. Insect control and irrigation regime was at the discretion of the farmer, in conjunction with the provincial district agronomist (PDA).

Table 1. Physical and chemical characteristics of lowland rice soils in Cambodia, and the percentage of the rice area they occupy.

Soil typea	Area (%)	Sand (%)	Silt (%)	Clay (%)	CEC	pH (1:5 CaCl)	Organic C (g/kg)	Total N (g/kg)	Colwell P (mg/kg)
Prateah Langb (Plinthustalfs)	28	50	37	13	3.71	5.0	4.3	0.2	10
Bakan (Alfison/Ultisol)	13	35	49	16	4.84	4.3	4.0	0.2	4
Prey Khmer (Psamments)	11	73	22	5	1.45	4.8	2.2	0.2	2
Toul Samroung (Vertisol/Alfisol)	10	28	29	42	16.0	4.5	11.7	1.0	7

aLocal name according to White et al. (1997). bLoamy Phase. Names in parentheses refer to the Key to Soil Taxonomy. Adapted from CARDI (2005).

Measurements

Soil samples were taken at 0-25cm, 25-50cm and 50-75cm to assess bulk density, soil moisture, soil nutrients and soil strength on the 13th December 2007 and 10th January 2008 at the Kampong Thom / Kampong Cham and Takeo provinces respectively. Time between soil sampling and sowing varied between sites. At the majority of sites, management of the crop, and collection of data and field observations, was the responsibility of the PDA; at some sites, it was the farmer's sole responsibility. The PDA or the farmer is then responsible for providing the data to CARDI scientists. Plant measurements consisted of emergence counts, 50% flowering, and nodulation. Observations on insect dynamics, weed spectrum and disease prevalence were recorded through the season. Amount of water applied was estimated. Yield was collected as total plot yield. Data was analysed using IRRISTAT® Combined Analysis of Variance.

Results and Discussion

Site and soil water characteristics

The proposed rotation system is based on sowing the legume following the rice crop as soon as practicable to maximise the use of residual soil moisture remaining after the wet season. Kirchhof et al. (2000) considered that legume crops following rice on clay soils could achieve acceptable yields without irrigation provided roots could access the subsoil water reserve. In this initial season, our experiments aimed to examine yield potential of legumes on different soil types, in the absence of other constraints, including water. Consequently, all sites required irrigation, due to the late sowing dates at most sites resulting in depleted soil residual moisture. Sowing date, or more specifically, the length of time between rice harvest and sowing the legume crop, has critical implications for production, related to soil drying and the resultant increase in soil strength (Kirchhof et al. 2000).

Sowing dates and length of time between rice harvest and sowing varied between sites, with resultant differences in soil profile moisture (%) at time of sowing (Table 2). Conclusions on the capacity of residual soil moisture in different soil types to grow a crop is confounded by differences in number of days from soil sampling to sowing (DTS) (7 to 73 days), and time between rice harvest and sowing (DR-S) (5 to 80 days). At some sites, such as KC BK, where rice was still to be harvested, and soil moisture values were relatively low, the profile was being rapidly depleted of moisture available for the subsequent legume crop. Using shorter season rice varieties is an option now available to Cambodian farmers, and this will provide a greater opportunity to add an additional crop to the rice farming system. Confounding the effect of irrigation and infiltration, a hard pan was found at approximately 20-30cm (values up to 8kN) at all sites, developed as a result of puddling practices in the previous rice phase. Sites varied considerably in their watering regime, ranging from 2mm/day with watering cans, to furrow irrigated weekly.

If we consider that the proposed system should be based on sowing the legumes into a full moisture profile, suggesting a criterion of sowing within two weeks of rice harvest, depending on farmer practice, then only one site, KC BK, satisfied this condition. However, soil moisture was already depleted by time of sowing. Results from this season indicate that soil moisture reserves only, may not be adequate for DS legume crop production, and that irrigation will be a significant component of this proposed system. Soil profile moisture and soil strength attributes and timing of sowing will be topics for future research.

Table 2. Soil moisture content (%) and days since rice harvest (DRH) (positive indicates that rice was still to be harvested) at time of soil sampling. Date of sowing, the number of days between soil sampling and sowing the legume crops (DTS), and number of days between rice harvest and sowing of legumes (DR-S) varied between sites.

Depth (cm)	Soil Moisture (%)									
	KC PL#	KC TS	KC BK	KT PL	KT PK	KT BK	TK PL1	TK BK	TK PL2	TK PK
0-25	Na	20.9	13.9	28.7	20.5	38.5	27.5	20.9	3.6	22.7
25-50	Na	40.8	18.4	34.9	33.9	38.5	25.8	20.4	26.4	15.4
50-75	Na	38.8	29.2	44.6	33.5	43.4	22.0	27.6	32.2	18.4
DRH	14	+9	+9	10	7	7	25	25	60	25
Sown (DTS)	29Jan (47)	27Feb (73)	27Dec (14)	4Jan (21)	27Dec(14)	21Dec (8)	17Jan (7)	9Feb (30)	31Jan (20)	11Feb (30)
DR-S	61	64	5	31	21	15	32	55	80	55

#Site was saturated with standing water on the soil surface, so samples not taken.

Plant establishment

Seedling emergence is a major limitation to legume production after rice for lowland soils (Rahmianna et al. 2000). We measured plant establishment but not emergence prior to re-sowing missing hills, so values do not account for re-sown plants and early mortality at some sites. There was a significant site by variety interaction (P<0.001) for plant establishment, where most sites produced adequate crop populations (>65% mean for all varieties). Results for selected sites are presented in Table 3 (other data not available). Plant establishment varied within soil type, indicating that differences in crop management, such as watering regime and insect management, confounded the effect of soil type. For example, within the PL soil type, severe surface crusting which restricted seedling emergence was observed at some sites if the soil surface was allowed to dry out, but when soil moisture was maintained, seedling emergence was satisfactory.

Table 3. Establishment % at selected sites for 6 legume varieties.

	Establishment (% of sown hills) at selected sites					
Variety	KC BK	KT PL	TK BK	TK PL1	TK PL2	CARDI PL
MB VC3541B	84	26	86	78	80	70
MB ATF3946	88	39	66	75	77	76
SB DT84	73	92	83	70	61	61
SB B3039	22	69	87	67	57	29
PN Smooth	93	86	75	85	86	63
PN Rough	91	83	92	80	82	63
LSD (5%)	Site x Variety: 20					

In-crop Observations

Insects were a major problem, consistent with previous studies in Cambodia with dry season non-rice crops (Chan et al. 2004), especially pod borers in soybean (Etiella zinckenella, Maruca testualis) and aphids on mungbean. At one site, greater than 90% pod damage in soybeans was estimated. Weeds were also a problem, mainly volunteer rice and nutgrass. No inoculum was applied to the legume seed, and field observations indicated that although peanut produced some effective nodules, the other two legume crops produced very few or no nodules.

Yield

Yield data was not yet available. However, observations indicate that peanuts are the most promising crop across all soil types, due to very low yields of soybean from insect damage, and poor mungbean growth.

Capacity

A limited capacity and understanding of legume crop production practices by Cambodian farmers and PDAs was observed throughout the experiments. Conducting experiments on farmer's fields also posed constraints with respect to data collection and crop management for optimum yield. A significant challenge will be the extension of these improved technologies to rural Cambodia.

Conclusion

Peanuts and the Prey Khmer soil type had the least production limitations, but conclusions on differences in legume crop suitability between soil types were confounded by management differences, especially time of planting in relation to rice harvest, watering regime and insect control. However, the experiments allowed identification of a number of constraints on legume production following rice. Insect damage was a significant constraint. Water requirement was the main factor influencing crop growth, influenced by time after sowing after rice harvest, and interaction with soil type. Future research will focus on this aspect, and associated management practices for better crop establishment and water use efficiency, such as the use of raised bed configuration, minimum tillage, and retention of surface residue to ameliorate the hard-setting soil surface attributes and to maintain soil profile moisture.

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11.2 Crop diversification meets conservation agriculture: a change in farming systems in Cambodia

Crop diversification meets conservation agriculture: a change in farming systems in Cambodia?

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Abstract

Agriculture, especially rice production, is the socio-economic basis of Cambodia, but is performing below its productivity potential. Crop diversification is a major avenue by which on-farm productivity could be improved. A number of projects are being conducted in Cambodia to address this challenge. One of these is ‘Crop Diversification in Lowland Rice-Based Cropping Systems’, which aims to develop a system based on rice production in the wet season, followed by legume crops grown largely on residual soil moisture in the dry season. In 2007-08, peanut, soybean and mungbean production was evaluated on 4 soil types commonly used for lowland rice production in Cambodia. Generally, crop establishment and growth was poor, attributed largely to soil constraints, especially poor soil structure as a result of wet cultivation for preceding rice production. This was compounded by inadequate provision of water to the legume crop, through either residual soil moisture, or irrigation. Conservation agriculture is generally not practiced in Cambodia, but there is potential for adoption of principles such as minimum tillage and retention of crop residues to improve production in Cambodian cropping systems. Experiments to examine the effect of these treatments on legume crop production on lowland rice soils were implemented in the 2008-09 dry season. Generally, the addition of mulch to the system improved crop establishment and yields, and decreased weed biomass. There is also complementary research being conducted on upland soils, such as the evaluation of a Direct Seeding Mulch Based System, which has demonstrated improved sustainability of the farming system. Although conservation agriculture principles show promise for the development of effective crop diversification in Cambodia, there are significant constraints to their adoption. These include competition for surface residue for grazing by livestock, the accessibility of suitable machinery, and technical knowledge and acceptance of the technology by the farmers. Conservation agriculture practices may have greater potential to modify and be adopted in upland farming systems, than lowland rice systems.

Key Words

lowland rice, legume, Cambodia,

Background

Agriculture is the basis of Cambodia’s economy and society, with 59% of the population of 15 million relying on this sector for their livelihood. However, the contribution of the agriculture sector to the Cambodian economy is declining, accounting for only 29% of the GDP in 2007 compared to 45% a decade prior (World Bank 2009). The agriculture sector is considered to be under-performing for a number of reasons, including weak research and extension systems, lack of irrigation and water control systems, poor access to market information, and lack of crop diversification (Charlesworth, pers.comm). Rice production dominates the agriculture sector, occupying about 2.6 million hectares, equivalent to 90% of the total cultivated area in a country of 181,000 km2. Rainfed lowland rice comprises nearly 90% of the rice area and is typically monocropped

(Farquharson, Chea et al. 2006). Improving agricultural productivity has been identified as a major avenue for poverty alleviation and food security in Cambodia; crop diversification by incorporating non-rice crops into rice based farming systems is a potential means by which farmer income and returns per hectare may be increased (Chan, Basnayake et al. 2004; Ouk, Chan et al. 2007).

Cambodia missed what is often termed the ‘green revolution’ due to political and civil upheaval during the 1970’s, with a relatively short history of agricultural research and development (Farquharson, Chea et al. 2006). This has contributed to the continued traditional and low input subsistence farming evidenced today, including slash-and-burn agriculture in upland areas, predominant use of animals for land preparation, and manual transplanting of rice in lowland areas. Cambodia is still recognised as a developing society (Farquharson, Chea et al. 2006). If we consider that “adoption of no till farming is indicative of the economic and industrial development of a society, and is a natural step forward when other components of development are in place” (Lal 2007), then it is understandable that the adoption of conservation agriculture principles, and other advanced farming practices, such as crop diversification and multiple cropping, is largely lacking in Cambodia. The challenge is to increase agricultural productivity through development of improved farming system packages.

Introduction

There are numerous organisations conducting agricultural research in Cambodia aimed at improving farmer livelihoods; crop diversification growing crops additional to rice, is a major focus. Experiments assessing legume production have identified numerous factors which contribute to poor crop yields, such as irregular crop establishment, low soil fertility, unpredictable climate, and of prime importance, low soil water availability (Seng, Eastick et al. 2006). Modification of existing traditional farming practices comprising of multiple ploughings and hand dibbling into hard setting and surface crusting soils, is required to ameliorate the effect of these constraints. The adoption of conservation agriculture (CA) principles is recognised as a potential avenue by which to do so. Namely; little or no soil disturbance; maintenance of soil surface cover through management of crop residues or green manure crops; and, the use of crop rotations, with associated beneficial features including erosion control and water conservation (Hobbs, Gupta et al. 2006; Lal 2007), may provide a basis for more reliable crop diversification.

An Australian Centre for International Agricultural Research project (Martin, Farquharson et al. 2009) was initiated in 2000 to improve production of a range of crops grown under upland conditions, including maize, soybean, mungbean and peanut. Research conducted within this project identified that the retention of soil surface cover and the use of mulch were beneficial to upland crop production (Bunna, Sinath et al. 2007). This project has continued to evolve (ACIAR ASEM/2006/130), and the assessment of no-till machinery in crop establishment is a significant priority (Bob Martin pers.comm).

A substantial amount of research has also been conducted by CIRAD (Centre de Cooperation International en Recherche Agronomique pour le Developpement) on Direct Sowing in Mulch based Cropping Technologies (DMC) in Cambodia. The strategies within DMC are based on CA principles. In alignment with these projects on crop diversification in upland farming systems, a project was initiated in 2006 to also examine non-rice crops in lowland rice based systems (ACIAR CSE/2006/040). This paper focuses on research conducted within this project, with some discussion on complementary projects also being conducted in Cambodia.

