Australian Government

Australian Centre for International Agricultural Research

Final report

project	Mechanization and value adding for diversification of lowland cropping systems in Lao PDR and Cambodia
project number	CSE 2012 -077
date published	13.12.19
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approved by	Dr. Eric Huttner
final report number	N/A
ISBN	N/A
published by	ACIAR GPO Box 1571 Canberra ACT 2601 Australia

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1 Acknowledgments

We wish to acknowledge the great contribution made by many farmers in our target villages in both Laos and Cambodia. They were willing to participate in the project and spend many hours with project staff discussing the advantages and disadvantages of the machinery to which they were introduced. Their involvement in field operations has created much useful data that are described in this report.

2 Executive summary

In both Laos and Cambodia, lowland rice is the backbone of agricultural production. There have been major changes in rice production systems due to reduced availability of rural labour and increased marketing options. This project focused on lowland rice systems in Laos and Cambodia, with three objectives; assess crop mechanization options for increased labour productivity; evaluate post-harvest innovations for adding value to meet market demand; and evaluate innovative cropping systems to take advantage of these mechanization and value-adding options. The project has worked in several villages in Central Laos and in southern Cambodia. In Laos, the combine harvester was introduced commercially just prior to the project's commencement, hence the focus of the project there was to determine factors that would affect combine adoption. Some paddies were amalgamated to make larger, levelled paddies totaling 15 ha, and the options for mechanized rice production were investigated.

The project has made several key findings. One is the identification of several factors that determine the efficiency of combine harvesting as measured by the area harvested in one day. Data for combine harvesting of over 300 paddy fields in Central Laos indicate that combine efficiency was low at 2.8 ha/day for small paddies (<1,000 m^2) but increased with field size to a maximum efficiency of about 5 ha/day when the field size was 2,000-3,000 m^2. Lodged crops reduced combine harvesting efficiency and this resulted in lower efficiency in the wet season compared to the dry season and for broadcast crops compared to hand transplanting or mechanized planting. The varieties chosen by the farmer were important as some tended to lodge and long-duration, bulky varieties had lower efficiency.

A survey of farming households in 10 target villages in Cambodia showed there has been a high adoption rate (from 30%-80% of households per village) of contract combine harvesting services since 2014. A key driver for adoption of these services was the cash income households received from dry season rice, suggesting the importance of its affordability. Modest service fees in Cambodia are associated with combines operating for many days across different rice-growing seasons and locations.

Securing drying facilities will be important for wider adoption of combine harvesting. Lack of access to artificial drying facilities increases the risk of the harvested paddy being spoiled when rainfall interferes with sun-drying processes, particularly in dry-season and early-wet-season crops. With the use of artificial drying, high physical grain quality is maintained, resulting in increased chance of marketing. Broken rice during milling is reduced when rice is dried using flatbed dryers rather than sun-drying, and this resulted in head rice yield of about 50% compared with less than 40% with sun-drying. High head rice yield was obtained when crops were harvested early during crop ripening, 25-30 days after flowering.

The project has made advances in understanding the interdependence between combine contractors, mills, farmers, and land developers, and this has resulted in identifying possible points for policy intervention. Based on understanding these interrelationships, the project has assisted implementation of mechanized rice production in Central Laos. The project has cooperated with the Khammouan Provincial Government, particularly the Extension Group, hence the largest impact has been seen in this province, where the number of combine harvesters has increased and larger paddy fields are being promoted through the provision of Government credit to farmers.

A number of farmers have begun using seed drills as they are rather cheap to purchase and operate and enable more rapid planting than hand-transplanting. Transplanters are

useful to seed producers but are cumbersome to operate and their economic merit appears less than the seed drill. Economic analysis indicates large benefits to farmers from using drill planting and combine harvesting, particularly in areas with high labour cost. The project also found that the spare time created through the introduction of machinery contributed to further increases in agricultural production. However, the full benefit of mechanization may not be realized until optimal conditions are created to maximize the benefit of mechanized rice production. These areas require further research and development efforts, especially to use varieties that enhance machinery use. These may include varieties with lodging resistance, particularly under broadcasting; with less bulkiness to aid combine harvesting; with photoperiod sensitivity allowing early planting by seed drill; and with the ability of seedlings to emerge from the soil when sown at depth by seed drills.

3 Background

Laos and Cambodia have several million smallholders managing subsistence-oriented, rice-based cropping systems who have the potential within the next decade to make the transition to mechanised, market-oriented farmers producing higher quality food and other produce for home consumption and the market, thus improving the livelihoods of more than 6 million rural poor. Rainfed lowland rice is the backbone of agricultural production in these countries; the crop is traditionally grown only in the wet season. Potentially high-value non-rice crops are not grown on a large scale in lowland paddies.

Rainfed lowlands occupy ~80% of all rice growing areas in each country. Rice is mostly grown in the wet season (WS) for home consumption, but can be grown in the dry season (DS) or early wet season (EWS) if water is available; currently in Cambodia 14% and 3% of total rice is grown in the DS and EWS, respectively. A similar proportion of DS rice is grown in Laos, but EWS rice is not common. In both countries, only around 15% of the total rice area has canal irrigation systems where double cropping, mostly rice-rice, is practised. In addition, perhaps 10-20% of the total rice area has access or potential access to limited amounts of water using tubewells and on-farm dams (supplementary irrigation areas).

Rice growing is subject to new pressures, partly because of the decreasing availability and increasing cost of rural labour. The use of combine harvesters has increased greatly in Cambodia, helping to offset the labour shortage, but combine harvesting often results in low-quality milled rice. In Laos, adoption of combine harvesters has been slower. In addition to combine harvesters, mechanised planting can help overcome labour constraints as hand-transplanting of rice is labour intensive, but mechanical planters are not commonly used in these two countries.

While rice is the main crop, it is often grown primarily as a subsistence crop in the WS and trade is still limited, though export of low-quality paddy rice from Cambodia to Vietnam has expanded greatly in the last few years. One reason for the limited marketing of rice, particularly for international trade, is the low quality of rice produced. With traditional sun drying of hand harvested rice grain, loss of grain is high and grain quality is low, making it difficult to market, particularly the crops grown in the EWS and late DS when there is a high chance of rainfall around harvest time. With the rapid spread of combine harvesting in Cambodia, drying paddy rice with high moisture content is now required. A high percentage of broken rice grain continues to be a major problem and post-harvest technologies need to be developed for improved grain quality.

Mechanization allows timely operations and earlier harvest of the rice crop, providing more windows for crop intensification and diversification. This and more market-oriented post-harvest operations will help farmers diversify, add value to their production, and increase their incomes. This in turn will promote greater involvement in the evolving market economy, particularly when farmers and agribusiness groups work together.

The overall project strategy was to take advantage of opportunities for mechanization, diversification, and value-adding that are becoming available in order to develop more intensive and diversified cropping options that can increase the output and incomes of smallholders in lowland cropping regions in the two countries. The strategy focused on the following three research questions:

- What are the productivity gains (yield, labour productivity, land-use efficiency) with the introduction of various types of mechanization in lowland rice-based cropping systems?
- What are the best options to add value to crop production in these cropping systems, and what is required to achieve them? (The focus here was mainly on arrangements for the use of artificial dryers to improve product quality.)
- What are the opportunities for increasing crop diversification with the use of combine harvesters, other machinery, and dryers, and what are the costs, benefits, risks, and livelihood impacts of these new cropping systems?

Thus the project focused on three interrelated aspects – mechanization, value adding, and diversified cropping systems. The plant improvement and agronomy activities conducted within this project were only those related to cropping system changes arising from changes in mechanisation and value adding.

Within each country, cropping systems were identified based on current cropping intensities associated with different degrees of water availability: traditional rice mono-cropping with no access to irrigation water (low water availability); current double cropping with supplementary on-farm irrigation available (medium water availability); and current double cropping with canal irrigation (high water availability). The focus was on testing mechanisation options and postharvest technology for DS and EWS crops in villages where there was medium and high levels of water availability. In villages where only one rice-monocrop was grown, the mechanisation options and postharvest technology were tested in the WS.

The aim was to assess the impact of these interventions and quantify (1) the productivity gain (yield, labour productivity, land-use efficiency) with various types of mechanization (combine and seed drill); (2) the improvement in grain quality through the use of well-managed artificial dryers and storage products and the consequences for value adding; and (3) the costs, benefits, risks, and livelihood impacts of new diversified cropping systems resulting from the use of quick-maturing varieties in combination with the introduction of mechanisation and post-harvest technologies.

Combine harvesters are the major new type of farm machinery but their availability differs greatly between the two countries. More than 6,500 units of combines are now available in Cambodia. However, there has been little research to improve agronomic efficiency in a system where combine harvesting is practised, particularly the timing of harvest in relation to crop maturity and the utilization of combine harvesting to develop innovative cropping systems. In Laos, the combine was introduced commercially just prior to project commencement, hence the focus there was to determine factors that would affect combine adoption. It has been shown in Vietnam that rice grain quality is strongly affected by the stage of grain maturity when the crop is hand-harvested and sun-dried before milling. There was a need to examine this relationship for combine-harvested grain which retains high moisture content without being subjected to sun drying in the field.

Another major mechanization issue, particularly in relation to the development of new, more flexible cropping systems, is mechanical seeding, particularly the use of the seed drill. A number of ACIAR projects had worked on the seed drill in both countries, and in Savannakhet Province it is now well accepted by farmers, with a number of seed-drill contractors operating. Seed drills attached to 2-wheel tractors are available from Thailand. Another method of mechanical planting is the use of transplanters. Transplanters are commercially available in Cambodia but not commonly used by farmers; they are used by a number of rice seed producers in Laos. The low affordability and high labour cost for seedling preparation are the main constraints to their adoption. The transplanters are thus suitable for high-value rice crops such as for rice seed and for premium export markets such as for organic rice. Very limited research had been conducted with transplanters in the two countries.

The introduction of combine harvesters has affected not only field operations but also grain drying practices. One of the major post-harvest issues with the use of combine harvesters is the lack of drying facilities for paddy rice with high moisture content, and a lack of understanding of the importance of proper drying practices in the rice mills that have installed flat bed and/or column dryers. The issue of rice cracking and grain losses is significant for EWS and DS crops when harvesting take place during wet weather. There is also a major issue of post-harvest losses at local mills that are processing paddy rice harvested and dried by traditional methods. Comparison of Laos and Cambodia will help identify the causes of the differences in harvesting-drying systems, such as differences in biophysical conditions, government policy, or export markets.

The third aspect of the project is the development of cropping systems based on the use of seed drills, combine harvesters, and dryers. Our focus was to take advantage of these technologies to develop more intensive and diversified cropping systems. For example, combine harvesting takes place about one week earlier than traditional hand harvesting. The use of combine harvesters has greatly reduced the labour requirement for rice harvesting and postharvest operations, thus providing options for farmers to plant a non-rice crop in a timely manner after rice harvesting. This intensification and diversification of cropping systems could also be achieved by having quick-maturing varieties of rice, mungbean, maize, or peanuts. Similarly some crop characteristics are suitable for mechanization, for example, lodging resistance in rice for combine harvesting and quick germination for drill-seeded crops under water-limited conditions. Varietal improvement is also essential for the production of high quality rice, for example, low-amylose-content, non-glutinous rice for export.

4 Objectives

The aim of this project was to identify mechanisation options and post-harvest technologies to enhance household livelihoods and food security in lowland rice-growing areas of Laos and Cambodia. This was to be achieved by utilising a systems approach, integrating mechanised cropping practices, including combine harvesting, and post-harvest practices, in particular artificial dryers, that together increased the intensification, potential for diversification, and labour efficiency of the cropping system and the market value of the produce. The specific objectives were to

1. Assess crop mechanization options for increased labour productivity;
2. Evaluate agronomic and post-harvest innovations for adding value;
3. Evaluate intensified, diversified, and market-oriented cropping systems to take advantage of mechanization.

Objective 1. Assess crop mechanization options for increased productivity

- 1.1. Diagnostic analysis of value-chain and agribusiness constraints and opportunities for mechanization
- 1.2. Agronomic evaluation of combine harvester performance
- 1.3. Agronomic evaluation of direct seeding drill and transplanter as well as land preparation measures
- 1.4. Socioeconomic analysis of mechanized cropping

Objective 2. Evaluate agronomic and post-harvest innovations for adding value

- 2.1. Diagnostic analysis of value-chain and agribusiness constraints and opportunities for dryers
- 2.2. Identification of optimum rice drying conditions in mills
- 2.3. Assessment of community dryers for rice and other crops
- 2.4. Analysis of physical properties of paddy during drying and milling
- 2.5. Variety selection for high quality
- 2.6. Identification and appraisal of value-adding options, especially packaging

Objective 3. Develop and evaluate intensified, diversified, and market-oriented cropping systems to take advantage of mechanization and value-adding options

- 3.1. Agronomic evaluation of innovative cropping systems under different water availability conditions
- 3.2. Variety selection for short duration
- 3.3. Socioeconomic analysis of intensified and diversified production systems

5 Methodology

Most activities were conducted in target villages with some irrigation water available so that crop intensification and diversification could be achieved, while other activities were conducted in rainfed lowland areas with little water available in the dry season. In each village we selected a farmers' group to work with so that our work could be evaluated by a number of farmers. In some villages, we worked with a seed-producers' group while in others an irrigation water-users' group was selected.

Some activities were conducted in both Laos and Cambodia, but others were conducted only in one country. In Laos the project initially concentrated on three target villages in Khammouan and Bolikhamxay where we assisted farmers to amalgamate their small rice paddies so that the effect of paddy field size on mechanization, particularly combine harvesting efficiency, could be evaluated.

The methodology of the project was divided into 10 groups of activities corresponding mainly to the Objectives/Activities in Section 6 and to the Key Results and Discussion in Section 7. The 10 groups are as follows (the numbers in brackets show the corresponding Objective/Activity in Section 6):

1. Baseline village information (1.1, 2.1, 3.3.1)
2. Agronomic evaluation of combine harvester performance (1.2)
3. Agronomic evaluation of planting machines and land preparation measures (1.3)
4. Socio-economic evaluation of mechanization options (1.1, 1.4)
5. Dryers (2.2, 2.3)
6. Physical properties of rice (2.4)
7. Value adding (2.6)
8. Agronomic evaluation of innovative cropping systems (3.1)
9. Variety improvement (2.5, 3.2)
10. Socioeconomic analysis of intensified and diversified production systems (3.3)

1. Baseline village information

Cambodia baseline surveys were conducted in ten target villages in three provinces (Takeo, Kampong Speu, and Kampot) to provide background information of these target villages as well as the magnitude of mechanization in each village. The villages were all in the rainfed lowland environment and were evaluated for key information about cropping systems, cultivation practices, irrigation water systems, land tenure, land uses, adoption of machinery, and non-farm income sources. The ten selected villages comprised Smon Monly, Snao (Prey Kabas district), Steung and Trapeang Chak (Tramkok district) in Takeo Province, Tadaeng Thmei, Khley Chas and Leangchey Thmei (Boseth district) in Kampong Speu Province, Chamlang Chrey (Banteay Meas district), Prey Toteung and Daem Snai (Kampong Trach district) in Kampot Province. Despite all being classified as in the same lowland environment, the villages varied widely in terms of population, number of farm households, size of village area, farming land, irrigation water resources, cropping practices, degree of intensification and diversification, and technology adoption. The survey was conducted at the beginning of the project, and again in late 2018 to see the changes during the project years.

2a. Agronomic evaluation of combine harvester performance (1.2) – field environments

This activity was conducted in Laos to determine factors that determined combine harvesting efficiency particularly the effect of field size as there was general concern that combines were not suitable for the small paddies that were common in Laos. In the first 3 seasons, the work was conducted in Khammouan and Bolikhamxay where we enlarged some fields. It was also conducted in Vientiane in the last 3 seasons.

A total of 56 rice fields with a combined area of 15 hectares were enlarged in three target villages soon after the commencement of the project; 26 fields in Pakpung village, Paksan district, Bolikhamxai province, 18 fields in Hatkhamhien village, Xebangfai district, Khammouane province and 12 fields in PakEtue village, Nongbok district, Khammouane province. In each village, about 5 hectares of fields that were originally less than 1,000 m^2 were enlarged and leveled by four-wheel tractor. The size of each enlarged field ranged from 1,020 to 8,560 m^2 depending on the slope and toposequence. In the sloping areas, topsoil was removed from higher to lower positions in the field, and this soil movement affected the performance of the subsequent rice crops where soil fertility was not improved.