The initial year of the lowland rice based crop diversification project identified a number of constraints to the successful production of legume crops following rice. Conservation farming practices could maximise the retention and utilisation of soil residual moisture after the rainy season, thus enhancing the potential for inclusion of rotation crops after rice. Could a change in farming systems incorporating conservation agriculture principles lead to more productive and diverse crop production in Cambodia?

Crop Diversification in Lowland Rice Soils

A project was initiated in the 2007-08 dry season to develop a system based on rice production over the wet season, followed by legume crops in the dry season. The original premise was that residual soil water remaining in the profile after the rice harvest could be utilised for growing a subsequent crop. There are a range of soil types used for rice production in Cambodia (White, Oberthur et al. 1997), so the initial season examined a range of lowland soil types for suitability for peanut, mungbean and soybean production. Legume production on rainfed lowland rice soils presents unique challenges. The soil physical, biological and chemical conditions induced by puddling during land preparation for the rice crop, are major contributors to the poor performance of secondary crops after rice (Kirchhof, Priyono et al. 2000; Kirchhof, So et al. 2000). This conclusion is consistent with the relatively low yields obtained in our initial season, where soil properties, as well as water availability and insect pests were identified as the major constraints to the establishment and growth of legume crops (Seng, Eastick et al. 2008). Surface soil crusting was observed to inhibit seedling emergence and peanut peg penetration, and a hard pan at approximately 30cm was observed to prevent root penetration, which caused subsequent moisture stress as the roots could not access the sub-soil moisture – which was one of the premises of the proposed system. Conservation agriculture practices may provide a potential means to ameliorate some of these constraints.

If we are to develop a system of legume after lowland rice, where the legume crop is grown primarily on residual soil moisture remaining after the wet season, then there is a very narrow window of sowing opportunity after the rice harvest. The most critical stage for root penetration is soon after the crop establishment phase where roots grow into, and possibly through, the puddled layer to tap subsoil water for future growth (Kirchhof, Priyono et al. 2000). Observations from the initial two years of the lowland rice diversification project would support this suggestion. Maintaining adequate soil moisture between the rice harvest, and sowing the legume crop, such that the puddled layer does not dry out and harden, consequently preventing root penetration, is the challenge. Retention of surface residue provides the opportunity to optimise retention of soil moisture in the profile through reduction in evaporative losses.

Maintaining soil surface residues and sowing minimal till would also reduce the number of land preparations and time required between rice harvest and legume sowing, effectively increasing the sowing window and maximising the amount of residual water retained for the legume crop. Mulch as a soil amendment increased legume yields (Kirchhof, So et al. 2000) and improved emergence (So and Ringrose-Voase 2000) after rainfed lowland rice in a study in the Philippines, due to its water conservation effect. Minimising evaporative losses and extending the sowing window would maximise the ability to grow a legume crop solely on residual soil moisture in Cambodian lowland farming systems.

However, the adoption of CA principles holds many challenges itself, particularly technical constraints such as mulch management, weed management, suitable planting machinery, and bed configuration (Hobbs, Gupta et al. 2006). We conducted a number of activities over the 2009 dry season to see how we could address these technical issues, and if subsequently, no-till and mulch management could help in the development of an effective rice / legume rotation farming system.

Mulch x Tillage x Planting Method

An experiment was conducted over four sites, each on different lowland soil types, to compare the effect of tillage, planting technique and mulch on mungbean establishment and yield when sown after rice. Tillage treatment was either ploughed or no-till; planting treatment was either hand dibbled, or with a prototype seed drill; rice straw of approximately 2t/ha was hand carried onto the plots for the mulch versus no mulch treatment. Crop establishment, weed biomass and mungbean grain yield were the parameters assessed.

There was significant variability in grain yield between sites. The experiment design within each site lacked statistical rigour, but trends indicated that treatment effects also varied between sites (Fig.1). Mulch produced an effect on emergence at all four sites (Fig.2), and planting and / or tillage interactions with mulch produced effects on weed biomass (Fig.3) and grain yield (Fig.1). Overall, planting method and tillage had little effect between the sites. Generally, use of mulch produced higher grain yield, higher mungbean emergence and less weed biomass than without mulch.

However, variability between sites this season suggests repeating the experiments next season, ensuring more uniform crop management across sites. Mulch management will be an important component to also consider next season; comparison of standing stubble compared to transported mulch may be examined.

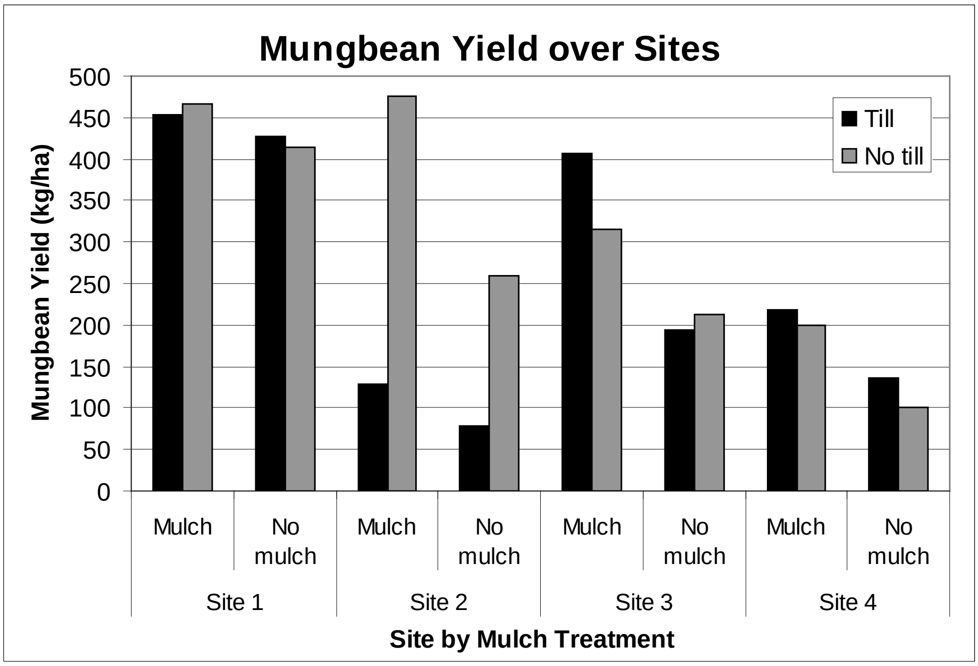

Fig 1. Mungbean grain yield across each site; means for mulch by tillage interaction.

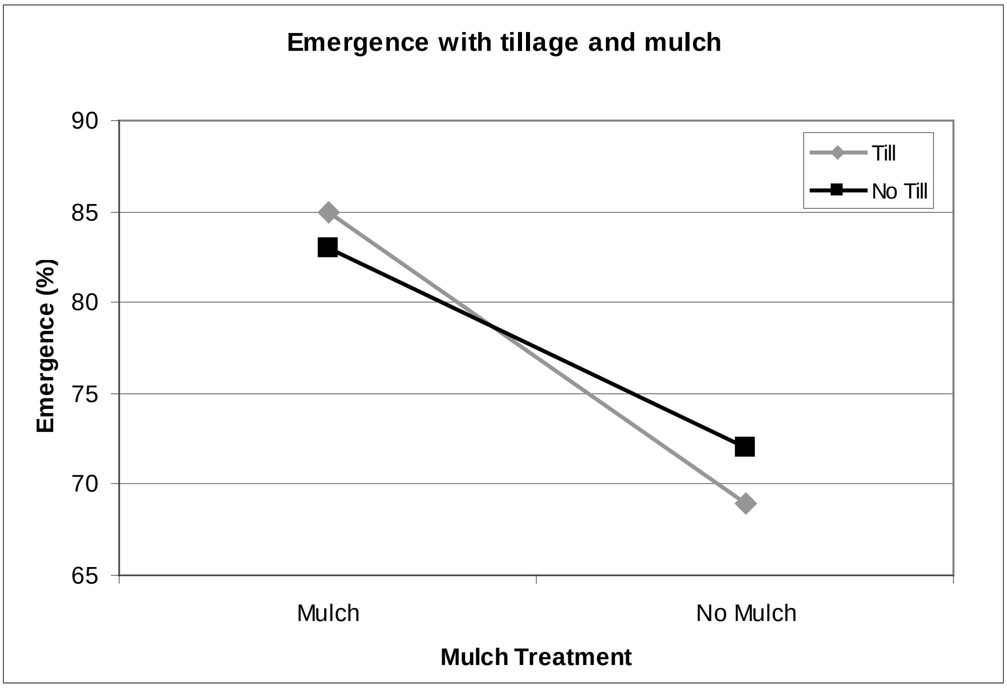

Fig 2. The addition of mulch increased mungbean seedling emergence at most sites; means for the mulch by tillage interaction from Site 2 are illustrated here.

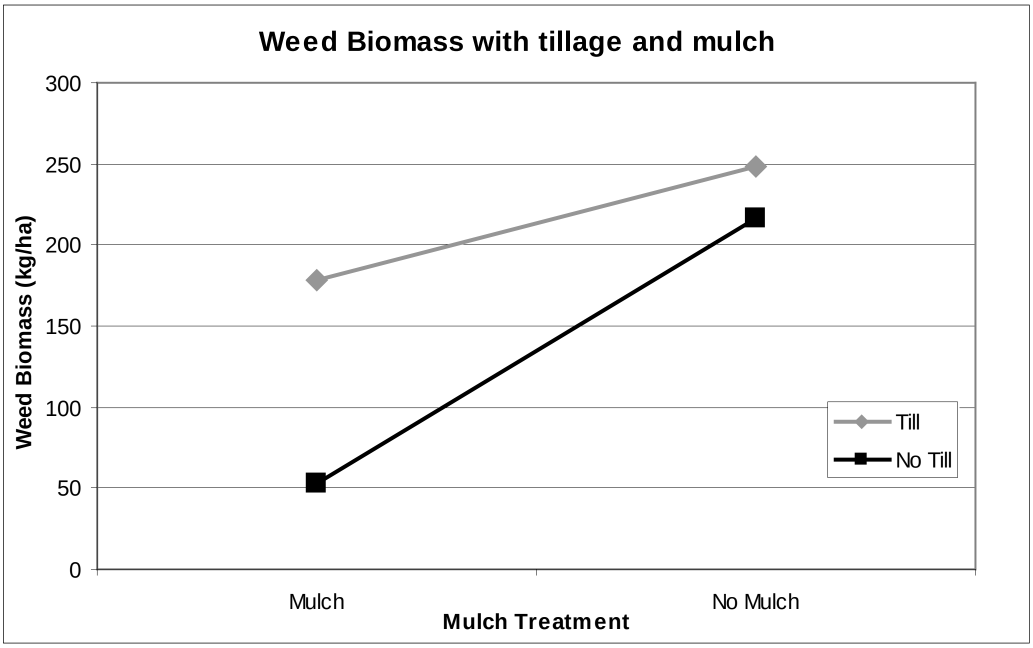

Fig 3. Means of weed biomass for the mulch by tillage interaction from Site 1 The addition of mulch decreased weed biomass at most sites.

Direct Seeding Mulch Based Systems (DMC)

ACIAR projects have been major contributors to development of CA principles in Cambodia. Another organisation, CIRAD, has also been a major driver in this field. Consistent with ACIAR concerns, CIRAD listed climate (flood and drought), soils (structure, acidity and low fertility), limited crop diversification and resultant low farmer income per hectare as significant constraints to agricultural productivity in Cambodia. DMC is proposed as a system to increase yields, and income per hectare, through soil improvement, crop diversification, biological activity of the rotation crops, and increased sustainability of the farming system (Boulakia, Kou et al. 2007). The three main principles of DMC are closely aligned with those defined as Conservation Agriculture; namely, permanent soil cover, no tillage, and species rotation.

There has been a dramatic increase in the last ten years of the area of upland soils sown to cassava (www.maff.gov.kh). However, yields are reported to be decreasing, attributed to declines in soil fertility. Cambodian farmers rarely use chemical fertilisers, and rely on inherent soil fertility for upland crop production. The concern of declining upland soil fertility provided significant impetus for the evaluation of DMC technologies (Boulakia, pers.comm). Cropping sequences being examined under upland conditions include combinations of cassava, maize, rice and soybean cash crops, sown in the wet season (June-August). Stylosanthes or Brachiaria ruziziensis are sown as intercrops approximately one month after the cash crop has emerged, the cash crop is harvested at the end of the wet season (Nov-Dec), with the intercrop remaining to provide soil cover and biomass over the dry season (Dec-May). At the commencement of the following wet season, this species then re-establishes, herbicide is applied, providing the basis as the mulch for the next rotation cash crop. Improvements in soil properties such as organic matter and water infiltration have been observed within three years (Boulakia, pers.comm). The use of cover crops, and no-till sowing, is currently being extended from upland conditions, to lowland rice conditions.

However, there are a number of constraints to the adoption of DMC, and of no-till legume sowing in rice-based lowland farming systems.

Constraints to adoption

A change in farming systems in Cambodia will involve a significant mind set change, and a significant development of technical knowledge and skills; even the concept of growing a crop other than rice is novel to most farmers. This was illustrated by a farmer who queried when the panicles would emerge from his new peanut crop! Ploughing is a well-established method of land preparation and weed control in Cambodian agricultural society, and no tillage is a concept few farmers have been exposed to.

In conjunction with this, are the issues of mulch management and weed control, and the associated use of herbicides. Very few farmers are familiar with herbicide options, and methods of application, especially the use of a machinery mounted boom spray. Underlying the mind set change and development of technical know-how is the socio-economic basis of Cambodian agriculture. The high reliance on cattle in traditional farming systems has implications for the adoption of CA. Lack of crop residue on the soil surface is one of the most important constraints limiting the adoption of no-till farming in developing countries, and this is often attributed to the use of crop residues for fodder for livestock (Lal 2007). Grazing and trampling post-rice harvest also leads to crustation and massive structure, where ploughing would be required to improve the soil structure, albeit temporarily. This is the situation in Cambodia; the majority of rural households rely on cattle for draught, also for manure, and, in most instances, also as a ‘bank’. Thus, demand for available fodder is high, and cattle graze the usually still-moist rice fields immediately after rice harvest, causing soil compaction. Less than 1% of Cambodian farmers use chemical fertiliser, relying on animal manure for fertiliser, primarily for high value vegetables, or their rice nurseries prior to transplanting. “Rice straw is for the cow, manure is for the plant”.

Bellotti, Biao et al. (2008) identified the high opportunity cost of crop residues for livestock feed, access to machinery such as no-till planters suited for animal draught, and improved capacity in weed management, as issues to be addressed prior to adoption of CA in the Loess Plateau in China. These are all issues applicable to adoption of CA in Cambodia, although there are some differences between upland and lowland systems.

It appears from the existing upland cropping production research that CA could evolve in these systems over time. However, in lowland systems, where there is a flooded and puddled rice production phase, this evolution may be more difficult. In order to fully recognise the benefits of CA, the rice production phase should also use no-till. Hobbs, Gupta et al. (2006) identified that growing zero-till rice in a double-cropping system would be a hard mindset for farmers to change. They also listed a number of technical issues to be addressed, consistent with others cited above, including weed management, suitable planting machinery, mulch management, and bed configuration.

As described above, the availability of suitable machinery is a major constraint to the adoption of CA, and is a vital component in the development of no till farming systems. Evaluation of suitable no till machinery is a priority for CA researchers in Cambodia.

Machinery

The use of machinery is increasing in Cambodia; with tractors for land preparation and sowing becoming more prevalent in upland farming systems, and power tillers in lowland rice systems for land preparation, although hand-transplanting is still widely practiced. However, the machinery is currently designed for conventional farming systems. The adaptation to no-till seed drills, and the necessary machinery to pull the seeder, is a major mind set change for the Cambodian agriculture sector. Even a 2-row no-till seeder cannot be pulled by a small 30-HP tractor normally available to Asian farming communities (Lal 2007). A prototype no-till seed drill attached to a Siam Kubota 12HP power tiller was recently designed in collaboration with CARDI and ACIAR (http://www.unapcaem.org/bbs/topic.asp?TOPIC_ID=1648), and tested in the 2008-09 season. Difficulties were encountered with inadequate soil moisture, and in loose soil surface residue. Modifications are still required, and this will be further tested in the 2009-10 season.

CIRAD has assessed a wide range of no till machinery, including a hand-pushed single row Knapick® experimental planter, a single and a double row plot Fitarelli® planter which can be used with a power tiller, and a commercial Vence Tudo® SA-11500 5-6 row field size planter which would likely be suitable only for large contractors. Early observations indicate that these planters show promise, but soil moisture conditions and mulch management are critical.

Further evaluation and extension of no-till machinery options will continue; evolution in Cambodia away from animal draught towards mechanisation is inevitable.

Quantifying benefits of CA

The research thus far conducted on lowland rice systems diversification has primarily focused on the production itself of the rotation crops, that is, the agronomy and to a minimal extent, the pest management, and the associated economic benefits to the farmer over an annual production cycle, as was the original scope of the project. The data collected in the initial 2 years of the study has been primarily yield and crop physiology data eg. time to first flowering. However, the inclusion of a legume rotation crop, especially if grown using conservation agriculture practices, must surely have some benefits to the overall soil and water management objectives generally being pursued through CA. Quantitative studies on water balance components such as runoff, drainage and soil evaporation, and soil quality components such as organic matter, have not been integral to the lowland rice-based crop rotation studies at this stage.

Water use efficiency was evaluated under different irrigation scenarios in the 2008-09 season; ideally this could be extended next season to compare between no-till and conventional till systems following rice, to better quantify the advantage in water use efficiency under different systems.

Conclusion

Research evaluating crop diversification to supplement the dominant rice enterprise in Cambodia has demonstrated there are many constraints to obtaining high yields in legume crops. Adverse soil properties, especially in lowland rice soils, such as hard-setting, surface crusting and a hard pan, may be ameliorated to some extent by the adoption of conservation agriculture principles. Research into practices such as no till and mulch retention have showed promise in improving crop yields. However, there are numerous challenges to be addressed prior to wide-scale adoption of such practices in Cambodia, including competition for surface stubble with livestock grazing, lack of availability of suitable machinery, and limited technical knowledge of farmers. In upland systems, it appears these constraints could be overcome in the immediate years, especially with the development of specialised machinery, and there well may be a change in these farming systems; the challenge will be much greater in lowland rice based systems.

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11.3 The effect of soil amendments and soil structure on minimizing constraints of lowland soils on growth of mungbean and peanut under glasshouse condition

The effect of soil amendments and soil structure on minimizing constraints of lowland soils on growth of mungbean and peanut under glasshouse condition

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Abstract

Crop diversification following wet season rice is one avenue of increasing agricultural productivity in Cambodia. Lowland rice soils have numerous physical and chemical constraints to non-rice crop production. A glasshouse pot experiment was conducted during dry season from January to April 2010 at the Cambodian Agricultural Research and Development Institute (CARDI). An omission pot trial investigated the effect of soil structure, soil fertility, soil pH, lime, and straw mulching on growth of mungbean and peanut. Results showed that at flowering time, the omissions of rice straw mulching and chemical fertilizer application had the largest effect followed by omission of cow manure application on growth of mungbean and peanut, while omission of either lime or disturbed soil structure reduced growth, but the effect was small and not significant. At final harvest stage, the omission of chemical fertilizer application still has the large effect on the total dry matter of mungbean and peanut, followed by lime application and straw mulching.

Keywords: Vigna radiate, Arachis hypogaea, soil constraints, disturbed and undisturbed soil.

Introduction

Legumes are traditionally grown in Cambodia as rainfed wet season crops on upland soils. There is tremendous potential for non-rice crops to be grown also on lowland rice soils following wet season rice, using residual soil moisture and supplementary irrigation systems in the dry season on well drained sandy soils (Nesbitt, 1997). Under rainfed lowland conditions, the paddy field is commonly left fallow during the dry season. However, legumes are occasionally grown as an opportunity crop with very little inputs and yields are therefore very low; 0.3-0.8t/ha in experiments in other countries (Kirchhof et al., 2000). The establishment of legumes into lowland rice-based cropping systems offers the opportunity to increase sustainable productivity and income of farmers in rainfed lowland rice production areas of South East Asia (Kirchhof et al., 2000).

However, there are numerous agronomic constraints to the production of dry season legumes after rice. The puddled soil, with associated soil compaction, soil surface crusting, and a hard plough pan, is a major cause of low crop establishment and poor early growth. In addition, the inherent low soil fertility and acidity of most Cambodian lowland rice soils also contributes to the low grain yield of legumes. High soil strength is closely related to soil compaction and increased soil bulk density, and also to reduction of soil water content and low organic matter within the soil. A pot experiment was conducted to evaluate the effectiveness of soil amendments of chemical fertilizer, cow manure, lime, rice straw, and soil structure to minimizing constraints of lowland soils on growth and yield components of mungbean and peanut.

Materials and methods

A glasshouse pot experiment was conducted during dry season from January to April 2010 at CARDI. The standard treatment (All) consisted of application of the soil amendments of cow manure, chemical fertilizer, lime, and straw mulch, while the other treatments consisted of the standard with one amendment omitted from each pot as outlined in Table 1. The soil for the experiment was taken from the top soil (0-20cm) from areas where rice crop was grown during rainy season. In the field, a hardpan existed at 20cm therefore in each pot we established a soil depth of 20cm. As such, the twenty litre (20cm wide x 25cm height) black plastic pots were packed with 11kg of air-dried sieved soil (disturbed soil) or 12.5kg of undisturbed soil (maintaining paddy structure and field water content) of a Prateah Lang (PL) soil (Vang et al, 2008). This 1.5kg difference in soil weight between disturbed and undisturbed soil, was largely due to water content of the undisturbed soil cores. Pots were maintained at field capacity for the duration of the experiment, and therefore it is likely that potential differences in water and nutrient availability due to differences in initial soil weight in the pots was negligible.

The pot experiment was a split plot design with two legumes (mungbean and peanut), considered main plot and eight soil amendments as subplot treatments with three replications. Five seeds of mungbean and peanut were sown (2-3cm depth) on 9 January, thinned to 2 plants per pot after 2 weeks. Mungbean reached maturity and was harvested on 13 March, while peanut was harvested on 25 March prior to maturity. One litre of water was applied daily per pot. Root length, root dry weight and total plant dry weight were measured for one plant at flowering (33DAS), and one plant at final harvest

Table 1: Treatments used in glasshouse experiment: All, All+Whole mixing are standards (Std); disturbed soil (DS); organic matter (OM); rice straw (ST); lime (L) and chemical fertiliser (CF); + indicates inclusion and – indicates without; Soil mixing depths indicated as whole (0-20cm); top half of pot (0-10cm); 3cm of sieved soil added to undisturbed soil surface (0-3cm).

Crop	Std All + whole mixing (0-20cm)	Std +All (0-0cm)	All-DS (0-3cm)	All-OM (0-10cm)	All-ST (0-10cm)	All-L (0-10cm)	All-CF (0-10cm)	Nil
Mungbean and Peanut	DS +	DS +	DS -	DS +	DS +	DS +	DS +	DS -
	OM+	OM+	OM+	OM-	OM+	OM+	OM+	OM-
	ST+	ST+	ST+	ST+	ST-	ST+	ST+	ST-
	L +	L+	L+	L+	L +	L-	L+	L-
	CF+	CF+	CF+	CF+	CF+	CF+	CF-	CF-

Soil amendments were allocated to two soil structures, either disturbed (DS+) or undisturbed (DS-) soil, and incorporated to different depths, as described in Table 1. The standard treatments were, all amendments applied, consisting of; 1) cow manure used as organic matter (OM) applied at 5 tons per hectare; 2) rice straw (ST) on the soil surface at the rate of 5 tons per hectare; 3) chemical fertilizer (CF) at the rate of 36 kg/ha of N, 130 kg/ha of P2O5 and 50 kg/ha of K2O, and 4) lime (L) applied at 0.5 tons per hectare. The Nil treatment consisted of no soil amendment addition and undisturbed soil structure.

The decision to use 0.5t/ha of lime application was the result of preliminary testing of different levels of lime application tested before the pot experiment started. The original soil pH for this pot experiment was 5.5, and when the three levels (0.8t/ha, 1t/ha, and 1.2t/ha) of lime were applied, soil pH was increased by 1.90, 3.50, and 3.54 units, respectively. In this case, 0.5t/ha of lime was selected to improve the soil pH from 5.5, aiming to achieve pH of 6.5.

Results

Root mass

Both crop and treatment main effects were significant ($p<0.05$) at final harvest stage on the root dry weight, with a significant crop effect at flowering (Table 2). A significant treatment by crop interaction effect only existed at flowering. On average the root weight in peanut was 0.07g and 0.30g higher than mungbean at flowering and final harvest respectively.

At flowering stage, the All-ST and Nil treatments produced the lowest root dry weight however, the Nil treatment for peanut was among the highest root dry weight. Similarly, the highest root dry weight was All+ Whole mixing for mungbean, while All and All-CF achieved the highest root dry weight for peanut. In peanuts, All-ST produced smallest amount of root dry weight at 0.13g.

At final harvest, both crops responded similarly to soil amendments with the All-DS (0.55g) having the highest root dry weight which was significantly greater than All-OM (0.49g) and the All and All+whole mixing treatments. The Nil and All-CF produced the lowest root dry weight (0.28g).

Root length

Root length at both flowering (7.5 vs 5.0cm) and final harvest (15.3 vs 12.3cm) was significantly higher in peanut than in mungbean. The growth of tap root between flowering and final harvest was 7.3cm in mungbean and 7.8cm in peanut. There was no significant effect of soil structure on root length.

Total dry matter

Significant crop and treatment main effects existed for total dry matter at both flowering and maturity however, there was no significant ($p>0.05$) crop by treatment interaction effect. While total dry matter in peanut was only slightly higher than mungbean at flowering (2.94 vs 2.56g), at final harvest peanut had considerably greater total dry matter than mungbean (11.24 vs 6.05g).