Beside the three target villages sponsored for field enlargement, we also studied combine harvesting efficiency in other villages in Khammouan Province, with and without field enlargement. In Navangthong village, where farmers enlarged and levelled their fields at their own expense, amalgamated field size ranged from 3,100 to 9,400 m^2, and in Tung village, where the original field size was retained, it was 225 to 700 m^2. A Kubota-DS70 combine harvester was used to determine harvesting efficiency in the target villages. The field size was determined and the time required for the combine to complete harvesting was recorded for each field, enabling calculation of harvesting efficiency (ie, work rate) in terms of hectares per day.

Farmers had planted rice with different methods in the study villages, including hand transplanting and use of a transplanter and direct seeding by broadcasting and using a seed drill or drum seeder and combine harvesting efficiency determined. Paddy rice harvested by combine was dried to reduce moisture content by sun drying and flatbed dryer. Yield was adjusted to 14% moisture content.

Similar methods were used for estimating combine harvesting efficiency for the other 3 seasons (WS 2016, DS 2016/17 and WS 2017) in Vientiane Province. In season 4, we harvested paddies in Ekxang village where some fields had been amalgamated by farmers but most were more typical small fields. Different varieties were grown and combine efficiency determined. Seasons 5 and 6 were spent near Rice Research Centre (RRC) where paddies had been levelled and enlarged earlier.

Photo 1. Original field (left) and enlarged field (right)

Photo 2. Combine harvester in operation

2b. Agronomic evaluation of combine harvester performance (1.2) – combine harvesting grain loss

This activity was conducted in both countries in the farmers' fields as some people were concerned there was a large loss of grain with combine harvesting.

In Cambodia, we evaluated 20 fields harvested by combine contractors and compared these to hand harvesting. The experiments were conducted for two years, from December 2014 to April 2015 and from November 2015 to March 2016, encompassing with 18 WS and 4 DS rice crops. The size of paddy field ranged from 120 to 4,000m^2, while the land level within fields varied by 7-15cm (maximum to minimum point). To assess grain loss in the fields for hand harvesting, we also used the square steel frame (0.25 m^2) to measure the amount of grain on the soil surface from the area we hand harvested, then measured the grain weight and moisture content. Similar measurements on the cutter grain loss on the ground were made for the combine-harvested fields. In addition grain loss from the combine harvester itself was made by using mosquito net cover over the combine outlet and all straw and panicles were collected following the procedure described by Siebenmorgan et al. (1994). Then grain weight and moisture content were determined from the materials to estimate grain loss during combine harvesting.

A further study on grain loss was made in relation to the time of harvesting during ripening in Cambodia (see below).

In Laos, yield loss estimation from combine harvesting was conducted in 5 villages in two provinces. In DS 2014/15, 8 sites collected data on yield loss and in DS 2015/15, 21 sites collected yield-loss data. Grain loss was determined by randomly collecting grain on the soil surface in one square metre soon after the area was combine-harvested.

Photo 3. Collection of grain lost in the field was done by randomly collecting grain loss during harvesting in areas of 1 m^2; about 10 samples were collected per site.

2c. Agronomic evaluation of combine harvester performance (1.2) – grain quality of paddies harvested by combine at different times during ripening

Combine-harvested paddy requires different methods of drying from hand-harvested paddy, and harvesting time during crop ripening may affect the grain quality. This activity was conducted at research stations for 4 wet seasons in Cambodia and 5 seasons in Laos. Three harvesting times at 25, 35, and 45 days after flowering were used in the earlier years, but harvesting intervals were shortened in later years in both countries. The methods were similar for all experiments, although treatments varied to some extent. A brief description of experiments in Laos is shown in Table 5.1 and crop growing conditions in Figure 5.1. The methods used for the first two experiments at CARDI in Cambodia are shown below.

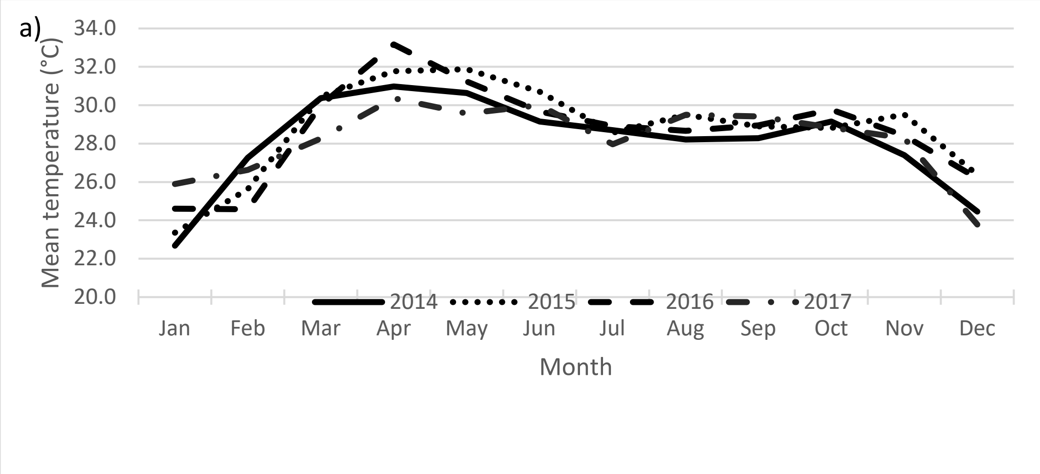
In the year 1 experiment, there were two adjacent blocks; one was allocated for combine harvesting and the other for hand harvesting. Each block was considered an experiment, and three times of harvesting around maturity (25, 35 and 45 days after 50% flowering) were randomized with three replications. The year 2 experiment was carried out in a spit-plot design with harvesting method (hand harvesting and combine harvesting) as the main plots and the harvesting time (25, 35 and 45 days after 50% flowering) as sub-plots, with three replications.

Combine and hand harvesting treatments followed the local practice and differed also in the post-harvest operations of drying, threshing, and cleaning of grain. For both treatments the crop was harvested from the whole plot. The combine (a Kubota-DC90) was used to harvest the crop thoroughly at a proper speed to ensure there were no excessive harvesting losses. For the hand harvesting treatment, a sickle was used to cut the rice stem, then the cut stem was laid on the stubble for sun drying in the field for 1-2 days until grain moisture content was 14%, then the stems were bundled and threshed by hand in the field. The grain was then milled and grain quality was determined. Broken grain was also separated from the head rice (whole kernels or at least 75% original kernel length) and their weights were determined.

Table 5.1. Seasons, harvesting time treatments, and drying method treatments of Experiments 1-5 in Laos. Xangsayasane et al. 2018a

Expt	Season	Time of harvesting (days after flowering)	Drying methods		
1	2014WS	25, 30, 45	Flatbed dryer	Sun drying 1a	-
2	2014/15DS	25, 35, 45	Flatbed dryer	Sun drying 1a	-
3	2015/16DS	25, 35, 45	Flatbed dryer	Sun drying 1a	-
4	2016WS	25, 30, 35	Flatbed dryer	Sun drying 1a	Sun drying 2a
5	2016/17DS	25, 30, 35	Flatbed dryer	Sun drying 1a,b	Sun drying 2a, b

Sun drying 1-using tarpaulin sheet; sun drying 2- using nylon net; a and b, rough rice dried for whole day (10 hours) and dried in the morning only (5 hours) for 2 days, respectively



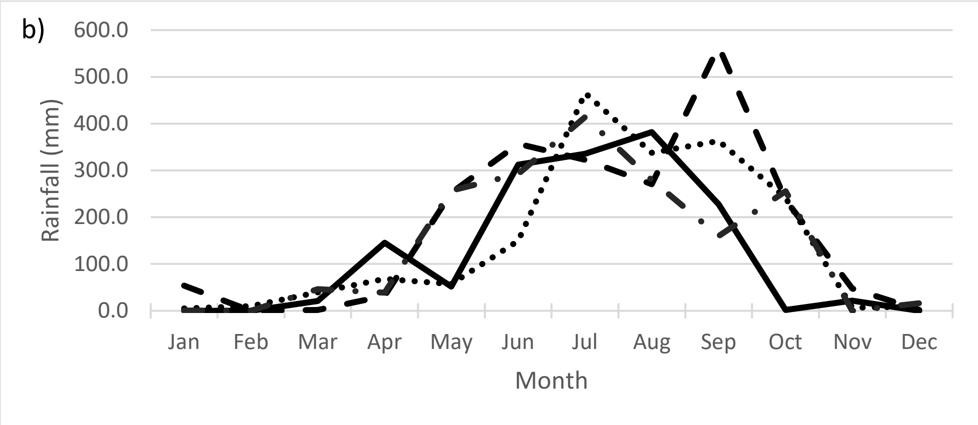


Figure 5.1a) Mean monthly temperature (°C); and b) total monthly rainfall (mm) for 2014 to 2017 in Laos. Xangsayasane et al. 2018a.

3a. Agronomic evaluation of planting machines and land preparation measures (1.3) – transplanters

The transplanter was considered to have a potential role in the following cases when there is not sufficient labour available for hand transplanting; where the crop is for seed production; where there is a need to control weeds after years of continuous broadcasting; and where there is a need to reduce crop duration in the main season to allow for more intensive cropping systems. We evaluated transplanter operation and yield performance in different villages.

In Laos we used Kubota transplanters which were owned by farmers group in Hatkhanhien, Tung, and Paketue in Khammouan, while in Pakpung, Bolikhamxay, the transplanter was provided by Takokkung Centre (Photo 4a). A total of 2,000 seedling trays were provided by the project to farmers for growing seedlings before planting rice by the transplanter. Land preparation was done by farmers following their usual practice. Rice was harvested by a combine from NAFRI (National Agriculture and Forestry Research Institute) and grain yield was adjusted to 14% moisture content. This activity was conducted in DS 2014/15, WS 2015, and DS 2015/16. Crop performance established from transplanter was compared with those established from different methods, and details are shown in Table 5.2. Demonstration of the use of transplanters continued until 2018.

In order to determine the effect of plant density in crops established using a transplanter, an observation trial was conducted at RRC in WS 2016. One field (about 2,100 m^2) was divided into 4 blocks (each block 480m^2) to test the effect of hill spacing when the rice crop was established with a transplanter. Row spacing was always 30 cm, but the hill spacing was 14, 16, 18 and 21 cm, where 16cm was often used for DS crops and 18 cm for WS crops (common hand planting spacing would be 20x20 cm for DS and 25x25 cm for WS). The number of seedlings per hill would be the same (5/hill). The number of trays used for each block was 12, 11, 10 and 9 which would be about 250, 229, 208 and 188 trays/ha. The hill number was counted and panicle density and grain yield determined at maturity. A similar experiment was also conducted at RRC in 2017.

In Cambodia, no villages owned transplanters so the project used a project transplanter in several villages. Eight farmers' fields were used for demonstration in WS 2015 and this was repeated in WS 2016 (13 farmers) and WS 2017 (6 farmers). The demonstration continued in 2018.

Table 5.2. The number of paddy fields tested under various establishment methods in different villages in Central Laos in three seasons. DS-dry season, WS-wet season. Xangsayasane et al. 2018b

Year	Villages	Total number of fields	Manual transplanting	Transplanter	Broadcasting	Seed drill	Drum seeder
2014/15DS							
	Hatkhamhieng	12	8	1	3		
	Pakpung	31	4	15	9	3	
	Tung	13		13			
	Paketue	5		5			
	Others	15	13		2		
	Total	76	25	34	14	3	
2015WS							
	Hatkhamhieng	1				1	
	Tung	37	8	24	5		
	Paketue	5	5				
	Others	22			9	13	
	Total	65	13	24	14	14	
2015/16DS							
	Hatkhamhieng	17	6	1	6		4
	Pakpung	59	6	4	31	6	12
	Tung	8	3	1		4	
	Others	1				1	
	Total	85	15	6	37	11	16
3 seasons	Total	226	53	64	65	28	16

3b. Agronomic evaluation of planting machines and land preparation measures (1.3) – seed drill

This section discusses the seed drill used for rice production. Project activities on drills used for non-rice crops are discussed under 7. Innovative cropping systems.

In Laos, seed drills imported from Thailand were provided by the project to five villages. The seed drill was attached to a hand tractor for planting rice (Photo 4b). In the wet season, the field was ploughed from the end of April to early May, a second ploughing was done in early to late May or after the first rain, and then harrowing was undertaken before seeding under dry soil conditions. In the dry season, the soil was prepared in December under dry conditions, while some farmers first flooded their rice fields and waited until the field was at field capacity before preparing the land. Dry rice seed was put in the seed box attached to the seed drill and seeded under dry soil conditions. After seedlings were 5 to 10 cm tall, the field was irrigated in the dry season, while in the wet season the field was left under rainfed conditions. On-farm demonstration of the use of seed drill was conducted from 2014 to 2018. In later years, different varieties with various degrees of photoperiod sensitivity were planted to determine suitable varieties for early planting.

Photo 4 a. Transplanter b. Seed drill

In Cambodia, drills developed earlier at CARDI (Cambodian drill seeder) were used for demonstrations in target villages each year. In 2014WS 16 farmers used the drill. In 2015, nine field demonstrations were carried out in the EWS in Takeo and Kampot. The objective was (1) to determine the differences between broadcasting (famer practice) and use of seed drill on rice yield in the rainfed lowland area of Cambodia and (2) to analyze the economic benefit between the two methods by recording production cost. All field demonstrations were divided into 2 plots and each field consisted of (1) CARDI technology package including Cambodian seed drill and (2) farmer practice including broadcasting. The nine field demonstrations (2 in Prey Kabas district, 5 in Tramkok district, and 2 in Bateay Meas district) were conducted in two provinces using the Chul'sa variety. Similarly 4 demonstrations were conducted in 2017EWS and also in 2018.

3c Agronomic evaluation of planting machines and land preparation measures (1.3) - soil moisture requirement for drill seeded crops

With the use of seed drill, seeds are sown before soil is saturated with water. Sowing depth can be readily controlled with the drill. Often drill is used when soil moisture content is below field capacity. Understanding of moisture content for establishment of different crops is required. Two field experiments were conducted at CARDI to determine soil moisture requirements for 4 crops (rice, mungbean, maize, and peanuts). The first replicated field experiment was conducted in January/February 2015. The crops were planted by hand at 3, 6, 9, 12, and 15 days after draining standing water. There was no rainfall during the experiment. The experiment was repeated in March 2016 at CARDI. In this new experiment, there were two trials, one with hand planting as in the previous experiment and the other with seed-drill planting. In the hand-planted trial, standing water was drained on 2 March and seed was sown at 2 and 5 cm depth on 4, 7, 9 and 11 March.

3d. Agronomic evaluation of planting machines and land preparation measures (1.3) – deep rippers

This activity was carried out in Cambodia where use of combine harvesters in recent years may have increased the compactness of the hard pan. Several experiments with maize or mungbean were conducted on farmers' fields as well as at CARDI. In 2017, there was a replicated maize experiment and demonstrations. In deep-ripped fields, two tynes about 20-30 cm apart were used and the depth of deep ripping was about 35 cm. The soil moisture content was less than 10% at the time of planting on 1 February and generally good establishment was obtained in both deep-ripped and control areas. In the deep-ripped experiment, there were 3 replications while in the deep-ripped demonstration trial a field (1,260 m^2) was halved for deep-ripped and control treatments.

Photo 5. Deep ripper in action

4a. Socio-economic evaluation of mechanization options (1.1, 1.4) – operations of combine contractors

In Cambodia, interviews were held with 16 contractors providing the services of different types of machinery – combine harvesters, reapers, 4-wheeled tractors, 2-wheeled tractors, and threshers. They serviced the target villages but lived in Kampong Speu, Kampot, Takeo, and Prey Vengh.

The second set of survey was conducted in January 2016 to examine financial aspects of combine contractors. With two separated surveys carried out in March 2015 and January 2016, a total of 41 mechanised contractors were traced in 10 districts of four provinces, Kampong Speu, Kampot, Takeo and Prey Veng. The results are used to conduct economic analysis of combine contractors shown in Final Report section 8.3.1 (Economic Impacts).

4b. Socio-economic evaluation of mechanization options (1.1, 1.4) – combine contracting options

Using the information provided above for input and output of combine operations, economic evaluation of combine contractor was made for different combine harvesting efficiencies and fee charges. The results are shown in Sections 7, 8.3.1 and 8.3.2.

4c. Socio-economic evaluation of mechanization options (1.1, 1.4) – planting machine options

Economic evaluation of transplanter option was conducted by surveying owners/users in 4 villages where transplanters were used in 1-6 seasons in Central Laos in December 2017. The cost (labour, hiring cost of transplanter and trays, and materials cost such as fuels) of preparing seed trays (soil preparation and seeding) and transplanting in the field was made. At the same time, the cost of hand transplanting was surveyed for seedbed preparation, seedlings pulling and hand transplanting in the field. Farmers considered land preparation for transplanting by hand and machines were almost the same, and this operation was not considered for the economic comparison of the two methods.