At flowering stage, the total dry matter was greatly reduced from All at 4.27g to 2.03g for All-ST and 1.47g for All-CF, while the nil treatment produced the lowest total dry matter at 0.95g. At flowering, All-L treatment was not significantly different from All or All+Whole mixing.

At final harvest the nil treatment produced the lowest total dry matter (3.78g), while All-CF treatment also produced low total dry matter (5.78g) compared with other treatments. All-DS produced the highest total dry matter at 12.21g but this was not significantly different to All-OM (11.37g) or the All (10.39g) and All+ Whole mixing treatments. By final harvest both the All-ST and All-L produced significantly lower total plant dry weight compared to the All treatments.

Table 2: Mean root dry weight (g/plant) of mungbean and peanut at flowering and final harvest for eight treatments (All+Whole mixing, and All are standards; All-disturbed soil (All-DS); All-organic matter (All-OM); All-rice straw (All-ST); All-lime (All-L) and All-chemical fertiliser (All-CF).

Treatment	Flowering			Final harvest		
	Mungbean	Peanut	Mean	Mungbean	Peanut	Mean
All+ Whole mixing	0.15	0.15	0.15	0.28	0.61	0.45
All	0.13	0.21	0.17	0.24	0.64	0.44
All – DS	0.12	0.16	0.14	0.48	0.61	0.55
All – OM	0.13	0.15	0.14	0.31	0.66	0.49
All – ST	0.06	0.13	0.10	0.16	0.53	0.35
All – L	0.12	0.20	0.16	0.15	0.56	0.36
All – CF	0.09	0.22	0.16	0.20	0.36	0.28
Nil	0.06	0.20	0.13	0.16	0.39	0.28
Mean	0.11	0.18		0.25	0.55	
LSD(5%)						
Crop	0.023**			0.068**		
Treat	Ns			0.023**		
Crop x Treat	0.065*			ns		

Conclusion

Crop diversification following wet season rice is one avenue of increasing agricultural productivity in Cambodia. Lowland rice soils have numerous physical and chemical constraints to non-rice crop production. The results of this omission pot trial showed that omission of rice straw mulch and chemical fertilizer had the largest effect followed by omission of organic matter application for growth. While the importance of Lime was not evident at flowering by the final harvest total dry matter was significantly reduced with the Lime omission treatment.

The positive effect of the inclusion of chemical fertiliser is to be expected given the inherent low fertility of the Prateah Lang soil type. This suggests that farmers could increase productivity by the addition of chemical fertiliser to improve productivity. However, the adoption of chemical fertiliser may be more difficult due to accessibility and cost. Rice straw however, which is an available resource, can help maintain biomass. While omission of either lime and or disturbed soil structure reduced growth, the effect was small and not significant. The treatment effects were generally larger in mungbean than in peanut indicating the sensitivity of mungbean but the interaction effect was often not significant. Our preliminary study indicated that the All soil amendments of cow manure, chemical fertilizer, lime, rice straw mulching, and sieved soil had potential for providing an adequate supply of nutrients for mungbean and peanut growth. However, there was no apparent advantage of disturbed soil for final total dry matter, root dry weight or root length. The results suggest that without lime both root dry weight and total dry weight is reduced at final harvest suggesting pH may be a concern at the latter stages of crop growth of mungbean and peanut, while this was not evident at flowering. The cow manure application tended to reduce the total plant dry weight.

Table 3: Mean root length (cm) and total dry matter (g/plant) for mungbean and peanut at flowering and final harvest for eight treatments (All+Whole mixing, and All are standards; All-disturbed soil (All-DS); All-organic matter (All-OM); All-rice straw (All-ST); All-lime (All-L) and All-chemical fertiliser (All-CF).

Treatment	Root length (cm)		Total Dry Matter (g/plant)	
	Flowering	Final harvest	Flowering	Final harvest
All+Whole mixing	6.21	14.73	4.02a	10.34a
All	6.85	16.53	4.27a	10.39a
All – DS	7.03	15.33	3.11b	12.21a
All – OM	6.76	13.08	2.65bc	11.37a
All – ST	6.15	13.75	2.03c	8.37b
All – L	6.63	9.63	3.54ab	7.48bc
All – CF	6.16	13.95	1.47cd	5.22cd
Nil	4.43	13.61	0.95d	3.78d
Crop				
Mungbean	5.01	12.31	2.56	6.05
Peanut	7.54	15.34	2.94	11.24
LSD(5%)				
Crop	1.07**	2.38*	0.41*	1.32**
Treat	ns	Ns	0.83**	2.65**
Crop x Treat	ns	Ns	Ns	Ns

Reference

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11.4 Development of sustainable legume production in rice-based farming systems in Cambodia

Development of sustainable legume production in rice-based farming systems in Cambodia

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Abstract

Lowland rice production is the dominant agricultural enterprise in Cambodia, traditionally grown as a single crop over the wet season, with land remaining fallow over the dry season. Development of a farming system where legumes are produced in the dry season following wet season rice, poses numerous constraints. These include: poor soil quality characteristic of lowland rice soils, provision and maintenance of adequate soil moisture over the dry season, and management of a novel crop for traditional rice farmers. A series of experiments were conducted from 2007 to 2010 to evaluate a number of production variables on two legume crops, mungbean and peanut, sown post-wet season rice. In lighter soils where legumes appear suitable for growth, soil-stored water from the wet season is not sufficient to grow legume crops, and supplementary irrigation water is required. Comparison between three bed configurations using gravity fed irrigation, and the traditional watering can method, found that flood irrigation on flat beds could improve yields, and farmers preferred this method over the labour intensive hand-watering method, although water use increased. Use of rice straw as mulch reduced weed growth and promoted legume growth, and increased water use efficiency. Future work will need to determine the most efficient bed configuration to facilitate irrigation and to optimise plant population, and to evaluate specific irrigation scheduling on the amount and timing of water required, in different soil types for more sustainable rice based dry season legume farming systems.

Key Words: mungbean, mulch, lowland, double cropping

Introduction

Rice is, and will remain, the most important crop in terms of area in many Asian countries including Cambodia. Over 90 % of rice in Cambodia is produced in the lowlands (under paddy conditions with bunds to store free water) and over 80% of this is grown under rainfed conditions in the wet season. Increasingly, as farmers meet their subsistence rice requirements, they explore new avenues to increase family/ farm income, including intensification, sometimes with supplementary irrigation, and diversification with higher value crops. The use of a short season early maturing rice variety before the main wet season rice crop is a major innovation that has made double rice cropping possible in Cambodia (Mak 2001). Many farmers now grow two crops of rice and are increasing family income by 37 and 25% in two provinces studied recently (Chea et al. 2004). However, there is little diversification to other crops even though the duration of the wet season in Cambodia provides more opportunity than in neighbouring Laos or NE Thailand to develop multiple cropping in lowlands. One of the priority issues for agricultural development is diversification of rice-based systems to increase farmer income. Short season legumes may be suitable to grow after rice. We have conducted a number of experiments over the last 3 years to determine suitability of growing a legume crop after rice harvesting in lowlands, and identified that coarse-textured soils are more suitable than heavy soils, and also peanuts and mungbean are more suitable than soybean (Seng et al. 2008).

In other areas of south-East Asia, conservation agriculture practices are utilized for double cropping in rice based lowland systems (Kirchhof et al. 2000). In some cases planting machines are used to save labour, and crop residues in the field are utilized to conserve soil moisture, prevent weed growth and reduce soil erosion. Results of a set of experiments are shown in this paper as an example of our efforts to improve legume yield after rice harvesting in Cambodia. This set of experiments conducted at 4 locations in 2008/09 dry season examined the effect of mulching (use of rice straw), planting method (manual vs seed drill) and tillage method (conventional vs no-tillage) on mungbean growth and yield. Another set of experiments (not reported here) were conducted including those to determine the amount and frequency of irrigation water requirement, fertilizer requirement, bed-configuration and plant density, and adapted genotypes of mungbean, peanuts and soybean. Results of these experiments and on-farm demonstration activities were used to analyze the profitability of growing legume after rice in lowlands.

Methods

The mungbean experiments were conducted after rice harvesting, from December 2008 to April 2009 under rain-fed lowland conditions at four locations (Takeo, Kampong Cham, Kampong Thom and Preah Vihear provinces). The experiments were carried out to test two tillage treatments under two planting methods with or without mulch with three replications. A split-split plot design was used in the trials; the tillage treatment was assigned as the main plot, planting method was sub plot and mulching was sub-sub plot. Plot size was 12 m2 and the total plot number was 24, total experimental area being approximate 690m2.

The tillage practices evaluated were no-tillage and conventional tillage. The no-tillage plots were not ploughed and glyphosate at rate of 2.5 L ha-1 applied 10 days before planting. The conventional tillage plots were ploughed two times by using tractor with seven disc plough, the depth ranging from 15 to 20 cm, with the first plough immediately after rice harvesting and second plough one day before the planting.

Planting method treatments were manual and seeding machine methods. In both methods row spacing was 40 cm, and the seed rate was 20 kg ha-1 with expected established plant density of approximately 200,000 plants ha-1. In the manual method, 3 cm deep holes were made with a stick at 30 cm intervals and seed was placed in the hole. The hole was then pressed by foot. The planting machine was adjusted to make similar plant spacing of 30 cm and press wheel was attached to improve soil-seed contact.

In the mulch treatment, rice straws were collected from nearby paddy fields and applied at the rate of 1500 kg ha-1. Nutrient composition of the mulch was not determined.

Weeds were controlled mainly by hand-weeding at 20 days and subsequently at 45 days after crop emergence. The fertilizer applied rate was 90-26-25 kg/ha (NPK) (Urea-124kg/ha, DAP- 95kg/ha and KCl- 37 kg/ha).

Soil moisture content was determined at planting and post harvest. The percentage of residue cover after seedbed preparation was visually estimated. Plants emergence was counted at 15 days after crop emergence. Grain was harvested three times due to the indeterminate maturity of the mungbean crop. At the final harvest weeds were also collected and dry weight determined. Rainfall, soil temperature and atmospheric humidity were measured at each location.

Statistical analysis was conducted using IRRISTAT 5.0 for each location and for all locations combined, to determine significance of main treatment effects and their interaction effects.

Results

On average, mulching of rice straw at 1.5 t/ha increased crop establishment from 72 to 83%, reduced weed biomass at harvest from 163 to 123 kg/ha and increased mungbean yield from 228 to 332 kg/ha (Table 1). These effects were generally consistent across the four locations, although there was significant location by mulch interaction effect on yield and weed biomass. The effect of mulch on grain yield was significant at p=0.05 at 3 of the 4 locations, with only a small mulch effect at Takeo resulting in significant interaction effect. Mulch was effective in conserving soil moisture, and even at maturity the mulched area had 1 % higher soil moisture content. On the other hand, planting method and tillage method appeared to have had little effect. The fact that the seed drill produced very similar establishment, weed biomass and grain yield to the hand planting is encouraging in that the use of a planter can save the labour cost. Only in one location did no-till produced higher yield.

Table1. Effects of mulching at different locations on mungbean seedling emergence, weed biomass and mungbean grain yield in lowlands after rice in Cambodia

Location	Emergence (%)		Weed biomass (kg/ha)		Grain yield (kg/ha)	
	Mulching	No-mulch	Mulching	No-mulch	Mulching	No-mulch
Takeo	83.5	73.9	115	232	459	421
Kampong Cham	84.3	70.7	318	370	302	168
Kampong Thom	83.2	72.6	21	40	360	203
Preah Vihea	81.1	71.5	37	11	209	117
Mean	83.0	72.2	123	163	332	228
LSD at 5% (interaction)	ns		17**		57*	

For the irrigation water requirement, a series of experiments were conducted to determine optimum irrigation frequency and amount of water required for mungbean and peanuts in two dry seasons. The mungbean results from one experiment indicate that irrigation is required every 3 days or so when watering can is used. In one of the experiments, water use efficiency of mungbean was found to be around 1.9-2.4 kg/ha/mm which is at the lower end of WUE commonly found in Australia. The common practice of hand watering was found to be labour intensive, often resulting in under-watering for mungbean and peanuts, and we have successfully developed furrow and flood irrigation methods in 2009/10DS. One of the key findings was that legume roots are shallow in lowlands, and water extraction was limited to the top 20 cm or so depending on the depth of hard pan. With the rather coarse textured nature of the lowland soil used in growing legumes, accessible stored water is limited, and thus the legume crops need to be irrigated frequently.

Conclusion

During the course of research, we have realized the importance of water availability on legume growth in lowlands. While the soil water stored at the end of the rice cycle may be available to the non-rice crops, the amount is generally small because of the limited soil depth that the legume crops can explore. Thus, it is essential that the farms have access to a supplementary irrigation source. We have found that the use of tube wells and on-farm storage ponds can provide sufficient supplementary irrigation to grow legumes successfully.

From the results of experiments and economic analyses, we developed the best bet technologies for growing mungbean and peanuts. The documents describing them were distributed and discussed with Provincial Department of Agriculture officers in two provinces. In 2009/10 dry season, these PDA established 20 demonstration farms where mungbean, peanuts as well as tomatoes were grown as per our best bet technologies. Some farmers produced very good crops of mungbean and peanuts, and farmers who attended one of the field days we conducted recently, were interested in growing these crops in the near future. A large proportion of farmers who were formally interviewed indicated that growing mungbean and peanuts were less risky than vegetable crops, because of large price fluctuation in the latter.

There are however, a few key areas where research is required to improve the profitability of growing legume after rice in lowlands. Important areas are development of no-tillage system and sound fertilizer management system.

Use of furrow/bed system is essential particularly for mungbean in some areas where ponding of water causes a major adverse effect on crop growth. This system has improved crop establishment and facilitated development of a furrow irrigation system. There are prototypes of a bedmaker available that will produce furrows/beds, and this will greatly improve labour productivity. The use of such implement needs to be tested with farmers for possible further improvement and assessing the likelihood of adoption of the furrow/bedmaker. This system needs to be compared with the no-till flood irrigation systems where operational costs will be small but requires careful management of the land from the rice cropping phase.

We have also noted that particularly ICRISAT peanut lines produced a large number of pods but some were empty and often the kernels were small. This is likely to be associated with Ca deficiency, but we would need to test this in the field. Similarly when water is fully provided in the pot experiment, chemical fertilizer application increased legume growth greatly (Cheth et al 2010). The effect of chemical fertilizer including Ca and lime on growth of mungbean and peanuts needs to be tested in the field.

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11.5 Improving profitability with variety improvement and the use of supplementary irrigation in Cambodia

Abstract

In Cambodia, rice is grown mostly in rainfed lowland where drought, low soil fertility and low inputs cause low productivity. The rice breeding program at CARDI since 2000, and CIAP (the Cambodia, IRRI Australia project) prior to the year has contributed to improve livelihood of many people in the country through improvement of rice varieties. The rice area covered by released varieties was estimated through a large survey with result of 17% in 2003, and the area increased each year to 59% in 2008. Released varieties are higher yielding than traditional varieties, and the increased productivity due to released varieties is estimated to be 467,000 tons with the monetary value of 89 million dollars in 2008.

As drought is a major problem in rainfed lowland rice, we have quantified the pattern of drought development in rainfed lowlands with the measurements of free water level throughout rice growth. Drought screening protocol has been developed, including field screening in wet season and use of drought response index as selection criterion to adjust for genotypic variation in maturity and potential yield. This has contributed to increased drought tolerance of many advanced lines in the breeding program. Beside drought, the rice improvement program is also working for submergence tolerance and high grain quality.

There is a good scope for intensification and diversification of rainfed lowlands for further improvement in crop values and family income, particularly where supplementary irrigation water is available. Peanuts are found to be adapted to lowland rice soils and can be grown successfully after rice harvesting.

Introduction

In Cambodia, rainfed lowland rice covers more than 80% of the total rice growing areas. The rainfed lowlands are bunded fields that are almost completely dependent on local rainfall and runoff for water supply (Ouk et al., 1995). Since the quantity and duration of rainfall are variable, floodwater depth and duration likewise vary. Floodwater depth can range from zero (0) to 50 cm from upper to lower field topography, and a floodwater depth of 30-50 cm or more may be experienced for a month. In this rice ecosystem, farmers have cultivated thousands of varieties for hundreds of years. However, these traditional varieties are low yield potential with an average yield of less than 1.35 t/ha prior to early 1990’s.

As dependent on rainfall, about 19% of rainfed lowlands in Cambodia is drought prone and 57% is drought and submergence prone (After Rice Almanac, 2002). The intensity of drought and flood varies from year to year and can completely damage 19% of the total rainfed lowland rice and reduce national yield by up to 250 kg/ha (MAFF, 2003&2005). Traditionally rainfed lowland rice farmers cultivate rice once a year. To secure food while demand is growing, a double cropping system must be introduced.

This paper briefly describes the research activities on rice improvement and supplement water use that benefit to Cambodian farmers in rainfed lowlands.

Rice variety improvement

The rice variety improvement program in Cambodia began in 1989 by the Plant Breeding team of the Cambodia-IRRI-Australia Project and the Cambodian Agricultural Research and Development Institute (CARDI, since 1999). The program has three phases and they are (i) improvement for high yielding, 1989-1994; (ii) improvement for high grain quality, 1995-2002; and (iii) improvement of popular released varieties for abiotic and biotic stresses, since 2003. The program focuses on (i) germplasm collection, evaluation and utilization, (ii) varietal development, (iii) varietal testing, and (iv) seed production of the released varieties.

A total of 38 rice varieties have been released through farmers participation; among those, nine varieties are early maturing and insensitive to photoperiod suitable for dry season, early wet season and upper field of rainfed lowlands (one is aromatic, three are moderately resistant to brown plant hopper and stripe stem borer); 16 intermediate maturing varieties (five are aromatic with sensitive to photoperiod and tolerant to submergence, five are insensitive to photoperiod, and six are sensitive to photoperiod with one is moderately tolerance to drought) are suited for medium field of rainfed lowlands; eight varieties are late maturing with sensitive to photoperiod (one is moderately drought tolerance, two are submergence tolerance); three for deepwater ecosystem and two for rainfed uplands (Ouk Makara, 2010).

Results obtained from on-farm adaptive trials with farmer's management conducted at more than 300 sites for each variety on average indicate all released varieties yielded 2-26% higher than the farmer's popular varieties with an average of 10%. A large interview with approximate 4,000 farmers every year was conducted in 14 provinces to investigate adoption of released rice varieties by farmers from 2003 to 2008. The rice area covered by released varieties significantly increased from 17% in 2003 to 59% in 2008 with the increased rate of about 8% per year. With this result, the increased productivity was estimated to be 467,000 tons with the monetary value of 89 million dollars in 2008.

Field Screening for drought tolerance in rice

A numerous experiments have been conducted from 1998 to 2002 to identify appropriate field screening protocol for drought, the pattern of drought development in rainfed lowlands with the measurements of free water level throughout rice growth, and putative traits related to drought tolerance.

Field screening for drought in rainfed lowlands consists of two water treatments, well-watered and water stress, located in neighboring fields separated by a bund. The well-watered field relies on rainfall and supplementary irrigation to provide adequate water throughout while the water stress field is drained from a desired date to simulate drought. In the water stress treatment, a 10 cm deep canal is dug throughout the fields to channel water into a hole, 50 cm deep, dug in the corner of the field. The water that accumulated in the hole is pumped out to keep the field free of standing water during the drained period (see more detail in Ouk Makara, 2003). This method allows severe drought (yield loss>40%) to develop even under rainfed conditions (Ouk Makara et al., 2006).

Establishment of drought conditions by draining the rainfed lowland paddies appears to be more effective for plant breeders to select for drought tolerant genotypes directly in the conditions when considering free water level around flowering stage (three weeks before and after flowering) as the yield reduction can be explained reasonably well by the water level during flowering time (Ouk Makara et al., 2004). The rate of yield reduction to free water level determined in this study (–1.68 % cm-1) explains the maximum level of yield reduction in relation to the water level under rainfed conditions and can be observed at farmer's level. So, potential yield estimated from water level and yield measured under rainfed conditions can assist in identifying drought tolerant genotypes.

While many putative and specific traits for drought tolerance such as osmotic regulation, root length, and root penetration have been suggested for selection for drought tolerance (Fukai and Cooper, 1995), a practical approach for selection of drought tolerance parent is to use a measure or an index of the relative yield of genotypes under stress to that under well-watered conditions as an integrative measure of the complex of traits that provide drought tolerance. For this purpose Bidinger et al. (1987a,b) developed a drought response index (DRI) using threshold values for the upper and lower 10% of the normal distribution (Z = +1.3 and –1.3) to identify drought tolerant (DRI > 1.3) and susceptible (DRI < -1.3) genotypes, to identify genotypes that are tolerant or susceptible to drought and applied this to pearl millet [Pennisetum americanum (L.) Leeke]. The DRI corrects grain yield under drought for variation in flowering date and potential yield under well-watered conditions, thus, assuring that genotypes selected will have drought tolerance traits.

Advancing method for DRI from computing the DRI from the mean GY of the genotype across replicates in the drought trial and the mean GY and days to flower (DTF) of the genotype in the well-watered trial (Bidinger et al., 1987b) to computing the DRI for individual replicates in the water stress treatment has enabled the DRI to be more fully analysed by ANOVA to study the consistency of the DRI values in different environments (Ouk Makara et al., 2006). With this advanced computed method, the plant breeding program of Cambodia was able to select some of genotypes with high DRI and high grain yield performed consistently across the range of water environments and using them as parents in rice breeding for drought tolerance in rainfed lowlands.

Rice breeding for submergence tolerant

Getting benefit from IRRI Sub1 work, breeding for submergence tolerant rice in rainfed lowlands has been enhanced by introgressing available Sub1 gene in to popular released rice varieties using backcross approach. Some progenies are promising and will be tested in target field environments soon.

Intensification and diversification in rainfed lowlands

In Rainfed lowlands, rice has been cultivated as monocrop and once in a whole year. With the availability of early maturing and insensitive to photoperiod rice varieties and introduced tube well and water catchment pond for supplementary irrigation, a system of early wet season and main wet season rice (Chea et al., 2001) has been adopted to more than 91,000 ha (3.3% of the total rice growing area) in 2009 (MAFF, 2009).

Regarding to diversify crops in rainfed lowlands, many studies have been conducted since 2000. Results obtained so far indicate that with supplementary irrigation a system of rice-legume appears better than a system of legume-rice (Ouk Makara et al., 2007). Sandy soils are more suitable than clay soils and peanut is more productive than mungbean and soybean. However, due to longer growing period and larger amount of irrigation water, peanut shows less profit than the mungbean. Results obtained from on-farm demonstrations in last season indicate rice-mungbean system to be promising due to (i) early maturing (45-55 days) mungbean varieties, (ii) price of mungbean in harvested period is about 2 folds of those harvested earlier from uplands, (iii) bed configuration and (iv) time of planting and water management. To make this system adopted, we need to further demonstrate it in larger fields with larger number of farmers involved with further improved technology over the one available in the last season.

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11.6 CARDI and the Provincial Department of Agriculture Conducted a Farmer Field Day in Takeo Province

CARDI and the Provincial Department of Agriculture Conducted a Farmer Field Day in Takeo Province

Angkor Borei District: The Cambodian Agricultural Research and Development Institute (CARDI), in cooperation with the Provincial Department of Agriculture (PDA), Takeo Province, recently conducted a farmer field day about crop diversification on rice-based systems in the lowland. The field day ceremony was celebrated in Sromok Village, Ponley Commune, Angkor Borei District, with 100 participants attending. The farmers and guests were very interested in improved technologies for mungbean and peanut production after wet-season rice harvest, and development of the model farm that uses supplementary irrigation for various farm activities. In this ceremony, Dr. Seng Vang, Deputy Director of CARDI, on behalf of Dr. Ouk Makara, Director of CARDI, thanked the PDA for their cooperation, research and involvement with the farmers, and commended the actions in following the strategy of Ministry of Agriculture, Forestry and Fisheries (MAFF) and the Royal Government of Cambodia for poverty reduction. Dr. Seng Vang pointed out a number of points related to seed selection, water requirement, nutrient

management, evaluation of planting technologies, including raised bed techniques and planting time, irrigation technique, land preparation methods, and the model farm. He further pointed out that the model farming system has provided benefit to the farmer through the increase of income, improvement in soil fertility, and increased daily food consumption. Diversification of farming enterprises also helps farmers to manage against the risk of climate change.

The farmer who has been involved in the development of the model farm says that with the implementation of CARDI model farming, after one year, he still has 500 kg of rice remaining, compared to having no extra rice before adopting the CARDI model farm system. He also has extra fish meat and vegetable, and also improved ability for animal raising such as poultry. Dr. Seng Vang also reminded the audience that the achievements of CARDI we had seen in the field have come from the supports of MAFF and the Royal Government of Cambodia, with financial support from the Australian Centre for International Agricultural Research (ACIAR) through a project on Intensification and Diversification of Lowland Rice Cropping System in Cambodia (CSE/2006/040).

Translated by Rowena Eastick and Vuthea from article published in Raksmey Campuchea Newspaper, 19th March 2010. Edited by Seng Vang. A Khmer TV station also covered the field day.

11.7 Economics of growing mungbean after rice in the rainfed lowlands of Cambodia

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Keywords: post-rice crops, supplementary irrigation, returns to labour

Introduction

About 84% of the rice area in Cambodia is classed as rainfed lowlands, supporting a single rice crop annually (Ouk et al. 2001). A wet-dry climate (with erratic rainfall in the wet season), low soil fertility, and insect pests limit rice production to subsistence levels, with a high risk of falling below subsistence in unfavourable seasons. Some farmers have incorporated a second rice crop in the early wet season, which can increase farm incomes by 25-40%, given access to water for supplementary irrigation (Chea et al. 2004). To further increase production in these conditions, an ACIAR project has introduced several non-rice crops following the main rice harvest, using different methods of supplementary irrigation – manual (with a bucket), pumping, and gravity-fed (from a dam). Mungbean was considered to have potential for efficient water use and high returns. This paper reports an economic analysis of mungbean cultivation based on field experiments.