Economic evaluation of seed drill was made similarly using input cost and income data obtained in 3 seasons in Takeo (see section 3a Agronomic evaluation).

5a. Dryers – in mills (2.1)

This small activity was conducted at three commercial mills near Phnom Penh. Rice cracking was observed from delivery of rough rice through drying and to milling processes.

5b. Dryers – flatbed dryers in comparison with sun-drying (2.3)

In Laos, flatbed dryers and sun-drying were compared in several seasons. In year 1, the experiments were conducted on-farm with participation of farmers in 5 villages (Pakpung village, Paksan district, Bolikhamxai province; Tung and Hatkhamhien villages, Xebangfai district and Paketue and Navangthong villages, Nongbok district, Khammouane province). Paddy harvested by combine was either sun-dried or by flatbed dryer (Photo 6). Dried paddy was collected for milling quality evaluation. A total of 16 paddy samples were collected from the farmers who participated in the experiment in the 5 villages – 8 samples from sun drying and 8 samples from the flatbed dryer. The flatbed dryer had 4 tonnes capacity and was used to dry paddy harvested by combine. The sun-dried paddy was harvested in the same manner and dried on tarpaulins which the project provided. Paddy was dried for about 10 to 12 hours on the flatbed dryer to reduce moisture content to 14%, while it took about 17-18 hours with sun-drying to reach the same moisture content. With sun drying, the paddy was dried from 8 am to 5 pm and was spread at a depth of 2 to 5 cm, and the paddy was turned over every 2 to 4 hours. When the paddy was dried to the target moisture content, samples were collected for milling quality evaluation.

In a set of experiments at RRC in Laos where time of harvesting during ripening was tested in 4 years, four experiments also examined sun-drying and the flatbed dryer. See section 5 Methodology 2c agronomic evaluation of combine harvester performance for similar work conducted in Cambodia.

In an experiment at RRC where head rice yields of three different glutinous varieties were evaluated when harvested by combine or by hand and stored for different durations, grain was dried using a flatbed dryer or sun-drying.

Photo 6 a. Flatbed dryer b. Sun drying

5c. Flatbed dryer options

Economic feasibility of flatbed dryer operation was considered for the charge rate and usage of the project flatbed dryer at Pakpung, Bolikhamxay in Central Laos.

6a. Physical properties of rice (2.4) – variety differences and storage

This was part of a MSc research project by Mrs Khamtai Vongxayya at Khon Kaen University. Three rice varieties grown in DS 2015/16 at ARC were harvested by combine or by hand and dried in the sun or artificially using a flatbed dryer. The dried paddy was stored at room temperature for up to 6 months. Milling quality of broken rice (%), milled rice (%), broken rice (%) and head rice (%) were determined after milling. Combine harvesting of VTE450-2 variety was delayed due to combine operational problems and was excluded from data analysis. This work has been expanded in 2017 and 2018 to examine the variety variation in head rice yield, and also how drying at room- temperature conditions affected head rice yield.

6b. Physical properties of rice (2.4) – varietal differences in broken rice and head rice yield under aerobic conditions with or without water stress

This work was conducted by a PhD student, Ms Ohnmar Myint, at Gatton, University of Queensland, from the 2016/17 season. In the first season, twenty contrasting japonica rice varieties were subjected to 3 water conditions in pot trials – well-irrigated aerobic rice (2-3 irrigations/week) with no water stress, 1-week stress, and 2-week stress. The water stress was imposed by stopping irrigation for the period and excluding rainfall by the use of rainout shelters. For each water condition, varieties were planted twice 10 days apart so that they were exposed to water stress at slightly different stages. The mild-stress water deficit was imposed 94-100 days after seeding for the first sowing time and 84-90 days after seeding for the second sowing. Crops were harvested and milling quality, including head rice yield and broken rice percentage, were determined in Wagga Wagga in NSW. In 2017/18 season, the same 20 varieties were grown aerobically with 2 or 3 times of irrigation. In another set of experiments, 4 contrasting varieties were studied in detail for their HRY response to water stress, time of planting, thinning and milling time.

7a. Value adding (2.6) – packaging and storage of milled rice

One experiment conducted at ARC in Laos, described in 5a above, examined the change in rice quality when paddy was stored for up to 6 months. There were three varieties, harvested by combine or by hand, and dried using flatbed dryer or sun-drying.

Another experiment was conducted at ARC to determine different storage conditions of milled rice for maintenance of quality. The effect of packaging under vacuum and nitrogen conditions was determined for brown rice and milled rice for three varieties (black rice, TDK8 and Kainoi). A similar experiment was conducted at UQ by a PhD student, Malik Nawaz.

7b. Value adding (2.6) – green and brown rice

This work commenced in late 2017 as a project of a PhD student, Chao Sinh. One experiment was conducted in Cambodia and another at Gatton. The crops were harvested at regular intervals after flowering to obtain green rice (immature grain) and then brown rice. Brown rice was produced in a standard manner, in addition paddy rice was germinated to produce germinated brown rice. Grain quality was determined and practical ways to add value to rice will be considered. At Gatton 8 varieties were used to determine genotypic variation in brown rice quality.

8a. Agronomic evaluation of innovative cropping systems under different water availability conditions (3.1) – rice/non-rice systems

This activity was conducted mostly as an on-farm demonstration. In both countries, the main emphasis was to demonstrate that the addition of a non-rice crop after harvesting WS rice will be beneficial to farmers when there is not sufficient irrigation water to grow DS rice.

In Cambodia, seed-drills were used for demonstration in target villages. They were packaged with CARDI technology. In EWS 2017, four field demonstrations were carried out in O'Saray in Takeo province with the objectives to (1) determine the differences between broadcasting (farmer practice) and using the seed drill on rice growth and yield under rainfed lowland conditions; (2) to demonstrate the difference in economic benefit between the two methods by recording the production costs for each; and (3) increase rice yield, food security, and income for farmers. All field demonstrations were divided into 2 plots: (1) CARDI technology package including Cambodian seed drill and (2) farmer practice. Among the four fields established by drill, three field crops appeared to have achieved good establishment while one had some problem with establishment as the drill did not drop seeds in a line.

8b. Agronomic evaluation of innovative cropping systems under different water availability conditions (3.1) – rice-rice systems

In Cambodia, a new rice variety with high grain quality has been released (Phka Rumduol Prang) which is suitable for planting around October-November. This variety could be used to develop a new cropping system as the existing varieties with high grain quality, such as Phka Rumduol, are not suitable for planting in the late WS-early DS period. The option to use Phka Rumduol Prang in late October-November after harvesting WS rice was tested at CARDI in DS 2015/16. To find the optimal sowing time, particularly the latest time Phka Rumduol Prang can be planted at the beginning of the DS, a non-replicated trial was conducted where this variety and Chul'sa were sown at 6 different times at 10-day intervals from 21 October, with seedlings transplanted 15 days after sowing. In Laos, a ratooning option was examined where currently only a single rice crop is grown each year. Ratooned rice could be produced at the end of DS when there is standing water at the harvesting.

9a. Varietal improvement (2.5, 3.2) – rice

For rice in Laos, the project targets were for quick maturity, improved aroma of early-medium maturing non-glutinous varieties, and photoperiod-insensitive glutinous black rice. Several crosses made in the first 12 months of project commencement or earlier have been advanced to the next generation each season throughout the project period. For quick-maturing varieties, the project conducted multiple location trials in Central Laos involving up to 19 quick-maturing rice varieties across 3 seasons.

9b. Variety improvement (2.5, 3.2) – non-rice crops in Laos

The objective of varietal improvement work for non-rice crops (waxy maize, mungbean, and peanuts) was to identify and select an early-maturing and high-yielding variety of each crop. All the experiments were conducted at the Research Farm, Agricultural Research Centre (ARC), Vientiane, Laos.

For maize, a randomized complete block design with 3 replications was used for selection of 30 lines for two dry seasons, DS 2015 and DS 2016. The 30 varieties were collected from local areas and neighbouring countries such as Thailand and China. Each plot consisted of 4 rows, 5 m long with spacing of 0.75 m between rows and 0.25 m between plants. Each variety was covered with ear bags, and the tassels of each selected plant were also covered with tassel bags to prevent cross pollination.

For mungbean and peanuts, germplasm was collected from Laos as well as from Thailand, Vietnam, and the AVRDC. They were grown for multiplication of seed in WS 2014 at ARC. A total of 16 varieties of peanuts and 25 varieties of mungbean were grown in 10 to 15 rows (depending on seed availability). In DS 2015, WS 2015 and DS 2016 yield trials were conducted at ARC. The experimental design was RCBD with 3 replications. Each variety was sown in 4 rows, each row 5m long. The distance was 30cm between rows and 25cm between plants. When seedling emergence was poor 5-7 days after sowing, seed were re-sown and only 1-2 plants/hole were kept.

9c. Variety improvement (2.5, 3.2) – non-rice crops in Cambodia

Mungbean, waxy maize, and peanuts were evaluated at CARDI initially, and some promising lines were tested on-farm. Mungbean lines were tested at CARDI. Promising maize lines were tested on-farm for a few years. CM1 maize was tested in 29 on-farm adaptation trials in DS 2016. Evaluation of peanut varieties for high yield performance and short duration continued during the project, and 12 varieties were tested in multi-location trials in DS 2016 and DS 2017.

10. Socioeconomic analysis of intensified and diversified production systems (3.3)

Our agronomic study of use of seed drill on crop intensification and diversification in two typical rainfed lowland villages with no canal irrigation but with ponds, one more water available than the other in Takeo, Cambodia indicated that the addition of a crop is feasible in some years. Thus in Tramkok commune 3 crops may be planted, and the other 2-2.5 crops in one year. We have thus estimated economic benefit of adding mungbean, using the cost of growing it and the profit from the sale of crop.

In addition, other information collected were used for the estimation of economic benefit of the intensified/diversified cropping system.

6 Achievements against activities and outputs/milestones

Objective 1: To assess crop mechanization options for increased productivity

No.	Activity	Outputs/ Milestones	Due date of output/ milestone	Comments
1.1	Diagnostic analysis of value-chain and agribusiness constraints and opportunity for mechanization	Output 1.1.1: Baseline data and information on value-chain and agribusiness collected and critical areas for mechanization identified Output 1.1.2: Opportunities and constraints to business development further identified with the availability of data collected in the project; Output 1.1.3: Sustainable agribusiness opportunities identified and generic business plans developed.	1.1.1 Sept 2014 1.1.2 Sept 2016 1.1.3 Dec 2017 (some mechanization items earlier)	Completed in 2014/15 (Report 23) Combine contracting opportunities identified. (Report 24,25; Journal Paper 2,11,12) Some opportunities identified and generic plan developed particularly for combine and seed drill (paper 10,11,12)
1.2	Agronomic evaluation of combine harvester performance	Combine efficiency determined; Output: 1.2.1.1) with contractors and field grain loss quantified in at least 4 villages in Cambodia, 1.2.1.2) quantified in at least 4 villages in Laos, and 1.2.1.3) for harvesting crops at different times of grain maturity. Output 1.2.2: Advantages and limitations of combine harvester identified	1.2.1.1 July 2015, 1.2.1.2 Sept 2016 1.2.1.3 Sept 2017 1.2.2 Sept 2017	1.1 and 1.2. Combine harvesting efficiency determined in both Cambodia and Laos; Journal papers 6, 9,11,12 and 13. 1.3. Harvesting time effect determined; Journal papers 6,9,13. 2. Advantages and limitations of combine harvester identified; Journal papers 2,11,12 Report 24,25)
1.3	Agronomic evaluation of direct seeding drill, transplanters and land preparation measures	Output 1.3.1: Farmers consulted and technologies for OFR identified; Output 1.3.2.1) productivity gain determined for transplanters with rice and seed drill performance relative to hand seeding tested with rice, maize and mungbean, 1.3.2.2) optimal soil moisture for drill planted determined for rice varieties,	1.3.1 Sept 2014 1.3.2.1, 1.3.2.2, 1.3.2.3 Sept 2016	1. Completed in 2014/15 2.1 Seed drill and transplanter for rice evaluated; Journal papers 10. 11, Report 24-26. Drill for non-rice crops investigated; Reports 26-28.

		maize and mungbean, and 1.3.2.3) effect of deep ripper on productivity of maize, mungbean and rice quantified. Output 1.3.3: Advantages and limitation of the various mechanisation items identified.	1.3.3 Sept 2017	2.2. Optimum soil moisture for drill planting determined for 4 crops; Report 40. 2. 3 Deep ripping effect on maize, mungbean and rice evaluated; Report 39. 3. Advantages and limitation of various mechanization items identified; Journal papers 10, 11, 12 Reports 26-28
1.4	Socioeconomic analysis of mechanisation options.	Output 1.4.1: Labour productivity and economic analysis determined; Output 1.4.2: Risk analysis determined.	1.4.1 Dec 2016 1.4.2 Dec 2017	1. Labour productivity and economic analysis determined for mechanization options; Journal paper 10.11,12. 2. Some risks are identified for each item 10,11,12

PC = partner country, A = Australia

Objective 2: To evaluate agronomic and post-harvest innovations for adding value

No.	Activity	Outputs/ Milestones	Due date of output/ milestone	Comments

2.1	Diagnostic analysis of value-chain and agribusiness constraints and opportunity for dryers	Output 2.1.1: Baseline data and information on value-chain and agribusiness collected and critical areas for dryers identified Output 2.1.2: Opportunities and constraints to business development further identified with the availability of data collected in the project; Output 2.1.3: Sustainable agribusiness opportunities identified and generic business plans developed	2.1.1 Sept 2014 2.1.2 Sept 2016 2.1.3 Dec 2017	1. Importance of artificial drying recognized. 2. Opportunities and constraints to business development identified from Pakpung, Laos, and further investigated in Takeo, Cambodia. 3. Agribusiness opportunities identified, including the limitation of the current type of dryer;
2.2	Identification of optimum rice drying conditions in mills	Output 2.2.1: Percentage of cracked grains determined and compared across harvesting (manual or combine) techniques and during the transport and storage prior to drying in mills. Output 2.2.2: The effect of temperature and moisture profiles (in flat bed and column dryers) on broken rice quantified and monitored over time. Output 2.2.3: Optimum drying conditions determined for different varieties and for paddy at different moisture conditions; Output 2.2.4: Millers adopt the new drying operating condition depending on the variety and moisture contents. Output 2.2.5: Economic benefit of adopting optimum drying regime evaluated	2.2.1 July 2015 2.2.2 Sept 2014 2.2.3 Dec 2015 2.2.4 Dec 2016 2.2.5 Dec 2017	1. Completed in 2015; journal paper 13. 2-5. Current practices in mills are documented for both countries (paper 13), but due to difficulty in securing participating mills, this part was discontinued.

2.3	Assessment of community dryers for rice and other crops	Output 2.3.1: Flat bed and solar dryers installed and tested; Output 2.3.2: Optimum drying temperatures and time requirements determined for various rice and non-rice crops at a range of starting moisture levels; Output 2.3.3: Optimum management system developed; Output 2.3.4: Cost/benefit of use of dryers determined	2.3.1 Dec 2014 2.3.2 Dec 2016 2.3.3 June 2017 2.3.4 Dec 2017	1. Flatbed and solar dryer tested since 2015; journal papers 8, 9. 2. Optimum drying time determined but drying temperature not examined due to difficulty in controlling it. 3. Optimum management system developed 4. Identified limited competitiveness of the present type of dryer; Journal paper 9,11
2.4	Analysis of physical properties of paddy during drying and milling	Output 2.4.1: Mechanical properties of rice kernels based on the moisture contents for all common varieties of paddy determined and fundamental research undertaken at UQ on rice cracking mechanism for rice varieties in Cambodia and Laos Output 2.4.2: Effect of readsorption of moisture by dried paddy on rice cracking of various varieties of rice grains quantified. Output 2.4.3: Varietal difference on rice kernel breakage at different moisture levels during dehusking and whitening/polishing stages determined Output 2.4.4: Effect of heating and cooling cycles and a range of humidities (as occurs in solar or sun drying during the day and night or sunny and cloudy periods) on rice cracking determined Output 2.4.5: Recommended best practise for drying for common varieties of rice developed to reduce rice cracking with a comparison of drying systems included	2.4.1 Dec 2016 2.4.2 Dec 2016 2.4.3 March 2016 2.4.4 March 2017 2.3.5 Dec 2017	1. Mechanical properties determined at UQ since 2016 July. 2-4. Variety differences in cracking and broken rice determined in NAFRI and UQ (Journal paper 8, conference abstract 16). Some of the variation in broken rice is due to variation in degree of milling (DOM). 4 Varietal variation in broken rice and head rice yield to various growing conditions determined; Conference abstract 16 5 Best practice for drying rice varieties determined; journal paper 8, 9.

2.5	Variety selection for high quality	Output 2.5.1: Variation in quality among advanced breeding lines established for each crop (rice, peanuts, waxy maize, mungbean). Output 2.5.2: High quality threshing peanuts, maize, and also non-glutinous rice in Laos will be identified through farmer participatory selection. Output 2.5.3: Seed of promising lines multiplied.	2.5.1 Sept 2015 2.5.2 Sept 2016 2.5.3 Dec 2017	1. Variety collection and characterization completed in 2014/15. 2. High quality varieties identified and on-farm testing conducted; Reports 29-32. Some promising rice lines are in replicated trials in Laos (Report 30). A new peanut line is ready for release in Cambodia. 3. Seed of promising lines multiplied.
2.6	Identification and appraisal of value-adding options (processing, packaging, branding) for selected crop products	Output 2.6.1: Several options for packaging and branding appraised and tested; Output 2.6.2: Development partners identified in Australia and marketability tested	2.6.1 Dec 2015 2.6.2 Dec 2016	1. Rice grain quality under three packaging conditions for several products tested after various storage durations; a report. The benefit of green immature rice, and improving texture of brown rice being examined. 2. A potential Australian partner identified but not approached.

PC = partner country, A = Australia

Objective 3: To evaluate intensified, diversified, and market-oriented cropping systems to take advantage of mechanization and value-added produce

No.	Activity	Outputs/ Milestones	Due date of output/ milestone	Comments

3.1	Agronomic evaluation of innovative cropping systems under different water availability conditions	Output 3.1.1: A few cropping system options (rice-maize, rice-mungbean, rice-peanuts, rice-rice, rice-rice-vegetable) are tested and productivity determined; Output 3.1.2: Water requirement identified for a few systems (rice-maize, rice-rice); Output 3.1.3: Contribution of mechanization (combine, seed drill) to the innovative cropping systems determined; Output 3.1.4: Contribution of availability of dryers particularly in early wet season rice in Cambodia and dry season rice in Laos, to the flexibility of cropping systems determined; Output 3.1.5: Economic benefit of using quick maturing varieties determined. Output 3.1.6: Agronomic package for innovative cropping system developed for three water domains investigated	3.1.1 Dec 2016 3.1.2 June 2016 3.1.3 Dec 2017 3.1.4 Dec 2017 3.1.5 Dec 2017	1. A few cropping systems tested and productivity determined. 2. Water requirement completed by June 2016. 3-4 Contribution of combine and seed drill and dryer to the innovative cropping system determined. 5. Values of quick maturing varieties are yet to be determined. 6. Agronomic package developed for some water domains (drilled rice for dry areas, ratooned option for flood-prone area, drilled non-rice crops after WS rice, and double cropping of high quality rice for favourable water conditions.
3.2	Variety selection for short duration	Output 3.2.1: Yield variation among quick maturity lines determined and other characters associated with mechanization conducted (determinate mungbean, maize and mungbean, and also quick maturing rice in Laos); Output 3.2.2: Suitable varieties identified; Output 3.2.3: Seed of promising lines multiplied.	3.2.1 Sept 2015 3.2.2 Dec 2016 3.2.3 Dec 2017	1. Variation in yield and other characters determined for rice, mungbean and maize. 2. Suitable varieties identified 3. Seed multiplied.

3.3	Socio-economic analysis of intensified and diversified production systems	Output 3.3.1: Baseline information on the farmers and their cropping system in selected sites Output 3.3.2: Economic and risk analysis determined; Output 3.3.3: Long term impacts on economy at micro and macro level identified; Output 3.3.4: Long term social impact considered; Output 3.3.5: Impact and inclusiveness of interventions monitored.	3.3.1 Sept 2014 3.3.2 June 2017 3.3.3 Sept 2017 3.3.4 Sept 2017 3.3.5 Dec 2017	1. Completed in 2015; Report 23 2. Some economic data are available. Potential effect can be large by avoiding flood risk, but further data are required for any determination of long term impacts.

7 Key results and discussion

1a. Villages baseline information- Cambodia

2014 survey

Unless stated otherwise, this section describes the results of survey conducted at the commencement of the project in 2014. In the 10 villages in 3 provinces, household size was quite consistent, averaging between 4 and 6, and accordingly the number of full-time household workers averaged 2 to 4. In Steung village the average landholding was only 0.7 ha but landholdings averaged between 1.0 and 1.9 ha in the other villages where DS rice fields were not available. Out of the 10 villages, 6 villages had some DS rice land, but the area was much smaller than the WS rice area. In 9 villages between 60 and 90% of households owned less than 1.0 ha of WS paddy land. In most villages less than 10% of households had more than 2 ha of paddy fields, but in Trapeang village about 40% had large paddy farms of 2 ha or more. The general cropping calendar for the surveyed villages is shown in Fig. 7.1. The actual choice of crops in each season was largely dependent on access to irrigation.

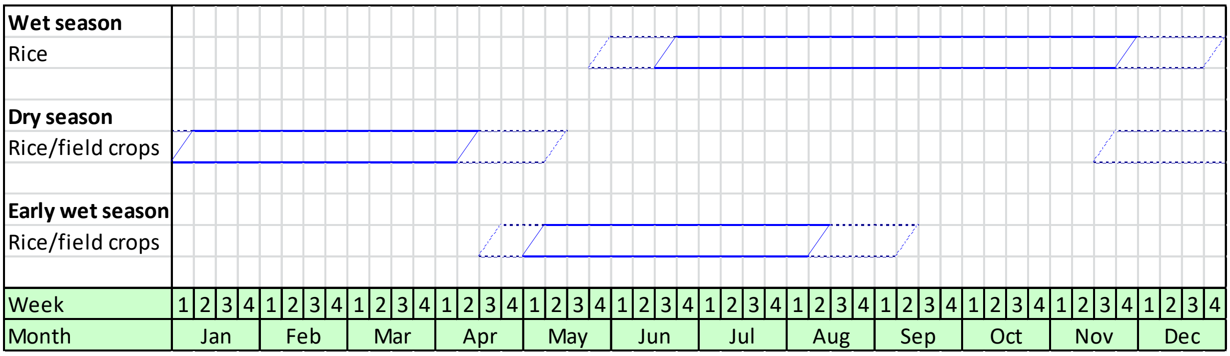


Figure 7.1 Cropping calendar for the ten surveyed villages

Though the study villages were generally categorised as being in the rainfed lowland environment, three major sources of irrigation water – small and large scale reservoirs, canal systems, and groundwater – were identified, but at least two villages had no access to irrigation water. The three identified sources of water were accessed by different methods of irrigation. The large and small reservoirs reported in four locations in Takeo and Kampong Speu Provinces were favourable for gravity irrigation, motivating farmers to grow DS rice. This was because there was no pumping cost, unless the water level in the dam was low, requiring pumping from the reservoir to the distributary canals, in which case a charge was applied. However, Steung village in Takeo, despite having access to reservoir irrigation, only had sufficient water to grow non-rice crops in the DS. Tadaeng Thmei village in Kampong Speu, which also had access to a large reservoir, preferred growing peanuts to rice in the DS due to the higher return, apart from minimising the water requirement.

Large water pumping stations lifting water from streams to concrete distributary canals were recently established in many locations in Kampot Province. This encouraged farmers to plant DS rice, despite having to pay water fees, because there was no risk of water shortage or crop failure. Farmers in these locations also grew glutinous corn during the DS. Another reliable irrigation source was groundwater from which water was extracted through plastic tubewells and portable engine-driven pumps. This type of irrigation was mainly adopted in Prey Kabas district of Takeo where farmers cultivated radish and cucumber in the DS.

Every farm household in the ten villages surveyed owned WS rice land which was fully cultivated, but not all households in the DS rice villages had access to plots of DS rice land. The DS rice land was not always fully cultivated because this would have meant the farmers experienced water shortage. Alternatively, farmers in all villages cultivated non-rice crops to minimise the water requirement during periods of water scarcity in the DS. Different crops were cultivated in those villages based on their long-term practices, with peanut, radish, watermelon, cucumber, glutinous corn, and pumpkin being the major DS non-rice crops. EWS rice was planted in every village in addition to WS rice, but only some households used only part of their paddy lands for this additional rice crop.

The cultivation of WS rice was mainly for household subsistence, with the surplus used for the cash income required to pay for production inputs and meet the household's daily expenses. Despite owning small rice fields, most farm households were able to sell some of their rice crop. The cultivation of EWS rice had a double role, providing extra rice to those households which experienced rice shortage and generating cash for those families which had sufficient WS rice. All DS non-rice crop cultivation was for cash income, with a small quantity retained for home consumption.

Only three of the ten villages could cultivate DS rice while the others grew only non-rice field crops. The non-rice crops were irrigated from small or large reservoirs, canals, and groundwater, but were also planted with no supplementary irrigation in some villages, with farmers relying on residual soil moisture and the slight chance of some early rainfall.

Both rice and non-rice crops were reported to be cultivated in the EWS between May and August, with a possibly wider planting window. The EWS rice crop was widely cultivated from May to August but harvesting could be delayed until September. Among the field crops, watermelon, cucumber, mungbean, pumpkin, and peanut were cultivated based on a high expectation of rainfall, regardless of the availability of irrigation.

Single-cropping (WS rice–fallow) was rarely practised in the study villages, having been replaced by double- or even triple-cropping systems, though generally only part of the paddy field was cultivated in the DS and EWS because of the restricted water supply. The double-cropping systems were WS rice–DS rice/field crops and WS rice–EWS rice/field crops. The triple-cropping system was WS rice–DS rice/field crops–EWS rice/field crops.

Crop intensification and diversification has the potential to improve the availability of cattle feed, either through planting forages or the utilisation of by-products from the non-rice crops. As a result, raising cattle can significantly contribute to farm household income. Even though cattle were owned by the majority of households, their role in land preparation had declined. Only 10-30% of households used cattle for ploughing their paddy fields, except in Tadaeng Thmei where the proportion was 80%.

The proportion of households with two-wheeled tractors varied from 2% to 19% and there was no report of four-wheeled tractors or other machinery such as reapers or combine harvesters. Though the number owning hand tractors in each village was small, this did not reflect their use for land preparation as every owner of a hand tractor could provide contract services, apart from the many contractors from other villages. Two-wheeled tractors were largely used for land preparation, though their usage varied from 20% in Ta Daeng Thmei to more than 90% in Daem Snai. Farmers indicated that tractors were more convenient than draught animal power, which required more working days and was difficult to coordinate with labour exchange practices. Two locations in Kampot reported that land preparation was done by a contractor with a four-wheeled tractor.

Apart from the increasing common problem of labour shortage, drought conditions had forced farmers to shift from the traditional practice of transplanting to direct seeding in 2014. According to the 2016 survey, the majority of farmers in the ten villages as well as other locations have continued to use broadcasting due to the constraint of family and hired labour. Farmers reported paying USD 150/ha for transplanting labour, excluding an estimated USD 50/ha for the cost of pulling seedlings. This was not only very costly but farm labour was often simply unavailable, with only old people and school-age children remaining in the village.

Though the village statistics showed no reapers or combine harvesters in the villages, this did not indicate the absence of mechanised harvesting. Contract services were available, as well as contract land preparation with four-wheeled tractors, though the latter was used only for DS rice land preparation in some locations in Takeo and Kampot. Harvesting of DS rice was largely carried out by combine harvesters, with some households reporting the use of reapers. However, in the 2014 survey, manual harvesting remained the dominant practice for WS rice due to the high incidence of lodging. Nevertheless, the trend of increasing labour shortage will increase the use of mechanised harvesting. The survey in 2016 showed that use of combine harvesters for WS rice had increased substantially. The cost of manual harvesting averaged around USD 130/ha, ranging from USD 80 to 180. The charge for hiring a combine harvester varied between USD 75 and 150, depending on the crop situation. The contract cost of harvesting WS rice was generally higher than for DS rice, with the use of short-statured and non-lodging varieties more favourable for the efficient performance of the combine harvester.

In most villages, 70-80% of households had members engaged in off-farm or non-farm work. One or possibly two family members, mostly daughters and sons aged between 25 and 35, went to work in the non-farm sector, either in Cambodia or other countries. According to village records, from 6 to 96% of households had a young family member employed in non-farm work outside their village but in-country, totalling 10 to 200 people per village. In addition, 7 villages had more than 20% of the total village population registered as workers in foreign countries, totalling between 20 and 130 people per village. The high income from non-farm employment encouraged young family members to leave the village, adding to the farm labour shortage.

2018 survey

A total of 502 farmers from different families were interviewed in 10 target villages and nearby areas in 2018. Results of some items have confirmed the earlier 2014 survey results but other aspects also highlight changes that have taken place in the last 4 years. In the region, WS rice is the main cropping activity, but rice was also grown in other seasons together with non-rice crops (Table 7.1). Income from crops per family was similar for WS rice, DS/EWS rice and non-rice crops, but the proportion of families engaged in non-rice crops was smaller. Overall crops contributed slightly more than livestock to total family income, but by far the largest source of family income was from non-farm work and most families were engaged in this activity. On the other hand, people engaged in off-farm work, such as casual labour for cropping, were limited. According to village statistics, non-farm activity was mostly in Cambodia, and the number employed in the country has increased in the last 4 years while the number of those working overseas has declined in the same period

(Table 7.1d). During the same period, the number of hand tractors owned by villagers increased to 370 hand tractors among 2181 families in 10 villages. Several villagers now own tractors and combine harvesters.

Table 7.1. Summary results of interviews in 2018 with 502 farmers in 10 target villages and nearby villages in Takeo, Kampot and Kampong Speu provinces in southern Cambodia. Tables 1d and 1e are based on village statistics, and the number of people is in relation to the total number of families (2181) in 10 villages.

a) Crop production. The proportion of families (%) involved, area (ha) and yield (kg/ha) in each cropping activity

	WS rice			DS rice			EWS rice			Non-rice crops		
	%	(ha)	kg/ha	%	(ha)	kg/ha	%	(ha)	kg/ha	%	(ha)	(USD)
Average	100	0.94	2,911	37	0.76	4,164	48	0.62	3,601	18	0.32	554

b) Commercial crop production- the proportion of families involved and income per family in each cropping activity.

	WS rice		DS/EWS rice		Non-rice crops	
	%	USD/year	%	USD/year	%	USD/year
Average	51	498	50	718	20	591

c) Major sources of income per family. The proportion of families engaged and income in each activity.

	Crops		Livestock		Off-farm labour		Non-farm work	
	%	USD	%	USD	%	USD/year	%	USD/year
Average	69	831	52	729	7	349	85	3,821

d) Number of people from 10 villages engaged in Non-farm work in the country and overseas in 2014 and 2018.

	Cambodia		Overseas	
	2014	2018	2014	2018
Total	890	1356	468	389

e) Change in farming machinery ownership between 2014 and 2018.

	Tractor		Hand tractor		Combine harvester		Reaper	
	2014	2018	2014	2018	2014	2018	2014	2018
Total	0	7	200	370	2	6	0	16

During the 4 year period, combine contracting service adoption has increased greatly in all villages, but there was considerable variation among villages (Figure 7.2). Thus, the adoption rate was more than 80% in 4 villages while it was less than 40% in 3 villages.