Materials and Methods

The analysis was based on data from two experiments in 2009-10 and 2010-11 where mungbean response to type and level of irrigation was tested on paddy fields with typically sandy soils of low fertility at CARDI near Phnom Penh (Eastick et al. 2010). Mungbean was cultivated under flatbed conditions from January to April, following a single wet season rice crop. Residual soil moisture was available for establishment, but supplementary irrigation was required. The main economic measure used was the net cash return per unit of family labour (NCRL). Rainfed paddy fields have little alternative use in the dry season and labour is also under-employed. The mungbean crop requires an outlay of cash for inputs and the expenditure of family labour. The farmer would not be concerned with the return to land but would be hoping for a positive NCRL that is higher than any alternative activity. NCRL was calculated by subtracting cash expenses from gross income and dividing by the number of days of family labour. Gross income was calculated by multiplying measured yield by the current farm-gate price. Cash expenses were based on current prices for seed, fertilizers, and fuel. Family labour was estimated for land preparation, planting, fertilising, applying cow manure, weeding, harvesting, and irrigating. Labour estimates were based on group interviews with farmers at field days, not the labour used in the experiment. NCRL was estimated for two irrigation levels and the three irrigation methods. The experiments used a wide range of irrigation levels and identified between 0.9 and 1.3 ML/ha as agronomically viable, corresponding to yields of

477 kg/ha and 689 kg/ha, respectively. These two levels were used in the analysis. For manual irrigation, the main input was labour, measured as days/ha. In the experiments, labourers were paid a daily wage to water the crop with a 12 L bucket. One labourer carried up to 96 buckets per 5-h day (1,152 L or 0.11 mm). For farm conditions, a 24 L container was assumed and a 7-h day, making 192 buckets (4,608 L or 0.46 mm) per day. For the pumping method, the main cost was the outlay for fuel. Pump capacity was estimated to be 1.5 h/L of fuel. For gravity-fed irrigation, labour was required to control the inflow of water.

Results

Table 1 shows the cash expenses and labour inputs assumed in the economic analysis. These are expressed on a per-ha basis though in practice labour and water constraints limit cultivation to around 0.2 ha. The cash expenses for seed and fertiliser were based on experimental rates and market prices (though fertiliser prices have fluctuated widely). Fuel was costed at USD 1.00/L. Pumping needed 50 and 72 h for the two irrigation levels, costing around USD 33 and 48 in fuel. The labour inputs varied with irrigation method and level. The labour input for land preparation only includes human labour; the opportunity cost of using family-owned draught animals is difficult to estimate but can be assumed to be negligible in the dry season. Likewise, the opportunity cost of cow manure was assumed to be negligible as it is not commonly traded, so only the labour required to cart the manure from the farm-yard to the field was included. Three rounds of hand-weeding were undertaken. With manual irrigation, the lower level of irrigation required around 37,500 buckets or 195 days/ha and the higher level required 54,200 buckets or 282 days/ha. The labour for controlling gravity-fed irrigation varied with the level of irrigation. The labour for harvesting varied from 30 days/ha for the low-irrigation/low-yield scenario to 43 days/ha for the high-irrigation/high-yield scenario, based on 16 kg harvested per day. Table 2 shows the computation of NCRL. Given a farm-gate price of USD 1.50/kg of grain, gross income varied from USD 716/ha to USD 1,034/ha for the two irrigation levels. Subtracting cash expenses, net cash returns/ha were highest for manual irrigation at the higher irrigation level (USD 854/ha). However, the labour requirement was very high for this method, so when net returns/ha were divided by labour input/ha, the net returns per day (NCRL) favoured the pumping and gravity systems, which returned between USD 3.70/day and USD 5.40/day for the two irrigation levels, more than twice the NCRL for manual irrigation and well above the rural wage of USD 2.00/day.

Discussion

Mungbean production appears a profitable use of family-owned resources of land and labour that are otherwise underutilised during the dry season. This depends on access to supplementary irrigation at between 0.9 and 1.3 ML/ha and a cost-effective method of irrigation. Hand watering is not attractive but pump and gravity irrigation are promising. Rural electrification would substantially reduce the costs of pumping. The upper yield obtained in the experiments is higher than the yield of around 610 kg/ha obtained in upland areas in the wet season, which is widely recognised as the most favourable environment for legume crops (Chea et al, 2009). This could be due to the rates of fertiliser used in the experiments as well as higher insolation. Actual yields on lowland farms in the dry season are lower than the experimental yields; access to working capital for fertiliser could be the limiting factor. However, the market price for mungbean grown after rice in the lowlands reflects that this is the off-season for upland production. Hence the price is relatively favourable and appears to be trending upwards. At USD 2/kg the NCRL at the high level of irrigation would increase to USD 2.8/day for manual irrigation and USD 7-8/day for the other two methods. Labour input per ha is high, but with only a portion of the rice-field cultivated, the total labour requirement would be feasible, while the addition to family income would be attractive. As farm activities are limited in the dry season, this provides an opportunity to utilise family labour on-farm rather than migrate in search of employment.

Conclusion

There is reasonable economic potential for mungbean cultivation following rice in the rainfed lowlands of Cambodia, giving a positive return to otherwise underemployed family resources of land and labour. Supplementary irrigation of around 1 ML/ha is needed to ensure yields of about 0.5-0.7 t/ha. Manual irrigation gives low returns to labour but pumping or gravity methods give a reasonable return, more than double the rural wage. Returns may improve with increasing demand for mungbean, improved access to fertiliser and credit, and reduced costs of pumping due to electrification.

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Table 1 Gross income, expenses and labour inputs for mungbean cultivation in rainfed lowland paddy field

Item	Unit	Quantity	Unit price (USD)	Total (USD/ha)
Output/income				
1.3 ML	kg/ha	689	1.50	1,034
0.9 ML	kg/ha	477	1.50	706
Cash expenditure				
Seed	kg/ha	20	1.50	30
DAP	kg/ha	195	0.54	105
KCl	kg/ha	50	0.88	44
Fuel for pumping				
1.3 ML	litre/ha	48	1.0	48
0.9 ML	litre/ha	33	1.0	33
Family labour				
Ploughing (2 times)	labour-	12	2.0	24
Harrowing	labour-	2	2.0	4
Planting	labour-	42	2.0	84
Manuring	labour-	5	2.0	10
Weeding	labour-	45	2.0	90
Manual irrigation				
1.3 ML	labour-	282	2.0	564
0.9 ML	labour-	195	2.0	390
Gravity irrigation (G):				
1.3 ML	labour-	7	2.0	14
0.9 ML	labour-	4	2.0	8
Harvesting:				
1.3 ML	labour-	43	2.0	86
0.9 ML	labour-	30	2.0	60

Table 2: Returns to mungbean production by irrigation level and method

Irrigation level (ML/ha)	Gross income (USD/ha)	Cash costs (USD/ha)		Net cash returns (USD/ha)		Labour input (days/ha)			Net cash return to labour (NCRL) (USD/day)		
		M/G	P	M/G	P	M	P	G	M	P	G
1.3	1,034	179	227	854	806	431	149	159	2.0	5.4	5.4
0.9	716	179	213	536	503	331	136	141	1.6	3.7	3.8

M = manual irrigation; P = pump irrigation; G = gravity-fed irrigation.

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Effects of straw mulch on mungbean yield in rice fields with strongly compacted soils

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Abstract

In rice-based lowland areas in the Mekong region, the lack of full irrigation water availability for post-rice legume crops and the poor soil physical and chemical conditions are major constraints for development of sound rice/legume double cropping system. In order to improve legume productivity, use of rice straw mulch and various crop establishment methods were examined in two series of mungbean experiments in Cambodia where soils were coarse and strongly compacted. In one set of experiments conducted at four locations in the first year the effect of straw mulch, planting method (manual vs seed drill) and tillage method (conventional vs no-till) were examined. Another set of experiments were conducted in the second year at three locations with four levels of mulch under two planting densities. On average in year 1, mulching of rice straw at 1.5 t/ha increased mungbean crop establishment from 72 to 83%, reduced weed biomass from 164 to 123 kg/ ha and increased yield from 228 to 332 kg/ ha. Mulch was effective in conserving soil moisture, and even at maturity the mulched area had on average 1 % higher soil moisture content. The amount of mulch between 1 and 2 t/ha did not show consistent effects in year 2, partly because some mulch treatments resulted in excessive soil moisture content and were not effective. Rice straw mulch had a significant effect on mungbean yield in 6 out of the 7 experiments conducted in two years, and mean yield increase was 35%. This yield advantage was attributed to better crop establishment, improved growth and reduced weed pressure, but in some cases only one or two of these factors were effective. On the other hand, planting method, tillage method and planting density had only small effects on mungbean yield in most experiments. Only in one location out of four tested, the no-till treatment produced significantly higher yield than the conventional method. Seed drill produced similar mungbean establishment and grain yield to the manual planting suggesting that the planter can be used to save the labour cost which is increasing rapidly in the Mekong region. Maximum root depth varied little with mulch or planting density, and was shallow (< 20 cm) in all three locations where this character was determined. It is concluded that while rice straw mulch increased yield of mungbean following rice, the inability of mungbean roots to penetrate the hard pan is a major constraint for development of a sound rice/mungbean cropping system in the lowlands with compacted soils.

Key words; lowland rice field, mungbean, straw mulch, crop establishment, weed biomass.

1.0 Introduction

Rice is the main crop for many lowland farmers in Southeast Asia. In most areas rice has been grown as monoculture for a long time. However, crop diversification is required to increase crop productivity and income for mostly subsistence farmers in the region. The rice-wheat cropping system is well established in the sub-continent, where temperature and water availability are suitable for this cropping system. In heavy soils in Indonesia and the Philippines, water holding capacity is high, and legume crops can grow well after rice harvesting using residual soil water. Crop diversification may not be easy to achieve in the Mekong region including Northeast Thailand, Laos and Cambodia where availability of irrigation water is limited and soils tend to be sandier with low water holding capacity and low nutrient availability (Pheav et al., 1996; White et al., 1997; Seng et al., 2001, 2008). The puddled lowland soils also tend to be high in soil strength with a relatively shallow hardpan which would affect growth of post-rice crops (Fyfield et al., 1990; So and Ringrose-Voase 2000).

Legume crops can be useful addition in rice-based rainfed lowland cropping systems with their ability to provide fixed N. Green manure crops such as Sesbania rostrata can contribute to improved N availability to the following rice crop in sandy soils of the Mekong region (Herrera et al., 1997). Groundnut residues of 5 t/ha increased rice N uptake from 39 to 51 kg/ha and rice grain yield from 2.8 to 3.1 t/ha in Kalasin province in NE Thailand (Kaewpradit et al., 2009). In another study in NE Thailand, Toomsan et al., (1995) found that when stover was returned to the field, N2-fixation of groundnut contributed 13-100 kgN/ha to the subsequent rice crop and there was a 12-26% increase in rice yield. However, this was not the case with soybean which had high harvest index, and most fixed N was removed with harvesting of the grain. Mungbean is often considered to be suitable as a post-rice crop in the lowlands, mainly because of its short crop duration which fits well in the cropping system where irrigation water is limited or temperature becomes very high in late dry season. Previous attempts to develop rice/mungbean double cropping in Cambodia have had limited success as often mungbean establishment was poor and consequently poor crop growth and low yield (Chan et al., et al.,2004, Ouk et al., 2007). In areas where water availability is limited and soil temperature is high, straw mulch may assist mungbean growth and yield, as found in India (Chaudhary et al., 1985). Verma and Kohnke (1951) have shown the potential beneficial effects of rice straw mulch to reduce soil temperature, soil surface crusting and evaporation of moisture. Van Den Berg and Lestari (2001) studying the improvement of local cultivation of soybean with 86 famers in Indonesia, found that the use of rice straw, spread over plots to a depth of 4-10cm, increased soybean yields across sites by 41%. They concluded that the beneficial effect of rice straw mulch depended on the degree of moisture stress and the physical properties of the soil. In sandy textured lowland soils in the Mekong region, rice straw mulch with legume residue may also help N availability during subsequent rice growth, as was found in rice-groundnut rotation system in NE Thailand (Kaewpradit et al., 2009). Rice straw mulch may tie up soil N and promote N fixation by the legume crop. Thus, rice straw mulch on non-rice crop in lowlands improves water, soil and temperature environments which results in (i) increased establishment (ii) improved growth of non-rice crops, and (iii) reduced weed growth directly or indirectly through improved crop growth, and these all contribute to increased crop yield. In addition to the positive effect of mulch on the crop, this practice of using crop residues as mulch contributed towards maintenance of soil fertility over a long period of time (Martin and Belfield, 2007).

Ploughing soils before planting is a common practice in the lowlands in the region, but this promotes soil evaporation and soil stored water is reduced. Another method of conserving soil water is the use of no-till cropping. The potential use of no-till establishment was examined in the present work, together with the use of seed drill. Increasing labour cost in the region has meant that any labour saving method is worth consideration.

The objective of the study reported here is to examine the effect of the use of rice straw mulch and various crop establishment methods on growth of mungbean crops planted after harvesting rice in lowlands in the Mekong region where hard pan development is common and can cause constraints to post-rice crops. Of particular interest is to attribute the magnitude of yield increase as a result of mulch application to improved crop establishment, better growth and better control of weeds.

2.0 Materials and Methods

Two mungbean experiments were conducted in lowland conditions after harvesting rice at the end of the wet season. The mungbean variety used was CARDI Chhey in all locations for the two years.