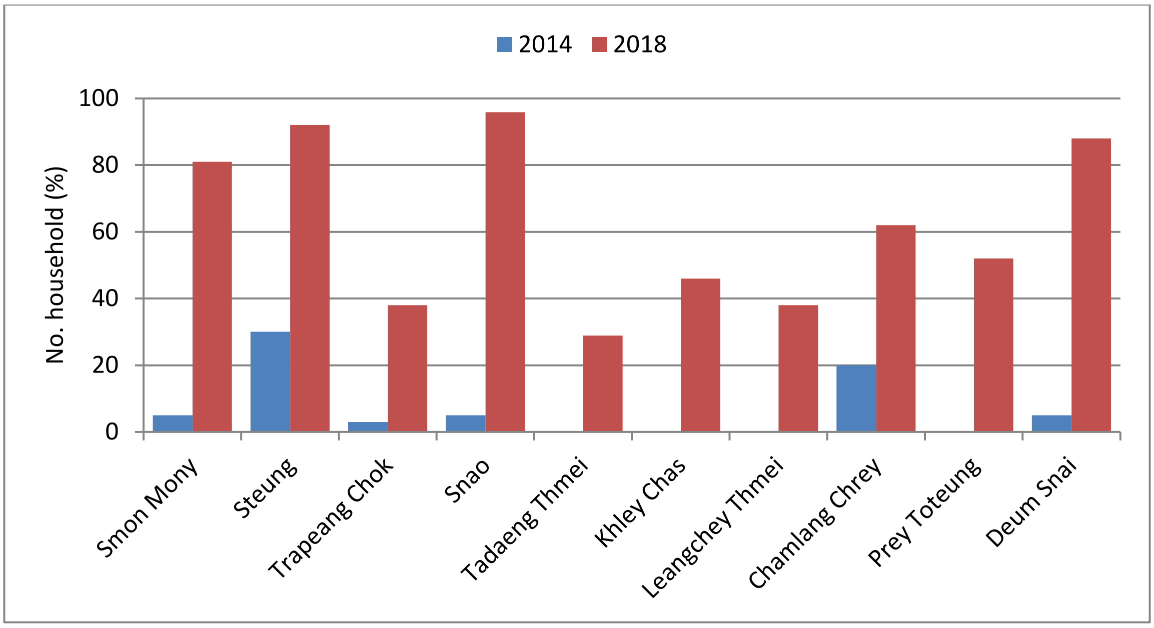


Figure 7.2. Change in adoption of combine harvesting service in 10 target villages in southern Cambodia over the last four years.

This variation in combine adoption among 10 villages was examined with a number of variables determined in the survey including family labour availability, rice area, income level from different on-farm and non-farm activities. The highest correlation was found with income from crops particularly DS/EWS rice income (r= 0.83**, Figure 7.3) compared to WS rice income (r=0.59ns) and total crop income (r=0.64*). Non-farm income was not related to combine adoption. While there were variations among villages in labour availability, rice area and also rice area/labour availability, they were also not related to combine adoption. Thus, there is indication that villages with high income from crops particularly DS rice, were more likely inclined to adopt combine harvester. This may be related to the cash available to pay combine contracting fees. This may also be related to historical development of combine adoption in that combine was first used for harvesting dry season crops which are generally shorter in stature and are less prone to lodging, and also grown more for commercial purposes rather than home consumption.

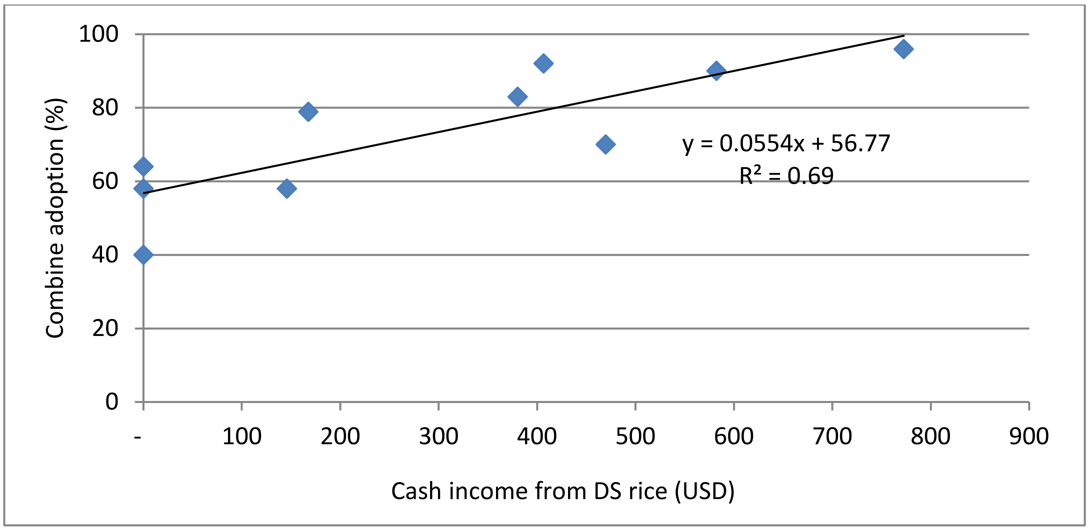


Figure 7.3: Relationship between combine harvester adoption and DS rice income among 10 villages surveyed in southern Cambodia in 2018.

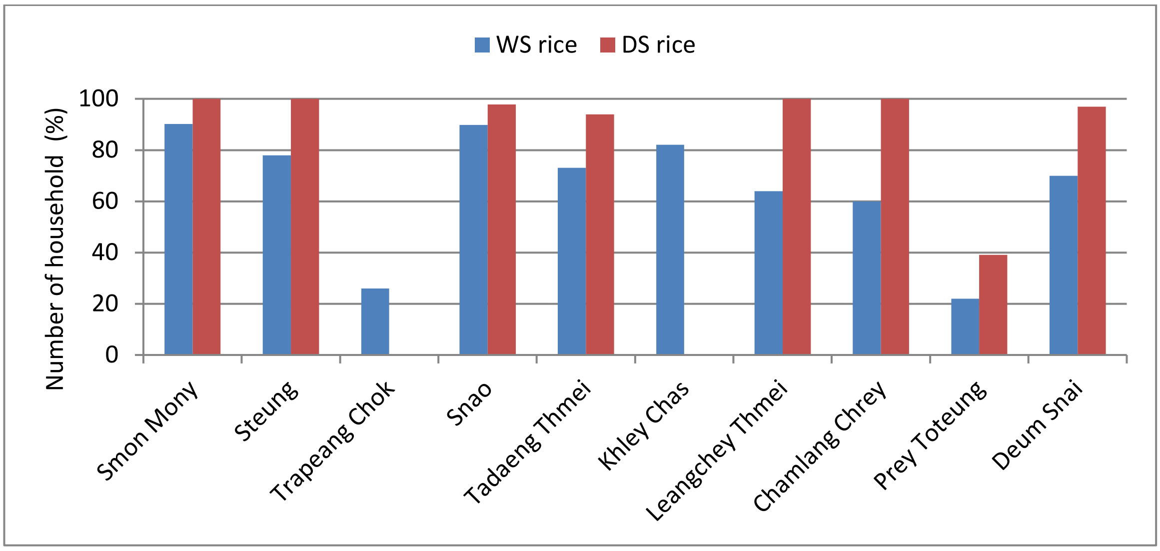


Figure 7.4: Adoption of manual broadcasting practice in 10 villages in southern Cambodia in 2018.

Another change that has taken place in the last 4 years is the rapid adoption of broadcasting; thus manual transplanting is now hardly practised in most villages where DS rice is grown (Figure 7.4). In WS, adoption of broadcasting exceeded 80% in three villages, but it is still less than 30% in two villages including Trapeang Chalk village where combine adoption was also low. Among 10 villages, there was similarity in adoption of broadcasting and combine harvesting; they tend to be high in DS irrigated areas and low in poorer villages.

In Trapeang Chok village, manual harvesting was still up to 60%, the highest figure among the ten villages. Off-farm work was engaged by the highest number of farmers in the village and also provided the highest income from this source of income. This could be consistent between the low rate of combine adoption and high income from off-farm labour earning from manual harvesting. This could also indicate that casual labours were easily hired here compared to other villages. Even though the farmers mentioned a couple of factors that determine combine adoption, financial constraint was one of the major barriers. They had to pay combine contract fee immediately after the harvesting job was completed but payment for hired labour could be delayed because they were neighbour households. According to Trapeang Chok village chief, there was a high rate of poor families in his village.

2a. Agronomic evaluation of combine harvester performance (1.2) – Field conditions

From the results of three seasons of experiments (DS 2014/15, WS 2015, DS 2015/16) conducted in Khammuan and Bolikhamxay in Laos, we found that combine efficiency as measured by the area of rice field harvested in one day was low at 2.8 ha/day for small paddies less than 1,000 m^2, and the efficiency increased with field size. The maximum efficiency of about 5 ha/day was obtained in a field size of 2,000-3,000 m^2, and no further efficiency gain was found over 3,000 m^2 (Figure 7.5). Thus it appears that 3-5 paddies/ha may be the optimal size for rainfed lowland rice in Central Laos. The time required to harvest a 1.9 ha farm was compared between small size fields of 500-1,000 m^2 and the optimal size of 2,000-3,000 m^2. The combine could harvest the 1.9 ha farm with optimally-sized fields in about 3 hours, while it took more than 5 hours in the more traditional farm with small fields (Figure 7.6).

The combine efficiency estimated above does not include the time required to cross the bund; the efficiency of an enlarged field would be further increased as the number of crossings is substantially reduced. However, another factor that would have affected combine harvesting efficiency was the distance between the paddies that were to be harvested, affecting travel time. While this was not determined in our work, judging from the time our operator spent in moving between the fields, this appears to exert a large effect on the overall combine efficiency and hence the profitability of operators. This suggests that a combine is most efficient when a number of neighboring fields of large size are harvested in one day. The advantage of larger field size may also apply to other mechanized field operations such as land preparation and planting by seed drill and transplanter.

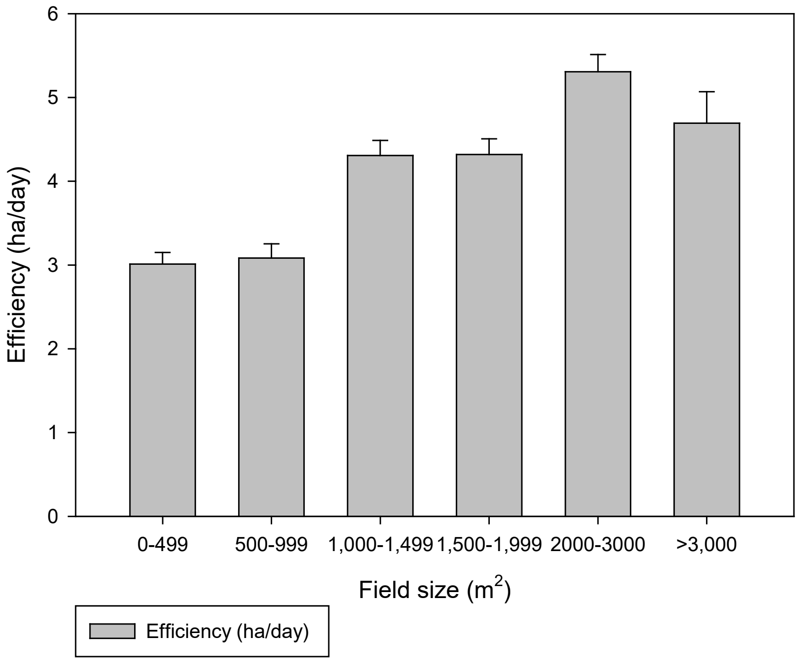


Figure 7.5. Mean combine harvesting efficiency (ha/day) and standard error for different field sizes (m^2) as measured in 3 seasons in Khammouan and Bolikhamxay, Laos. Error bars indicate SE. Xangsayasane et al. 2019

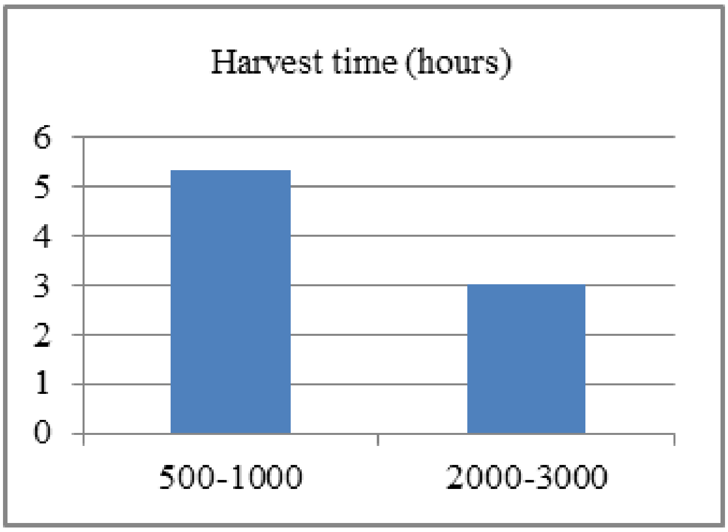


Figure 7.6. Combine harvesting time (hours) required to harvest 1.9 ha rice farm with small (500-1,000 m^2) and large (2,000-3,000 m^2) paddy sizes

The combine efficiency response to field size was similar in all seasons, although the actual efficiency varied slightly among the seasons. However, we found that yield advantage of enlarged field size was small in any season. That is, yield was generally not affected by field size; the mean yield was 3.1 t/ha across the three seasons studied.

The advantage of larger field size may also apply to other field operations such as land preparation and mechanized planting; these advantages for different operations may be examined in the future. In addition, farmers in our villages believe water is saved with enlarged fields, perhaps also as a result of leveling. Time spent in water management may also be reduced with the reduction in the number of levees.

It should be pointed out, however, that large paddies are not always advantageous if field enlargement requires considerable soil movement. The slope of the land is critical – if we wish to move soils of only 10 cm depth, then a 2% slope would result in 5 m wide paddies (500 x 0.02 = 10). If the slope is greater than this, a proper method of removing the topsoil first and leveling the subsoil before putting the topsoil back on the field needs to be considered. Unless this procedure is followed, the subsoil will be exposed and plant growth might be severely affected. In sloping areas where the size of paddies is small, enlargement should follow the contour lines to reduce the chance of subsoil exposure, meaning that long, narrow paddies may be created. Thus, the optimal size as well as the shape of the enlarged field would depend on the topography of the area. Development of a competent four-wheeled tractor contracting service is required for proper field enlargement.

While paddy field size is an important factor determining combine harvester efficiency, other factors are also important. The results of three dry seasons and three wet season suggests that harvesting is more efficient in the dry season (Table 7.2). Combine harvesting was most efficient in DS 2015-16 despite the small mean size of the fields (1,280 m^2), compared with 1,756 m^2 in DS 2014-15 and 1,506 m^2 in WS2015. Combine harvesting in the WS was less efficient, perhaps because fields tend to be boggy and there is more lodging (Photo 7.1). The latter was partly due to the use of traditional rice varieties with tall plant types in the WS. This reduced efficiency in the WS corresponds to combine contractors charging more in the WS in Cambodia (USD 100/ha cf. USD 70/ha in the DS). In DS 2016/17 and WS 2017, combine efficiency was similarly high when the field size was large and crops were well managed near Rice Research Centre.

Table 7.2. The mean field size and combine harvesting efficiency determined in six seasons in Central Laos. Xangsayasane et al. 2019

Seasons	Number of fields harvested	Field size (m^2)	Combine efficiency (ha/day)
DS2014/15	75	1,715	4.17
WS2015	62	1,506	3.45
DS2015/16	76	1,280	4.06
WS2016	125	2,021	3.24
DS2016/17	45	3,383	4.89
WS2017	22	3,192	4.98

The method of crop establishment also affected combine efficiency. When data for the three seasons are combined, it is clear that crops established from broadcasting gave rise to less-efficient combine harvesting than transplanted crops (Table 7.3). This was the case even though fields established by broadcasting were considerably larger (which would increase combine efficiency). Thus when fields were selected so that the mean size was about 2,000 m^2 across all crop establishment methods, the difference became greater. The combine efficiency of the broadcast crop was about 21% lower than with hand transplanting. At least part of this inefficiency was associated with the tendency of broadcast crops to lodge. Of the 65 crops established from broadcasting, 17 lodged, while no lodging occurred in transplanted crops. When the combine efficiency for lodged crops was compared with non-lodged broadcast crops of similar field size, the mean yield of lodged crops was 37% lower than for non-lodged crops (Table 7.3).

(a)

(b)

(c)

Photo 7.1. Non-lodged (a) and lodged field (b); boggy paddy field with standing water (c)

Table 7.3. Effects of crop establishment method on combine efficiency and lodging effect for (a) all fields, (b) a subset of similar sized fields and (c) a subset of broadcast crops. Mean field sizes are also shown. Standard errors are shown in brackets. Xangsayasane et al. 2019.

Establishment method	Number of fields	Mean field size (m^2)	Mean efficiency (ha/day)
(a)	All fields (n=179)		
Broadcasting	65	2,000	3.57 (0.16)
Hand transplanting	50	1,451	4.01 (0.19)
Transplanter	64	1,008	3.89 (0.29)
(b)	Similar-sized fields (n=123)		
Broadcasting	65	2,000	3.57 (0.16)
Hand transplanting	32	2,008	4.53 (0.30)
Transplanter	26	1,977	4.49 (0.30)

(c)

Broadcast crops	Number of fields	Mean field size (m^2)	Combine Efficiency (ha/day)
		All field (n=65)	
Lodged	17	782	2.16 (0.20)
Non-lodged	48	2399	4.03 (0.15)
	20	768	3.49 (0.22)

Another set of factors affecting combine efficiency was related to the choice of variety in relation to the position in the toposequence (Table 7.4). In WS 2016, we harvested our crops early as our material was photoperiod-insensitive and planted in upper positions in the toposequence, together with some villagers' crops. However, most villagers' fields used photoperiod-sensitive KDML105 or other late-maturing varieties planted in the lower part of the toposequence. These late-maturing crops in the lower paddies were harvested much later and had lower yields (1.78 cf 3.23 t/ha), but they took longer to harvest by combine (3.0 cf. 3.6 ha/day). The lower yield in these late-harvested, lower fields may have been partly related to the use of old seed, as the farmers had not renewed their seed for a long time and had been using saved KDML105 seed from their own crops for many years. These crops in the lower fields also lodged more frequently (25/75 crops harvested by combine, cf. 3/50 combine-harvested, short-duration crops in the upper fields). However, even in the fields with no lodging, the efficiency of combine harvesting was less in the lower fields. This may be related to the larger biomass of long-duration, photoperiod-sensitive varieties.

A sharp contrast in the performance of varieties planted in the upper and lower fields is seen in Table 7.4. The upper fields were generally smaller and the crops were harvested earlier (all by 21 October) while the lower fields were larger and harvested during 11-20 November. The project recommended varieties XBF1, XBF2 and VTE450-2, which were all planted in the upper fields and harvested early. These had high yields and high combine harvesting efficiency, despite the generally small field size. On the other hand RD6 and TDK4, photoperiod-sensitive varieties grown in the lower fields, gave lower yields and appeared to have lower combine harvesting efficiency. The effect of different varieties on combine harvesting efficiency requires further study.

As these data for Exkang included two distinct field types harvested at different times, only the early-maturing crops, including all our crops in the upper fields, were considered further in analysing combine harvesting efficiency (Table 7.4). The effect of field size on combine harvesting efficiency was in general similar to the previous results obtained from Khammouan and Bolikhamxay, and it now appears clear that 2,000-3,000 m^2 should be considered an optimal size for combine harvesting efficiency (given the make and capacity of the combine used). In DS 2016/17 and WS 2017, analysis of combine harvesting efficiency was conducted using 45 fields near RRC (Table 7.5). For any given field size group, combine harvesting efficiency was similar to that obtained in Ekxang in WS 2016, but as the field size was generally larger in the RRC area, the efficiency was >30% higher.

Table 7.4 Combine efficiency and grain yield of rice varieties planted in upper and lower fields in Ekxang village, Vientiane, Laos, WS2016. Standard errors are shown for combine efficiency and grain yield. Xangsayasane et al. 2018

Variety	Number of fields	Mean field size (m^2)	Mean combine efficiency (ha/day)	Mean yield (kg/ha)
			Upper fields	
TDK9	8	652	2.93 (0.17)	2,906 (263)
VTE450-2	24	768	3.82 (0.18)	3,110 (261)
XBF1	3	1,111	3.92 (0.24)	3,272 (385)
XBF2	8	1,021	3.55 (0.42)	3,251 (392)
TDK12	5	990	3.43 (0.36)	2,411 (185)
			Lower fields	
KDML105	42	2,952	3.28 (0.17)	1,702 (53)
RD6	19	2,568	2.75 (0.15)	1,582 (54)
TDK4	14	2,171	2.49 (0.26)	2,308 (77)

Table 7.5. Combine harvesting efficiency for WS2016 (upper and lower fields), DS2016/17 and WS2017 in Vientiane. Combine efficiency obtained in upper and lower fields are shown separately in WS2016. Standard errors are shown in brackets. Xangsayasane et al. 2019.

Field size (m^2)	WS2016 (Ekxang) Upper fields		WS2016 (Ekxang) Lower fields	
	Number of fields	Combine efficiency (ha/day)	Number of fields	Combine efficiency (ha/day)
<500	13	2.63 (0.18)	1	1.53 (-)
500-1,000	23	3.78 (0.12)	11	2.33 (0.24)
1,000-1,500	7	4.08 (0.10)	15	2.54 (0.24)
1,500-2,000	2	4.09 (0.13)	10	2.85 (0.26)
2,000-3,000	2	4.83 (0.31)	12	3.35 (0.21)
>3,000	3	4.27 (0.35)	26	3.46 (0.23)
All	50	3.61	75	3.00
Average size (m^2)	987		2709	

Field size (m^2)	DS2016/17 (near RRC) Number of fields	DS2016/17 (near RRC) Combine efficiency (ha/day)	WS2017 (near RRC) Number of fields	WS2017 (near RRC) Combine efficiency (ha/day)	Fuel efficiency (ha/10L)
<500	0	-	0	-	
500-1,000	2	3.30 (1.16)	3	3.97 (0.13)	0.63
1,000-1,500	4	4.26 (0.76)	3	4.20 (0.08)	0.58
1,500-2,000	6	4.41 (0.66)	5	4.64 (0.06)	0.82
2,000-3,000	12	5.01 (0.28)	3	5.00 (0.23)	0.78
>3,000	21	5.21 (0.35)	8	5.76 (0.14)	1.09
All	45	4.89 (0.21)	22	4.98	0.85
Average size (m^2)	3,383		3,192		

2b. Agronomic evaluation of combine harvester performance (1.2) – grain loss

The rice grain loss from the use of combine harvesters in 20 paddy fields in Cambodia ranged from 3.2 to 6.2%, averaging 4.9%, compared with losses from hand harvesting which ranged from 1.3 to 5.0% and averaged 2.7% (Table 7.6). Yield loss tended to be higher in DS crops (4 crops averaging 5.6%).

Table 7.6. Mean rice grain yield, grain loss in the field, grain moisture content and fissured grain in two harvest methods (manual and combine) used by 20 farmers across 4 seasons. Mean values for each season and all 4 seasons are also shown. Bunna et al. 2018b.

Season	Number of farms	Grain yield (kg/ha)			Grain loss (%)		
		Manual	Combine	Mean	Manual	Combine	Mean
Y1 WS	8	4,130	4,090	4,110	2.5	5.3	3.9
Y1 DS	2	4,840	4,930	4,890	4.5	5.6	5.0
Y2 WS	8	3,660	3,640	3,650	2.5	4.2	3.4
Y2 DS	2	4,930	4,990	4,960	2.5	5.7	4.1
Mean	20	4,090	4,090	4,090	2.7	4.9	3.8
LSD at 5% (HM)				Ns			0.2**
LSD at 5% (F)				182**			0.6**
LSD at5% (HM×F)				Ns			0.9**

HM-harvest method; F-farm; ns-not significant; ** p<0.01

Grain harvest loss was small when the crop was harvested at 25 days after flowering, but increased with delayed harvesting time in CARDI experiments (see below 2c). This would be caused by grain shattering at the time of harvest and higher incidence of lodging with delayed harvesting. The heavier grain loss found with the rice harvested by combine would be caused by plants lodging and also because, at later harvesting, the grain was too mature for harvesting by combine. On average the loss was 2-5% greater in combine-harvested crops. However, the loss from hand harvesting included only the reaping operation but not losses during field drying, transportation, threshing, and cleaning.

An earlier study (CARDI 2011) showed that losses during field drying, collecting, and threshing of hand-harvested crops was about 4%. Hence, when these additional losses are included, the total grain loss from hand-harvesting and combine-harvesting methods may be similar. For crops harvested by 35 days after flowering, the total loss would be less than 10%. It should be pointed out that the yield loss from combine harvesting depends on the speed at which the combine is operated in the field. The present study employed a rather slow speed and the result may be considered at the lower end of grain loss in the field.

Similar results were found in Laos; yield loss from combine harvesting varied from 0.1 to 5.1% of the total yield in DS 2014/15 and DS 2015/16. Establishment methods did not appear to affect the yield loss percentage. The mean yield loss was about 1.5%, which should be acceptable by the industry. The loss depends on several factors, but higher combine speed would increase grain loss. As combine harvesting does not involve separate threshing and handling of grain as in manual harvesting, the loss found here should be considered to be less than the expected loss from hand-harvested crops.

2c. Agronomic evaluation of combine harvester performance (1.2) – time of harvest during ripening

The first set of two experiments conducted at CARDI produced similar results; only the second set of results are shown here (Table 7.7). Grain moisture content was similar between hand- and combine-harvested crops. The mean moisture content was high at 27.6% when harvesting occurred at 25 days after flowering, decreasing slightly at 35 days and then sharply to 14.9% at 45 days. Grain yield was not affected by time of harvest or harvesting method, with a mean yield of 3,700 kg/ha. Grain harvesting loss in the field increased sharply from 1.3% to 12.3% with hand-harvesting and from 4.1% to 11.2% with combine-harvesting as the harvesting was delayed from 25 to 45 days after flowering.

Table 7.7. The effects of harvesting method and timing on rice grain moisture content and grain yield and grain loss for experiment 2 (2015) (Bunna et al. 2018a).

Harvesting time	Grain moisture content (%)			Grain yield (kg/ha)			Grain loss (%)		
	Hand	Combine	Mean	Hand	Combine	Mean	Hand	Combine	Mean
25 days	27.6	27.7	27.6	3,763	3,901	3,832	1.3	4.1	2.7
35 days	23.8	24.6	24.2	3,669	3,705	3,687	4.9	8.4	6.7
45 days	14.8	14.9	14.9	3,599	3,619	3,609	12.3	11.2	11.7
Mean	22.1	22.4	22.2	3,677	3,742	3,709	6.2	7.9	7.0
LSD 5% (method)			ns			Ns			1.7 *
LSD 5% (time of harvest)			1.3 **			Ns			2.1 **
LSD 5% (method)*(time)			ns			Ns			ns

ns - not significant, *significantly different at 5%, ** significantly different at 1%

Fissured grain proportion at the time of harvest was not affected by the harvesting method, but increased sharply as harvesting was delayed from 25 (18.3%) to 35 (54.4%) to 45 days (87.6%) after flowering (Table 7.8). Brown rice proportion was little affected by time and method of harvesting, while the white rice proportion decreased with delay in harvesting and was lower in combine- than hand-harvested crops at 25 and 45 days after flowering. Head rice yield decreased sharply with delay in harvesting, but it was also slightly lower in the combine- than the hand-harvested crop.

Table 7.8. Milling quality of rice harvested by hand and combine at 25, 35 and 45 days after flowering (Bunna et al. 2018a).

Harvest time	Brown rice (%)			White rice (%)			Head rice (%)		
	Hand	Comb-ine	Mean	Hand	Comb-ine	Mean	Hand	Comb-ine	Mean
25 days	74.8	74.4	74.6	66.4	59.5	62.9	43.9	42.1	43.0
35 days	74.7	76.0	75.3	55.8	55.9	55.8	29.2	29.8	29.5
45 days	76.1	75.2	75.7	49.4	38.8	44.1	19.8	14.2	17.0
Mean	75.2	75.2	75.2	57.2	51.4	54.3	31.0	28.7	29.8
LSD 5% (method)			ns			3.1**			2.4 *
LSD 5% (time)			ns			3.8**			2.9**
LSD 5% M*T			1.3*			5.4*			ns

ns- not significant, *significantly different at 5%, and ** significantly different at 1%

As harvesting was delayed from 25 to 35 and 45 days after flowering, grain moisture content decreased and grain fissuring increased, indicating that grain fissuring increased with time as low-moisture grain encountered variation in air temperature and humidity during the ripening stage. Thus there was a strongly negative correlation between moisture content and fissured grain proportion at the time of harvesting (Figure 7.7a). Similarly, broken rice proportion increased and head rice yield (HRY) decreased with delay in harvesting; the proportion of fissured grain was directly correlated with broken rice proportion and HRY (Figure 7.7 b and c).

HRY was on average 2-6% higher with hand- than with combine-harvesting, but this difference was small for crops harvested at 25 days after flowering. The difference noted in HRY between the harvesting methods may not be attributable to differences in the methods as such, as grain fissuring was similar between the two methods; rather, this may be caused by the different methods used for drying grain after harvesting. Sun-drying of hand-harvested rice plants before threshing may have contributed to maintaining high HRY compared with sun-drying on a plastic sheet of threshed rough rice from combine harvesting. One reason for the lower HRY of the combine-harvested crop would be higher drying temperature (Truong et al. 2012) as it is likely that the rough rice on the plastic sheet was exposed to higher temperatures than the rice plants dried on the stalk. Further work is required to improve HRY by using artificial drying with a constant temperature.

The two seasons' experiments in Cambodia indicated that the optimal harvesting time for rainfed lowland rice appeared to be 25-30 days after flowering, when grain moisture content is still high, exceeding 25%. As most farmers do not keep a record of the flowering time of their crops, description of appropriate panicle conditions for optimal harvesting time may be required. This conclusion was supported by the other experiment in Cambodia (year 3, where HRY did not vary significantly between 25 and 35 days after flowering) and 5 experiments from Laos. The results from Laos confirm those obtained in 2014 and WS 2015 in Cambodia that harvesting 25 days after flowering provides the highest head rice yield. The WS 2016 and DS 2016/17 results from Laos indicated that 30 days after flowering is already too late.

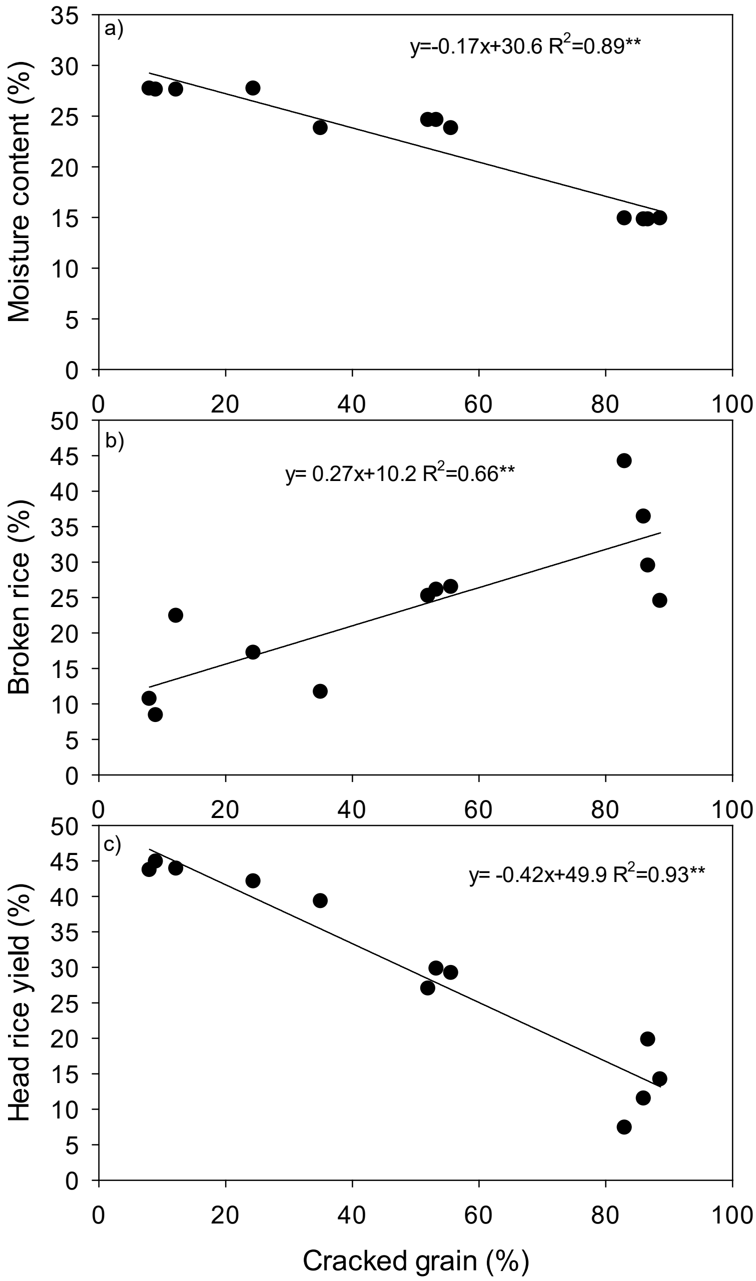


Figure 7.7. Relationships between (a) moisture content (%); (b) broken rice (%); and (c) head rice yield (%) with fissured/cracked grain (%) across Experiments 1 and 2 (Bunna et al. 2018a)

HRY and related measurements from four year WS results from Cambodia are summarized in Table 7.9, and Figure 7.8 shows interrelationships among grain moisture content at harvesting, accumulated temperature from flowering, fissured grain at harvesting, and head rice yield. Thus, delay in heading resulted in increased accumulated temperature, causing increased fissured grain at harvesting and decreased head rice yield. Similar results were obtained from 5 seasons work in Laos (Figure 7.9). The results clearly indicated linear decline in head rice yield with increased heat sum with base temperature of 10°C. However, decline in head rice yield was faster when sun-drying was used, compared with artificial drying.