2.1 Effect of mulch, planting method and tillage method (Experiment 1).

Experiment 1was conducted from December 2008 to April 2009 at four locations (Takeo, Kampong Cham, Kampong Thom and Preah Vihear provinces) in Cambodia. The soil types of the experimental area were Bakan (Alfisol/Ultisol), Prateah Lang (Plinthustalfs), Prey Khmer (Psamments) and Prateah Lang soil types, respectively. The chemical/physical properties of these soils are well described in White et al., (1997) and Bell and Seng (2004). The Preah Vihear site was newly cleared while other locations had a long history of rice growing under lowland conditions. Each trial tested two tillage treatments under two planting methods with mulch and no mulch applications. A split-split plot design was used in the trials, the tillage treatment being assigned to the main plot, the planting method sub plot and the mulch application sub-sub plot. There were three replications and each plot size was 4 x 3m.

The tillage treatments consisted of no-till and conventional tillage. The no-till plots were not ploughed and rice stubble was retained. Glyphosate was applied at the rate of 2.5 L ha-1 at 6-14 days before planting. The conventional tillage plots were ploughed twice using a tractor with seven disc plough, the plough depth ranging from 15 to 20 cm. The first plough was immediately after harvesting rice and second plough one day before planting mungbean. The fertilizer rate was 90N- 60P2O5 -30K2O kg/ha (urea 124kg/ha, DAP 95kg/ha and KCl 37 kg/ha) for all trials (locations) and was applied during land preparation and as top dressing. High N fertilizer rate was used in the experiment to ensure N was not limiting mungbean growth as no healthy nodules were observed on mungbean in an earlier investigation conducted under similar conditions to the present work. Fertilizer was applied by spreading over the surface of no-tillage plots and incorporating it with the last plough in the conventional tillage plots. There were no furrows in this experiment, and the land level was kept flat throughout the experiment. To avoid development of plant water stress, irrigation water was applied by hand using buckets whenever soil surface became dry.

The planting methods tested were a) manual planting (dibbling) and b) seed drill (machine). In the manual planting, 3 cm deep holes were made using a dibbling stick and three seeds were placed in each hole and the soil was pressed firmly around the seed with the feet. The row spacing was 40 cm and hill spacing was 30 cm. Both manual and seed drill plantings used a seeding rate equivalent to 20 kg/ha. The seed drill was followed by press wheel.

In the mulch application treatment, rice straw was collected from nearby paddies, and applied at the time of mungbean planting at a rate of 1500 kg/ ha which created about 1cm thick mulch on the soil surface. Gravimetric soil moisture content (0-20cm) was determined at planting and post harvest in three replications. Rainfall, soil temperature and atmospheric humidity were determined daily. Percentage of crop establishment was measured from three 0.5×0.5 m areas per plot at 15-22 days after planting (DAP). Weeds were sampled from 6 random positions using a quadrat frame (0.5×0.5m) in each plot. Weed samples were taken on 15-22 DAP and again 43-48 DAP. Weeds were oven dried and dry weight determined and combined dry weight from the two sampling times was used to show the magnitude of weed infestation. Mungbean grain was harvested three times in each trial.

Statistical analysis was conducted using Genstat version 13. Single site (location) analysis was followed by combined analysis across locations, with treatment main effects and interaction effects determined.

2.2 Effect of mulch and planting density (Experiment 2).

Experiment 2 was conducted after harvesting rice from December 2009 to April 2010 at three locations (Takeo and Kampong Thom provinces and in Cambodian Agriculture and Research Development Institute (CARDI) in Phnom Penh). The two locations in Takeo and Kampong Thom were different from those used in year 1. The soil type was Prateah Lang at all the experimental sites. The Kampong Thom site was planted on 24 December 2009, followed by Takeo on 13 January 2010 and CARDI on 23 February 2010. Each experiment was carried out to test four mulching treatments under two plant densities with three replications. The four mulch treatments were the rice straw mulch application level of 0, 1.0, 1.5 and 2.0 tons/ ha. The two planting densities were plant spacing of 20 and 25 cm on 20 cm rows (250,000 and 200,000 hills/ ha). A split plot design was used in each experiment, the mulching treatments being assigned to the main plots and plant densities to sub plots. Plot size was 10 m2.

The experimental field was ploughed twice with 2 weeks between them, and harrowed by using power tiller. The depth of the plough ranged from 15-20 cm. One day before planting, the second ploughing was done, followed by bed making first by bed maker implement and then manually. Each plot consisted of one wide bed with six rows. The seed holes were made by stick and depth of seed placement was 3 cm. Three seeds were sown per hole. The fertilizer application rate was 90N-60 P2O5 -30 K2O kg/ha (Urea 124kg/ha, DAP 95 kg/ha and KCl 37kg/ha). Fertilizers were applied as basal prior to bed formation and top dressing 14-23 days after planting.

The experiment was irrigated regularly from two weeks after sowing to the first harvest, except in CARDI where the water was pumped to wet-up the soil before planting. The total number of irrigation application was 6, 3 and 10 for Kampong Thom, Takeo and CARDI. The amount of irrigation water was determined by multiplying calibrated flow rate of the pump and the time spent for irrigation at each time and the total amount varied between 54 and 119 mm. Water use efficiency was calculated by dividing grain yield by total water applied (irrigation plus rainfall). Irrigation water was applied through channels and furrows. Because of the use of wide rows, irrigation water did not penetrate into middle rows, and hence water level was raised to wet the central part of each plot. This caused inundation in some parts of the experiment.

Gravimetric soil moisture content was measured at 0-10cm, 11-20cm and 21-30cm depth at planting and post harvesting, by collecting 200 g soil samples randomly from 3 positions per replication following the method of Bell and Fisher (1993). Weed dry matter was determined as for Experiment 1. The temperature and humidity were monitored by using data-loggers at the Kampong Thom and Takeo locations. The statistical analysis was conducted as per Experiment 1

3.0 Results

3.1 Effect of mulch, planting method and tillage method (Experiment 1).

Soil water content at planting was higher under no-till than tillage treatment in all locations, although the difference was rather small in Kampong Cham (Table 1). However at maturity, there was no significant effect of tillage method. Mulch on the other hand produced higher soil water content (13.6 vs 12.4%) at maturity, and the effect was particularly large in Kampong Cham.

Among the three treatment factors, mulch had the largest and most consistent positive effect on crop establishment and yield. Mulch improved crop establishment by about 10% in all locations with mean of 72.2 and 83.1 % for no mulch and mulch respectively with no significant interaction effect of mulch and location (Table 2). On the other hand, the combined analysis across locations indicated significant location by mulch interaction effect for both weed biomass and grain yield. Mulch significantly increased grain yield, between 77 and 80%, except in the high yielding site of Takeo where the increase was not significant. In locations where weeds had a larger biomass (Kampong Cham and Takeo), mulch reduced weed biomass, while there was no significant positive effect at the other two locations where weed biomass was small. Thus, at Kampong Cham and Takeo there was a significant correlation between crop establishment and weed biomass (Figure 1).

Seed drill was quite effective and in most cases the crop establishment was similar to hand planting and there was no significant difference in yield between the two planting methods. However, in Kampong Thom and Takeo there was a significant interaction between planting method (drill vs hand planting) and mulch application. In both cases, grain yield was lowest in manual planting with no mulch application. The case for Kampong Thom is shown in Table 3. In this location, the low yield was to some extent related to poorer crop establishment with manual planting and no mulch application.

The effect of no-till was rather small and non-significant in all locations except for Kampong Cham where yield of the no-till treatment exceeded conventional tillage method (data not shown). However, this was not related to crop establishment or weed biomass.

3.2 Effect of mulch and planting density (Experiment 2).

Temperature and air humidity were similar in the three provinces. Daily mean minimum and maximum temperature over the experimental period ranged from 25.7 to 31.9 oC in Takeo, 25.1 to 32.1 oC in Kampong Thom, and 24.8 to 38.7 oC in CARDI. Rainfall during the cropping period varied from only 13.5 mm in Takeo, 53 mm at Kampong Thom and 75 mm at CARDI. Overall, soil water content at planting was around 4% greater at CARDI (23.8%) than at Kampong Thom and Takeo which were quite similar (Table 4). However, across all three soil depths the soil water content depletion was largest at Kampong Thom (avg. 7.3%) compared to 4.1 and 3.1% average depletion at Takeo and CARDI.

The effect of planting density was rather small in all locations, and non-significant for most attributes determined. There was also no significant interaction effect of planting density and mulch.

The results in Takeo indicated that mulch had a large effect on crop establishment, weed biomass and mungbean yield (Table 5a). Thus, establishment was improved from 59% to 67-73%, weed biomass was halved, and yield and water use efficiency increased by more than 100%. Root length varied from 15.7 to 17.0cm.

In Kampong Thom, mulch had a significant effect on emergence, weed biomass and mungbean yield (Table 5b). The highest amount of mulch (2 t/ha) reduced crop establishment, and this would be related to excess water noted in the plots with the highest amount of mulch applied. However, weed biomass was reduced in this treatment and the grain yield and water use efficiency was highest. Root depth tended to be increased with mulch (from 17 to 20cm), although this effect was not significant. While the high planting density produced higher yield than the low density (527 vs 421 kg/ha), this was partly due to slightly higher crop establishment (79.6 vs 72.2%) (data not shown).

At CARDI, some plots with mulch application showed poor crop establishment, with the lowest mean of 63% when 1.5 t/ ha of mulch was applied (Table 5c). The relatively poor crop establishment with 1.5 t/ ha mulch application may explain the rather small effect of mulch on yield at this location. While mulch tended to reduce weed biomass and increase root depth, the effects were not significant at p=0.05. The mean root depth of 14.2 cm observed at this site was the shallowestamong the three locations. Planting density had no significant effect on any characters determined at this location.

4.0 Discussion

Application of rice straw mulch had a larger effect on mungbean yield than the planting and tillage methods in the experiment conducted in year 1. While the mulch effect was less in year 2, rice straw mulch had a significant effect on mungbean yield in 6 out of the 7 experiments conducted across two years, and mean yield was increased by 35%. The reduced effect of mulch in year 2 was partly related to poor crop establishment observed in some mulch application plots as a result of wide bed formation and the irrigation system used in year 2. The use of wide beds meant that water in the middle of the bed was not sufficient and so irrigation water level in furrows was raised, resulting in some water logging conditions particularly where mulch was applied. This was not an issue in year 1 when there were no beds and furrows, and no water logging was noted.

The positive effect of straw mulch on grain yield was related to increased crop establishment and reduced weed biomass, particularly under weedy conditions. The effect of mulch on yield may be considered through its effect on improved crop establishment and reduced weed biomass, and also its effect on mungbean growth directly through favourable water and perhaps temperature conditions, or indirectly through increased crop establishment and reduced weed growth. Their contribution to yield is analysed below. The 7 experiments can be classified into two according to the amount of weed biomass in control plots (without mulch). Kampong Thom and Preah Vihea in year 1 had low weed biomass of less than 50 kg/ha and this is unlikely to have had any effect on mungbean growth while other locations had sufficient weed infestation to affect mungbean growth.

4.1 Weed control. Mulch had a positive effect on weed control where weed was amply present. This would be due to direct effect of mulch reducing weed emergence as well as improved mungbean establishment and promoted growth of mungbean with mulch which also resulted in the crop being more competitive against the weeds. The competition between mungbean and other plant species has been well known, and improved mungbean growth suppresses weeds, which in turn further improved mungbean growth and yield. Thus, there were some indication of direct negative relationship between weed biomass determined about 20 and 45 DAS and mungbean yield in some experiments (eg Kampong Cham in year 1 and Takeo in year 2). The relationship was also apparent when the 5 experiments with ample weeds were combined (Figure 2). However, mungbean yield in the two non-weedy sites were low despite the low weed pressure, indicating some other factors were limiting yield. In rice-wheat system in Bangladesh, rice straw mulch greatly improved crop establishment and reduced weed growth by 20 DAS (Rahman et al., 2005). These effects in the early wheat growth stage were such that removal of the straw mulch at 20 DAS produced similar growth and yield to the wheat crop that was mulched until maturity.

Increased crop establishment. This was observed in all four locations in year 1 and one of the three locations in year 2. There was higher water content in the top soil even at harvest time in year 1, and this improved water level was likely to be a reason for increased crop establishment in experiments where water logging was not an issue. Increased soil water content with mulch was noted by others in mungbean in India (Chaudhary et al., 1985) and peanuts in Vietnam (Ramakrishna et al., 2006). The increased establishment may be also related to lower temperature, as air temperature was already high at the time of planting and mulch would have reduced soil temperature as reported for maize and cowpea in Nigeria by Maurya and Lal (1981). Rahman et al., (2005) also found about 50% increase in plant density at 20 DAS in wheat in Bangladesh when mulched with rice straw, as a result of improved soil temperature and moisture conditions. While straw mulch improved crop establishment in most experiments in the present study, the higher establishment alone may not have fully explained the large increase in grain yield (mean increase of 35%) as the increases in establishment were about 15-25% (from 72% to 83% in year 1, and 59% to 73% in Takeo in year 2). The experiment in year 2 indicated that increased planting density by 25 % had no effect on grain yield in two of the three experiments conducted, but had about 25% increase at the other location .