Table 7.9. Grain moisture content, fissured grain and head rice yield (HRY) of rice crops harvested between 25 and 45 days after flowering (DAF) in 2014-2017. Values are means of manual and combine harvesting. Bunna et al. 2018b

	Harvest time (DAF)	2014	2015	2016	2017
Grain moisture content (%	25	26.9	27.7	24.9	25.8
	30	-	-	23	22.8
	35	24.7	24.2	18.7	16
	45	18.1	14.9	-	-
Fissured grain (%)	25	8.5	18.3	16.9	8.3
	30	-	-	34.8	12.3
	35	43.5	54.5	42.3	23.2
	45	84.5	87.7	-	-
Head rice yield (%)	25	44.3	43	38.3	39.2
	30	-	-	41.6	43.4
	35	33.2	29.5	37.3	42.4
	45	9.5	17	-	-

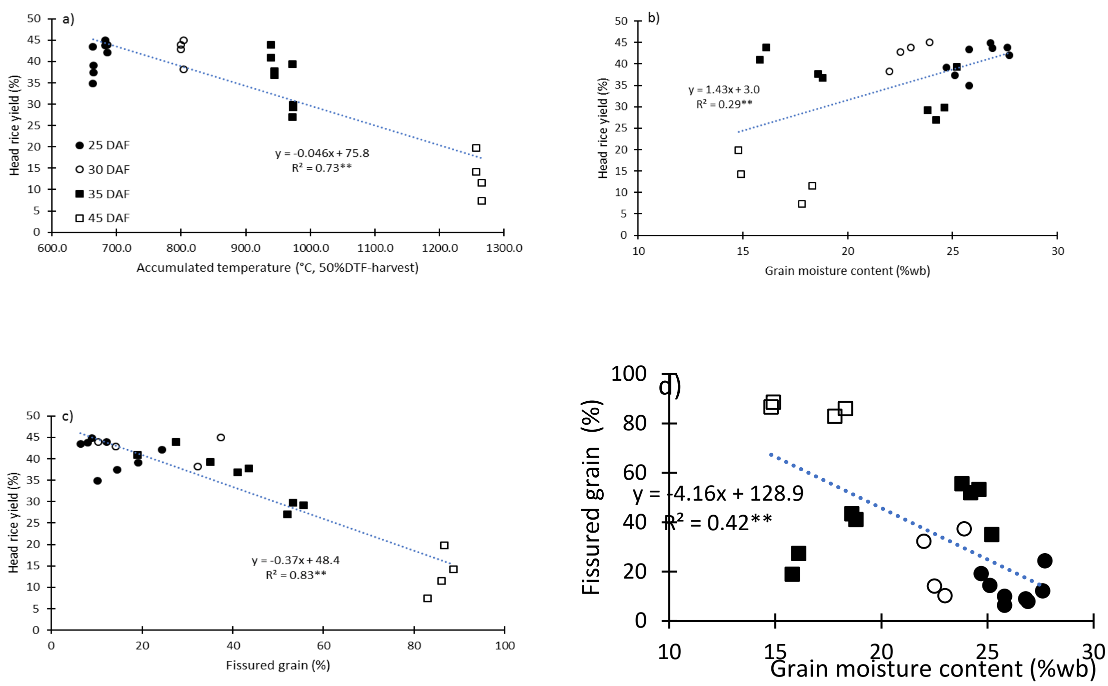


Figure 7.8. Relationship between head rice yield and a) accumulated temperature (°C, from 50% flowering to harvest); b) grain moisture content (%wb); and c) fissured grain; and d) between fissured grain and moisture content (%wb), for crops harvested manually or by combine at different times during ripening in 2014-2017. Bunna et al 2018b

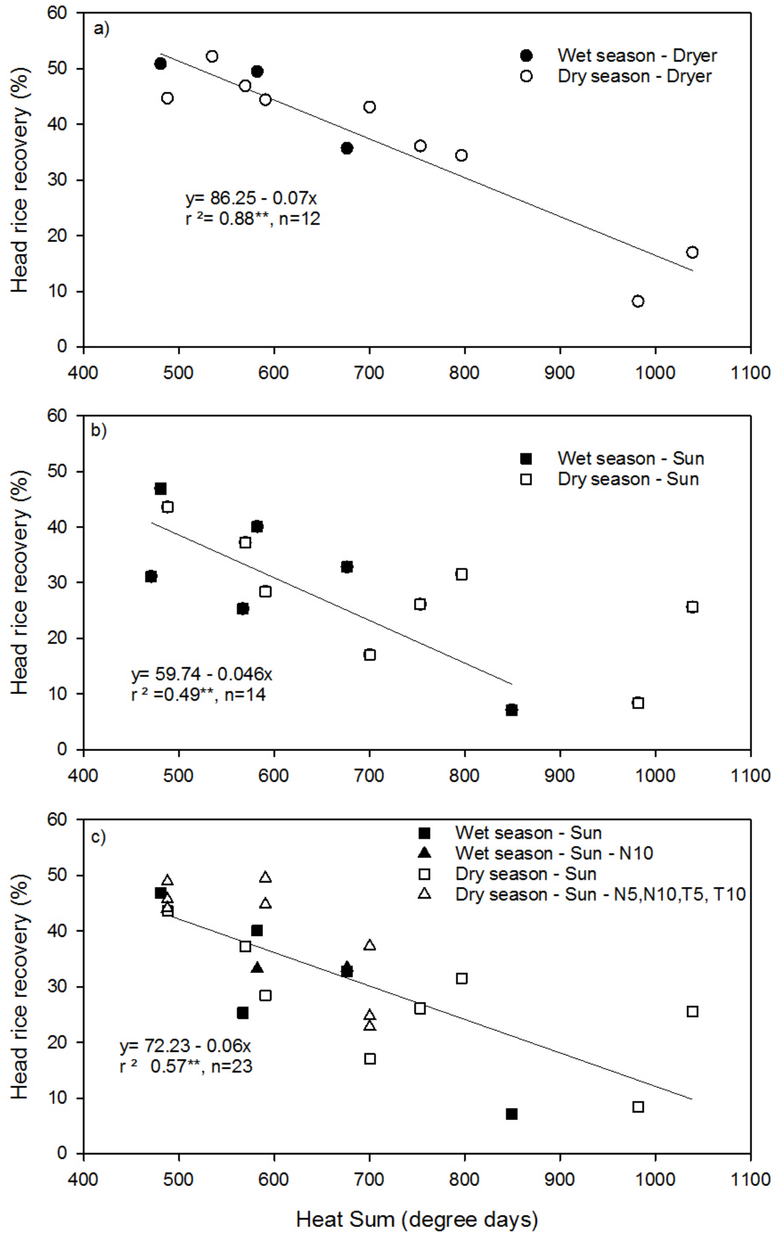


Figure 7.9. Relationship between Head rice recovery (%) and heat sum (degree days) for material dried via a) mechanical dryer; b) Sun drying using a Tarpaulin; and c) sun dried with various combinations of netting (N) and tarpaulin (T) and drying time in hours (5 or 10) in Laos. Xangsayasane et al. 2018a.

3a. Agronomic evaluation of planting machines and land preparation measures (1.3) – transplanter

Khammouan and Bolikhamxay

Grain yield of 213 crops established with a transplanter, a seed drill, hand-transplanting, and broadcasting was estimated on a village/season basis across three seasons in six villages in Khammouan and Bolikhamxay, Laos. The results show that the yield using a mechanized planting device was slightly lower than using manual methods (Table 7.10). The transplanter produced crops with a similar mean yield to broadcast crops but 8% lower mean yield than hand-transplanted crops. Crops established from the transplanter generally had a lower plant density, which appears to be particularly disadvantageous in the DS, when farmers generally use higher plant density when hand-transplanting. The mean yield of drill-planted crops was 15% lower than for hand-transplanted crops. However, there was some variation among villages and among seasons. In the WS, the seed-drill yield was similar to that of broadcast crops, but was 12% lower than hand-transplanted crops. It should be noted that the farmers were not experienced with these mechanized planting methods and it is likely that the yield will increase as they gain more experience. At the same time, the project exposed some limitations of drill-seeding, such as poor establishment, particularly in clay soils, and more weeds compared with transplanted fields. However, weed control is easier in drilled than in broadcast crops. When drills were used in low-lying fields, poor establishment and growth may result due to excessive water and submergence.

Table 7.10. Mean yield (combine-harvested) for different plant establishment methods for different villages in 3 seasons in Khammouan and Bolikhamxay

Year	Hand transplanting	Transplanter	Seed drill	Broadcast	Drum-seeder
DS 2014/15	3,612	3,252	3,783	4,017	
WS 2015	3,152	3,073	2,834	2,456	
DS 2015/16	3,988	3,605	2,570	3,698	2,771
Mean	3,584	3,310	3,062	3,390	2,771
Yield %	100	92	85	95	77

For the WS crops for which the yield was estimated in the project, the number of crops established by seed drill, broadcasting, and hand-transplanting was similar. However, these establishment methods were not necessarily compared under similar conditions and the results here should be treated as survey results rather than experiments, particularly as the number of farmers who used seed drills was small and paddies were located in a particular area, different from transplanted areas.

The superiority of transplanting may be a characteristic of WS rice; it may be more difficult to establish the crop with direct seeding and weeds may be more of a problem. In the DS, only a small number of farmers used drills and generally the yield was lower than the other establishment methods. While the yield of crops established from drills or transplanters were often lower than that of hand-transplanted crops, this may change as farmers gain more experience. Moreover, while the yield of the drilled crop may not exceed that of the transplanted crop, the advantage of drilling is the labour saved at the time of planting when compared with hand transplanting.

The results of two dry season experiments in Rice Research Centre in Vientiane show the advantage of larger number of seed trays used in transplanter (Figure 7.10). Row spacing was always 30 cm, but the hill spacing varied from 14, 16, 18 to 21 cm in the first season and wider range in the second season. The farmers in Gnomellata in Khammouan appear to be using less number (147 trays/ha), and this probably caused yield reduction in the farmers' fields.

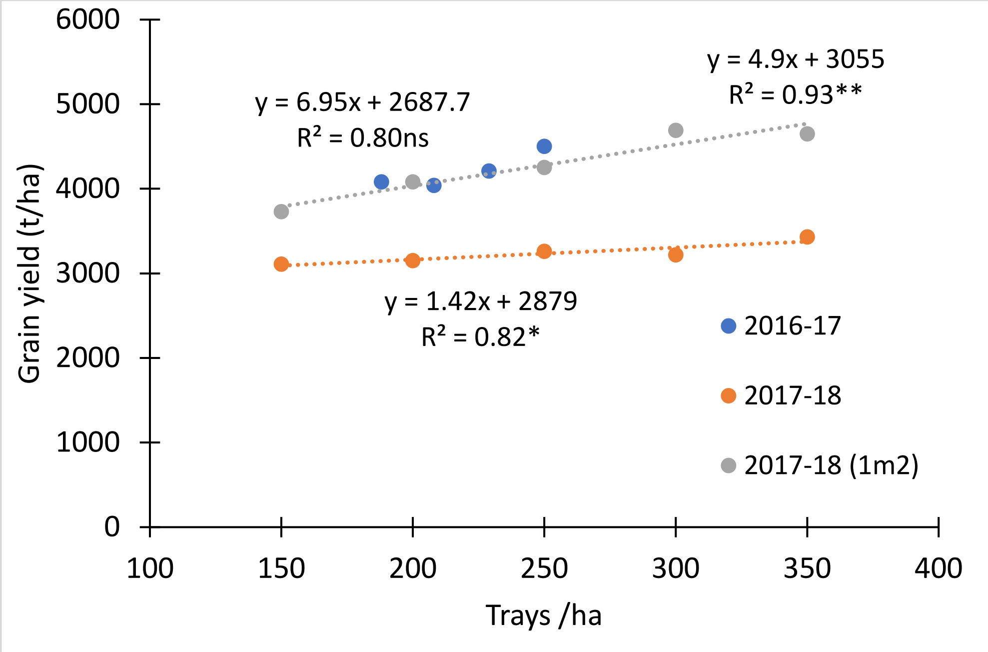


Figure 7.10. Relationship between grain yield and the number of trays used for transplanter planted rice crops at Rice Research Centre, Vientiane in 2 dry seasons. In the second year, yield was estimated for the whole plot basis and $1m^2$ sampled area basis. Xangsayasane et al. 2018b

Kampot and Takeo

Of the 8 demonstration plots in Cambodia in WS 2016, 3 were damaged by flood, in 2 cases resulting in complete crop failure. In all cases flood came 12-14 days after crops were transplanted, and they were submerged for 6-11 days. Two crops destroyed were submerged for 12 and 6 days respectively, but another which was submerged for 8 days survived with some plant loss (Photo 7.2). The surviving plants had limited tillers and the plants looked rather poor. In Snor village where the trial was submerged for 2 days, the plants in low-lying areas were badly affected by flood; they would have been submerged for a longer period than the trial. This indicates the importance of land levelling and drainage to reduce the submergence period. Another issue would be the vigour of seedlings in trays, which are shallow and would limit root growth. In some cases seed trays were left in a shaded area and seedlings may not have been hardened. Depth of seedling placement may also be considered, as possibly the placement was too deep.

Photo 7.2. In one field in Kampot (above) the crop established from a transplanter survived while in another field (below) it failed completely. In both fields, the hand-transplanted crop with old seedlings survived the flood.

In these 4 trials where flood had an effect, there were also hand-transplanted areas next to the machine-transplanted area, as seedlings in 20 seed trays were not sufficient to plant the entire area. The hand-transplanted seedlings were of local varieties and were old (45-60 days or perhaps even longer) and they survived the flood in all locations. It is not known whether this was related to seeding age as such or seedling health at the time of submergence. While seedlings from the transplanter were shorter than hand-transplanted seedlings at the time of flood, this is unlikely to have been the factor as, when the water level went down, it went down quickly and the duration of submergence was not much different. For 2014-17, 21 fields were planted by transplanter, and 2 failed. The average yield of remaining crops were 3.16 t/ha.

The major advantage of the transplanter is the saving in time and labour compared with hand transplanting, and better weed management compared with broadcasting, as Cambodian farmers appreciated in a farmers' meeting. Thus, it may be that transplanters could be used in paddies where weeds have become a problem after continuous broadcasting in the WS or EWS+WS.

However, the transplanter has several technical constraints, apart from economic issues. One is that it requires levelled land; uneven establishment is common if land is not levelled. Sandy soil is not suitable for use of the transplanter. Even with hand-transplanting, the land is ploughed just before transplanting, but with the transplanter, the land has to be further harrowed. Another limitation is the use of young seedlings due to the use of trays and the physical limitation of the transplanter itself. The latter can be overcome by trimming leaf blades, but root growth would be limited and roots would become entangled in old seedlings, making it difficult for them to be picked up by the transplanter. The use of young seedlings may be causing susceptibility to submergence, as mentioned earlier, and hence the transplanter should be avoided in low-lying areas where flooding is likely to be a problem. They should also be avoided in areas where golden apple snail is a problem, particularly in the WS.

In Laos, the transplanter produced similar yields to hand-transplanted crops in the WS, but about 20% lower yield in the DS. Crops established with the transplanter generally have a lower plant density, and this appears to be disadvantageous in the DS when farmers generally use higher plant density in hand-transplanted crops. The row spacing (30 cm) of seedlings established with the transplanter appears too wide for the tropical Lao and Cambodian environment. Perhaps this is an issue to be discussed with manufacturers. Farmers would like to use more seed trays to increase the plant density in the DS, but often the number of trays is limited; about 200-220 trays would be required per hectare for establishing a crop with sufficient plant density.

3b. Agronomic evaluation of planting machines and land preparation measures (1.3) – seed drill (for rice)[1]

In the Lao experiment where 213 crops were established from different methods across 3 seasons, grain yield established seed drill varied greatly, and the comparison with other methods was often confounded with different growing conditions used for different establishment methods. Thus, comparison was made when two or more methods were used on the same farm in the same season where growing conditions were expected to be similar among the crops established from different methods. There were 3 farms where both drill and manual transplanting were used in the same season and 2 farms where drill and broadcasting were used (Table 7.11). When drill was compared with manual crop establishment, drill was not disadvantageous in terms of achieving high yield.