Increased crop growth due to improved environment. The fact that mulched plots had higher soil water content even at harvest indicated that mungbean would have had better soil water environment under mulch. This may be related to increased infiltration and reduced soil evaporation of water from irrigation and rainfall. It is also likely that reduced soil temperature had positive effect on mungbean growth. Similarly the mulch was likely to have helped reduce volatilisation loss from the urea, and increased N availability for the rice crop. Usefulness of rice straw mulch and groundnut residue in increasing N uptake and rice grain yield was demonstrated in a similar rice-based cropping system in NE Thailand (Toomsan et al., 1995; Kaewpradit et al (2009). Thus, the favourable growing environment created by mulch would have resulted in improved crop growth and hence yield directly in addition to its indirect effect through increased crop establishment. Yield increase due to mulch was large in the two cases of low weed pressure suggesting that the yield advantage was caused by improved environment for mungbean growth, as in these cases, crop establishment increased only from mean of 72 to 82 %, and hence unlikely to explain 78 % increase grain yield. This suggests the favourable conditions created by mulch promoted growth, in addition to a small contribution from increased plant density.

Thus, it can be concluded that straw mulch had a positive effect on mungbean yield through various pathways. In some cases, weeds were not a major problem (e.g. Kampong Thom in year 1), yet yield was improved with mulch application. In others (e.g. Kampong Thom in year 2), while crop emergence was not improved, yield was improved. In some others, there were contributions from all these factors.

While the amount of straw mulch required was not conclusive in these experiments, 1-2 t/ha of straw mulch had rather a large effect. It is expected that the area planted to mungbean after rice is much smaller than the rice area on a farm, and it is likely that sufficient straw would be available for mulching. This is particularly so with the increase in tractor mechanisation and the decrease in use of draught animals. If mulch is required for alternative uses after mungbean planting, it could be removed at a later stage. The work of Rahman et al., (2005) showed that the removal of rice straw 20 days after planting of wheat had only minor effect on crop yield.

While mulch had positive effect in most cases, other treatments of no-till, use of seed drill and higher planting density generally had rather a small effect. No-till had no positive effect except at one location; one of the difficulties with the use of no-till in rice stubble areas, is that rice becomes a volunteer weed if not controlled using herbicides. One option would be to wait until the rice plants die, before planting of non-rice crops, but it is likely that delayed planting will have reduced soil water content and therefore more irrigation water would be required. One advantage of conventional tillage is the incorporation of fertilizer to reduce losses of urea-N through volatilisation. Another would be to reduce the soil strength and to increase aeration for better root growth. The fact that the use of seed drill resulted in similar crop establishment and yield to the crop established from manual planting suggests that the seed drill can be used when the labour cost exceeds and approaches the depreciation cost of seed drill. In the year after these experiments were completed, we further tested no-till using seed drill at several locations. While crop establishment was not affected in this method, crop growth was rather poor, perhaps soils were too compacted and aeration was not sufficient. On the other hand, general observation was that the seed drill was successful when it was used after land was thoroughly prepared using conventional tillage. This mechanised system of land preparation after rice harvesting followed by drill seeding of mungbean may happen rather quickly in the Mekong region where labour cost is increasing rapidly.

While the use of seed bed formation resulted in increased mungbean yield in year 2 over year 1, the overall yield level was still not very high. The highest yield was around 600 kg/ ha under mulch at CARDI in year 2. One major limitation identified in the work was the shallow root system of mungbean in lowlands where hard pan limited the root depth to less than 20cm. It is likely that this shallow rooting zone limits the supply of water and nutrients to the plants throughout crop growth. If non-rice crops following rice in the lowlands are to become a major industry, it would be necessary to find a crop management system that increases the rooting zone.

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A list of Figures.

Table 1 Effect of tillage (Till) at planting and mulch post-harvest on soil water content (%) at 0-20cm depth at four locations (Loc) in Cambodia in 2008-09 dry season.

	At planting			Post-harvest		
Location	Tillage	No till	Mean	Mulch	No mulch	Mean
Takeo	11.3	14.0	12.7	13.3	12.0	12.7
Kampong Cham	5.0	5.3	5.2	13.1	11.0	12.1
Kampong Thom	18.0	21.3	19.7	15.6	14.7	15.2
Preah Vihea	4.1	5.2	4.7	12.6	11.9	12.3
Mean	9.6	11.4	10.5	13.6	12.4	13.0
LSD0.05Loc	0.98**			0.80**		
LSD0.05Mulch	ns			0.50**		
LSD0.05Till	0.69**			ns		
LSD0.05LocxTill	1.30**			ns		
LSD0.05LocxMulch	ns			ns		

** indicate significance at $p<0.01$; ns indicates not significant.

Table 2 Effect of mulch on crop establishment, weed biomass and grain yield of mungbean at four locations in Cambodia in 2008-09 dry season.

Location	Crop establishment# (%)		Weed biomass (kg/ha)		Grain yield (kg/ha)	
	Mulch	No-mulch	Mulch	No-mulch	Mulch	No-mulch
Takeo	83.5	73.9	115.5	232.4	460	421
Kampong Cham	84.3	70.7	318.7	370.8	302	169
Kampong Thom	83.2	72.6	21.7	40.7	361	203
Preah Vihea	81.1	71.5	37.2	11.3	209	118
Mean	83.1	72.2	123.3	163.8	332	227
LSD0.05Interaction		ns	27.7(**)		77.6(**)	

** indicate significance at p<0.01; ns indicates not significant.

#Crop establishment was measured from three 0.5×0.5 m areas per plot at 15-22 days after planting.

Table 3 Effect of planting method (p) and mulch (m) on mungbean establishment, weed biomass and grain yield at Kampong Thom in 2008-09 dry season.

Planting method	Establishment (%)		Weed biomass (kg/ha)		Grain yield (kg/ha)	
	Mulch	No-mulch	Mulch	No-mulch	Mulch	No-mulch
Manual	85.5	71.7	26.3	37.5	405	175
Seed drill	81.5	73.7	17.0	44.0	317	232
Mean	83.5	72.7	21.7	40.8	361	203
LSD0.05p	ns		ns		ns	
LSD0.05m	3.2**		16.4*		40.4**	
LSD0.05pxm	3.5(p=0.06)		ns		52.0**	

* and ** indicate significance at p<0.05 and p<0.01 respectively; ns indicates not significant.

Table 4 Soil water content (%) at planting (P) and post-harvest (PH) for three depths at three locations in dry season 2009-10 in Cambodia.

	0-10cm		11-20cm		21-30cm		Mean across depths	
Location	P	PH	P	PH	P	PH	P	PH
Kampong Thom	14.0	9.6	20.5	12.9	23.5	13.7	19.4	12.1
Takeo	12.1	10.6	22.6	16.0	25.0	20.9	19.9	15.8
CARDI	18.6	17.6	26.0	20.9	26.9	23.8	23.8	20.8
Mean	14.9	12.6	23.0	16.6	25.2	19.5	21.0	16.2
LSD0.05	1.9**	1.1**	1.3**	0.9**	1.4**	1.1**		

* and ** indicate significance at p<0.05 and p<0.01 respectively.

Table 5 The effect of mulching rate on crop establishment, weed biomass, grain yield, root length and water use efficiency (WUE) for mungbean grown in a) Takeo; b) Kampong Thom; and c) CARDI in Cambodia in 2009-10 dry season.

Takeo

Mulch (t/ha)	Crop establishment (%)	Weed biomass (kg/ha)	Yield (kg/ha)	Root length (cm)	WUE kg/ha/mm
0	59.3	418	182	15.7	2.70
1	73.1	274	430	17.0	6.37
1.5	73.3	217	367	16.0	5.43
2	66.7	200	463	16.8	6.86
Mean	68.1	278	360	16.4	5.34
LSD0.05	10.3*	122*	123*	ns	
b) Kampong Thom					
0	78.0	339	485	17.0	4.25
1	77.0	240	414	20.0	3.62
1.5	78.0	225	456	19.0	3.99
2	71.0	157	541	20.0	4.74
Mean	76.0	240	474	19.0	4.15
LSD0.05	3.7**	93.9*	55.1**	ns	
c) CARDI					
0	74.8	118	504	12.9	2.85
1	78.5	92	638	13.2	3.60
1.5	63.3	43	535	14.9	3.02
2	78.8	45	588	15.7	3.32
Mean	73.9	75	566	14.2	3.20
LSD0.05	10.4*	ns	84*	ns	

* and ** indicate significance at p<0.05 and p<0.01 respectively; ns indicates not significant.

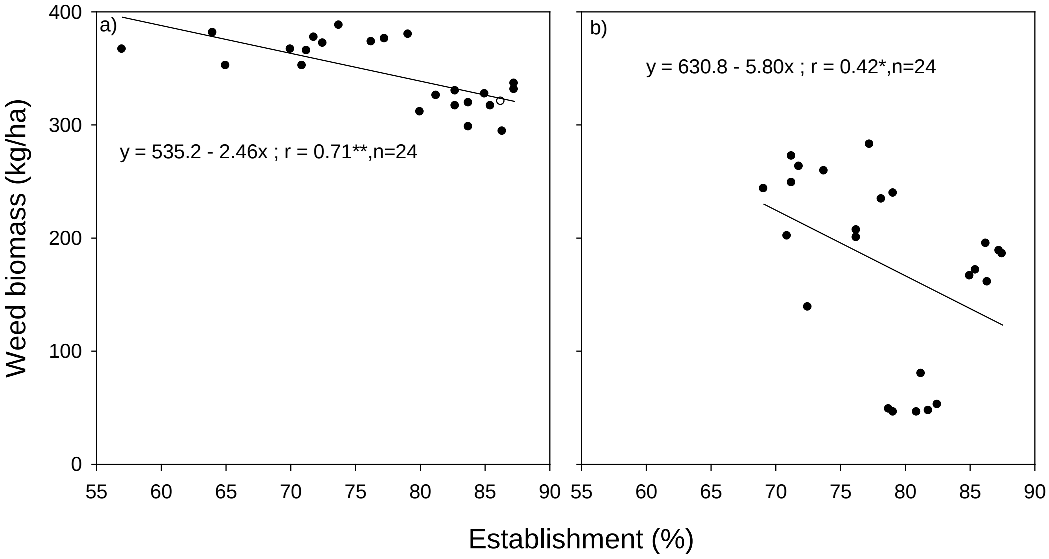

Figure 1 Relationship between weed biomass and mungbean establishment in Kampong Cham and Takeo in Cambodia in 2008-09 dry season.

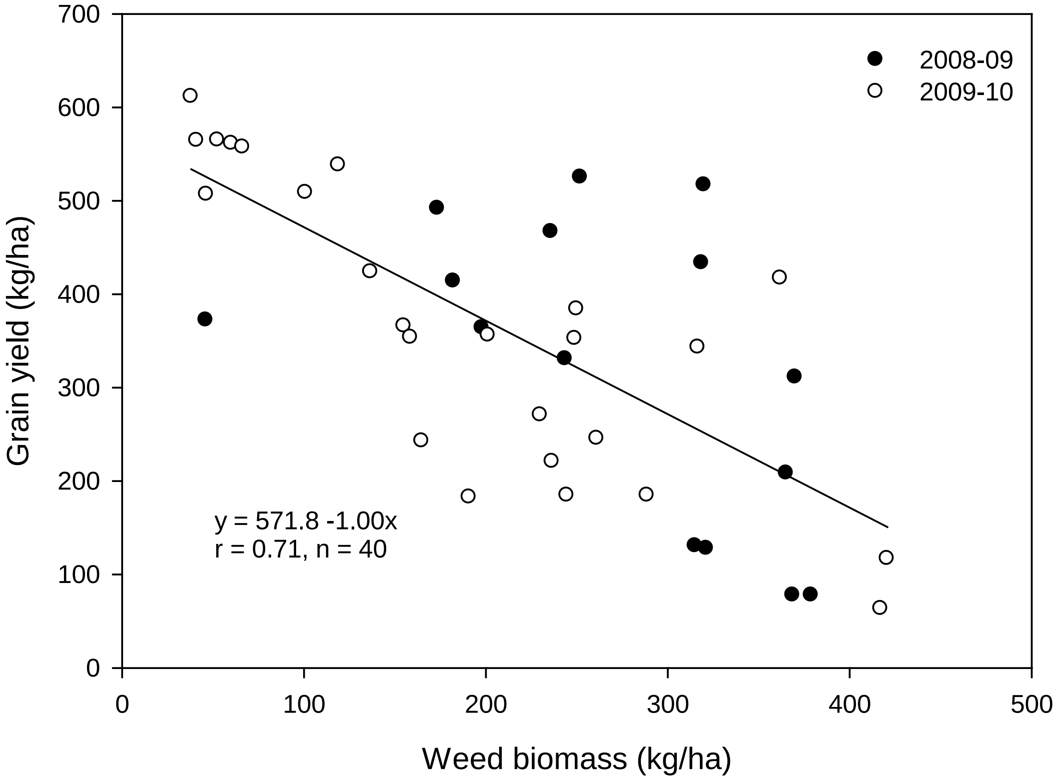

Figure 2 Relationship between grain yield of mungbean and weed biomass when experiment average for weeds biomass was greater than 50kg/ha in two dry seasons in Cambodia.