[1] *For drill activities for non-rice crops see section 8 below on innovative cropping systems.*

Table 7.11. Grain yield (kg/ha and as % of hand planting in brackets) of crops established from drill or transplanter compared with manual transplanting or broadcasting within the same farm and in the same season. Each farmer is numbered from 1 to 10; farm 10 was in Ekxang village, Vientiane. Yield was estimated from the whole field. Xangsayasane et al. 2018b.

Farmer no.	Manual transplanting	Drill	(%)
1	3,562	3,359	(94.3)
2	2,234	2,863	(128.2)
3	3,427	3,505	(102.3)
	Manual transplanting	Transplanter	
4	2,791	3,227	(115.6)
5	2,812	2,435	(86.6)
6	5,371	3,327	(61.9)
	Broadcast	Drill	
7	3,167	3,178	(100.3)
10	2,636	3,137	(115.2)
	Broadcast	Transplanter	
8	1,383	2,681	(193.9)
9	2,783	3,201	(115.0)
6	4,476	3,327	(74.3)

For seed drill activities in Laos, it was noted in the previous section that yields were generally lower than for hand-transplanted crops under favourable conditions. However, this difference may not be as important as other perceived advantages that the seed drill could offer, particularly the time saving and early planting under dry soil conditions. Thus, the adoption of the seed drill and the transplanter is unlikely to be due to their ability to produce higher crop yield. It is more likely to be related to the labour-saving nature of mechanized planting, either at the time of planting compared with hand-transplanting or later in the season through reduced weeding compared with broadcasting. The advantage of drill planting for ease of weed control was also recognized in Ekxang village when they used the seed drill for the first time in WS 2016.

In Cambodia, demonstration sites were planted in WS 2014 and WS 2015 in Takeo and Kampot with two Cambodian seed drills (4- and 6-row) and a broadcast field adjacent. The results obtained from both years' field demonstrations show that crop establishment with the seed drill was apparently better than with broadcasting and also made for easier weed control. The average grain yield from eight seed-drill demonstrations with the Chul'sa variety was 4.57 t ha^{-1}, about 1.5 t ha^{-1} higher than with farmer varieties (see further details in Section 4c Socio-economic evaluation).

The project has demonstrated that drill-seeding speeds up the operation of crop establishment, although the yield of the drilled crop is commonly less than that of the hand-transplanted crop. The main advantage of drill-seeding is the time saved compared with hand transplanting, and this was acknowledged by farmers in a field day in Cambodia. Another advantage is the ease of weed control compared with fields established by broadcasting. The project has also demonstrated in Laos and Cambodia that seed-drills can be used in rice as well as some other crops, such as mungbean, peanuts, and maize. This increases the usage of the seed drill considerably, and provides more options to farmers; for example, peanuts may be considered too labour-intensive if hand planted and may not be tried because of this, but the drill could make peanuts a viable crop in rotation with WS rice, leading to the development of a new diversified cropping system (see section 10). At the same time, the project showed the limitation of seed drills for rice, such as poor establishment, particularly in clay soils, and more weeds compared with a transplanted field. When drills are used in low-lying fields, poor establishment and growth may result due to excessive water and submergence. Participating farmers have become aware of the advantages and disadvantages of seed drill technology, and are refining the technology to maximize the benefit to their own farms.

3c Agronomic evaluation of planting machines and land preparation measures (1.3) – crop establishment under limited soil moisture conditions

Year 1 Experiment

This replicated field experiment included peanuts, mungbean, maize, and rice. Seed was planted at 2 cm depth in January/February. Each crop was planted at 5 different times after irrigation, with an interval of 3 days between sowings. The crops differed in their response to time of sowing after irrigation, while varieties of a given crop behaved similarly, except for maize. Sowing 1, which occurred 1 day after the field was irrigated, had 28% soil moisture content at sowing depth, resulting in establishment of about 100%, 90%, 40-90%, and 60% in peanuts, mungbean, maize, and rice, respectively. In the second sowing, with soil moisture content of around 22%, establishment was reduced to about 30%, 80%, 40-70%, and 15%, respectively, indicating the susceptibility of rice to adverse conditions, particularly reduced moisture content and increased soil strength. All crops failed to establish from the third sowing when soil moisture content was reduced to around 20%. The results for mungbean and rice are shown in Fig. 7.11.

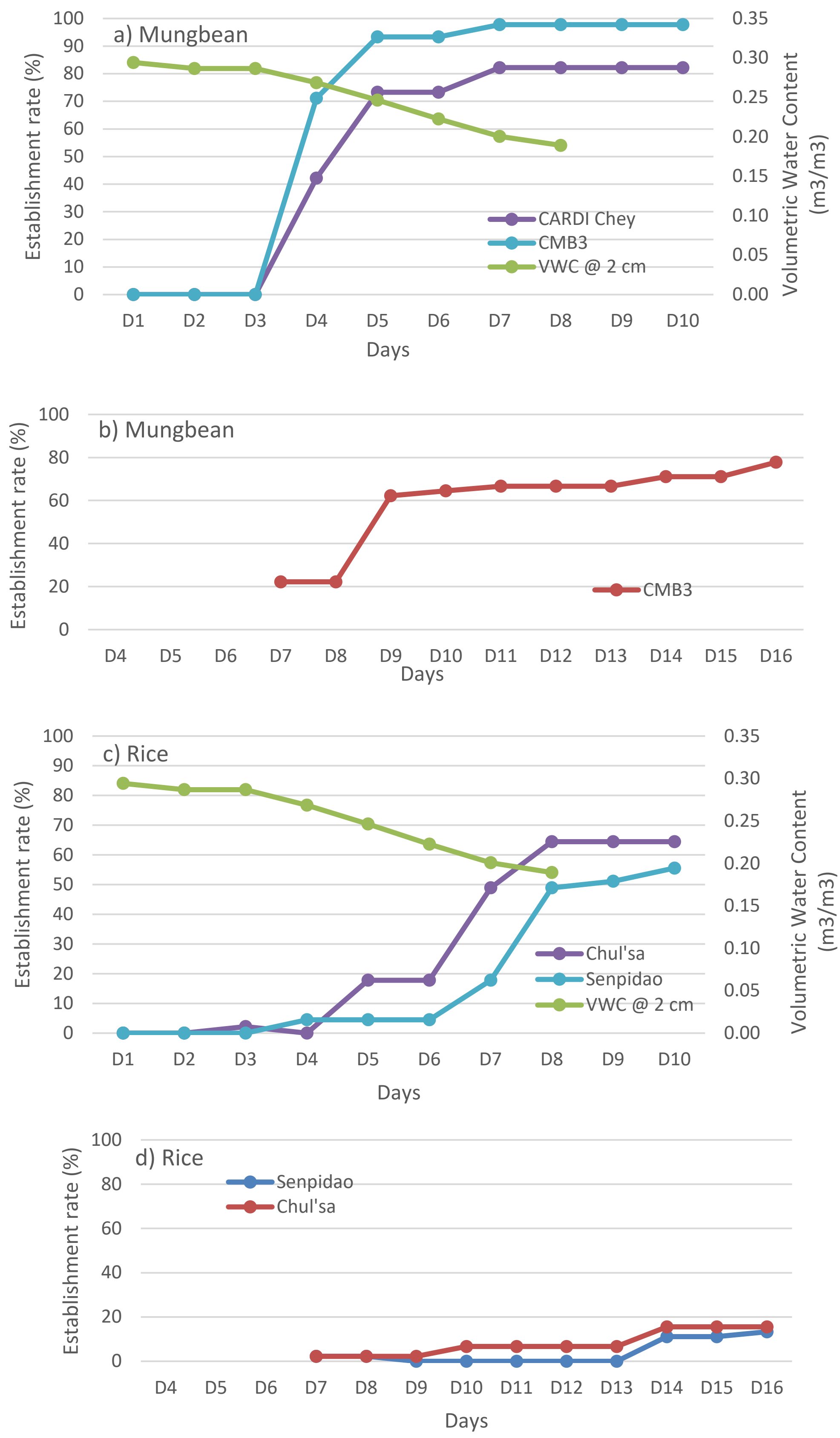


Figure 7.11 Seedling emergence of two varieties of mungbean (a and b) and rice (c and d) when sown at 1 (a and c) and 4 (b and d) days after draining water. Mungbean varieties were CARDI Chey and CMB3, while rice varieties were Chul'sa and Sen Pidao. Volumetric soil moisture content is also shown in green.

Year 2 Experiment

Seed of four crops was planted manually and using a seed drill at different soil depths and at different times after standing water was removed. There was no rainfall during the experimental period and temperatures were high (Figure 7.12). The maximum air temperature in the hand-planted field was around 33ºC, gradually increasing to 37ºC on 22 March. Soil temperature at 10 cm depth was lower than the air temperature soon after draining water from the field, but it gradually increased to exceed the air temperature. Soil temperature at 5 and 2 cm depth was about 7 and 10ºC higher than the air temperature, reaching 42 and 47ºC at the end of the experiment. Standing water was drained on March 2, and soil water content fell gradually to 12-17% at soil depth between 2 and 5 cm by March 11 when the last crop was hand planted, and then soil water fell to 8-12% at the end of the experiment period. Soil moisture content at 10 cm depth was higher and fell to just below 20% on 22 March.

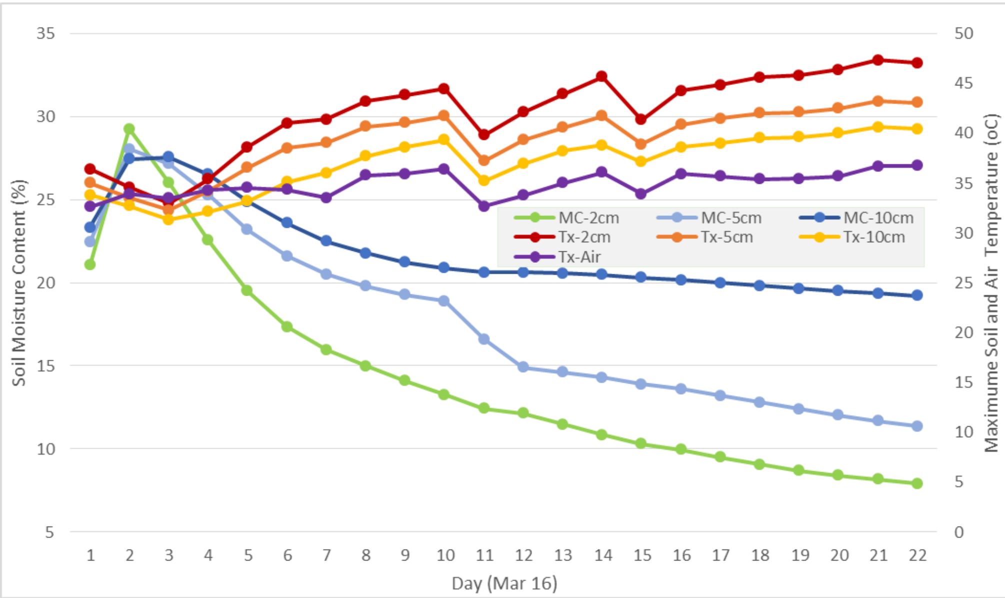


Figure 7.12. Change in air and soil temperature and soil moisture content in the hand-planted field. Soil temperature and moisture were determined at 2, 5 and 10 cm below the soil surface. Hand planting took place on 4, 7, 9 and 11 March.

In all hand-planted crops (Figure 7.13), maximum establishment exceeded 80%, and establishment was always better when seeded at 5 cm than at 2 cm (Photo 7.5 and 7.6). The establishment of crops sown at 2 cm depth was generally good at the first sowing (S1 - 4 March) when soil moisture was the highest and soil temperature was the lowest, and decreased in S2 and S3. At S4, rice had very low establishment, particularly when sown at 2 cm soil depth, indicating the narrow window of sowing opportunity available in rice. Mungbean also had lower establishment by S4, while peanut and maize maintained high establishment from S1 to S4, particularly when sown at 5cm depth. Establishment for rice planted at 5 cm depth was lower than other crops at S1 but increased at S2 and S3.

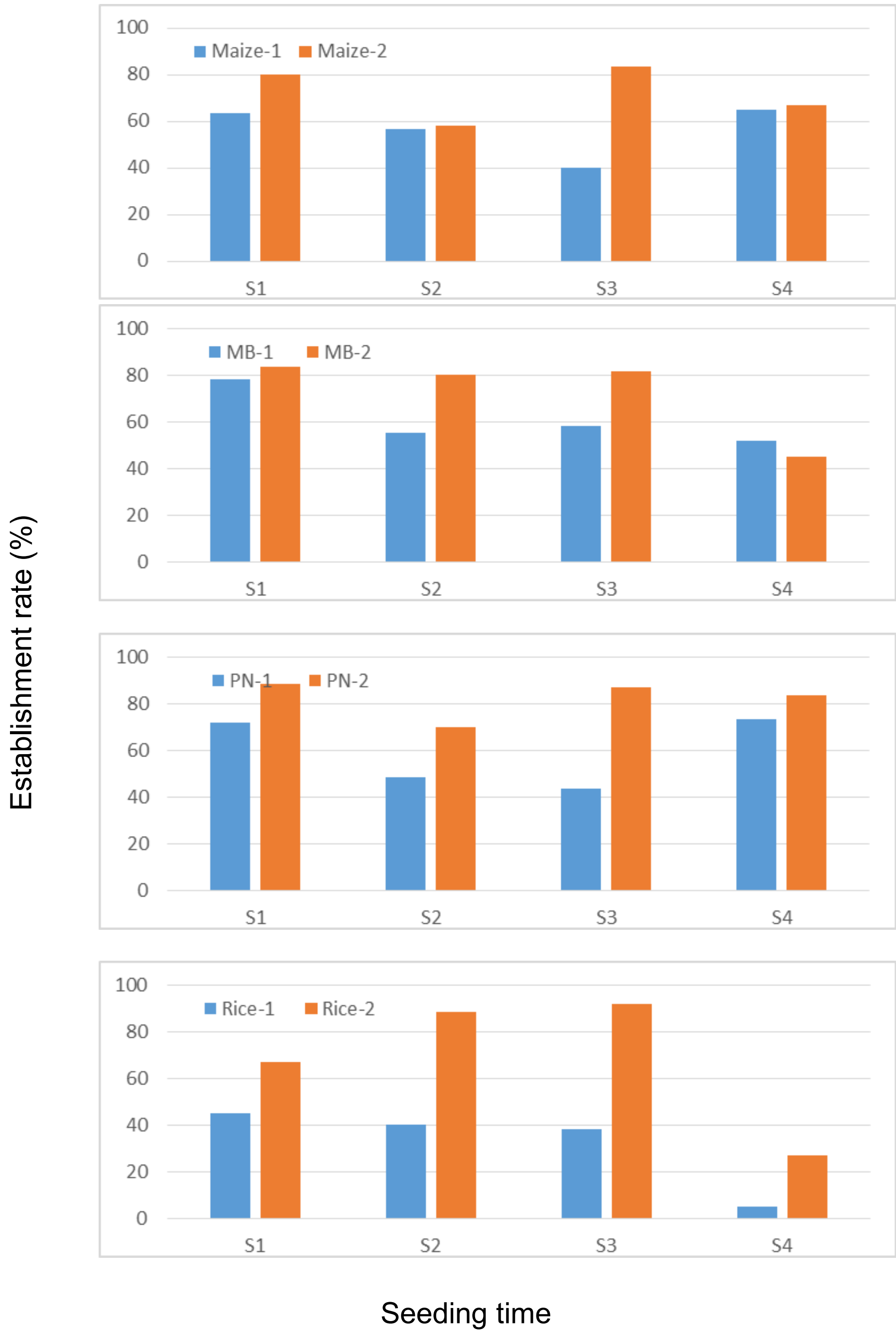


Figure 7.13. Final establishment rate for maize, mungbean (MB), peanut (PN), and rice at four seeding times (S1-S4) and two soil depths – 1 (2 cm, blue) and 2 (5 cm, orange).

Photo 7.3 Mungbean establishment from hand seeding at a soil depth of 2 cm (left) and 5 cm (right)

Photo 7.4 Makara and Shu discussing establishment of maize in the four-crop experiment at CARDI

The results showed variation between rice, mungbean, peanuts, and maize in seedling emergence from soils of different moisture content. As the soil dried out, establishment from deep (5-6 cm) planting was better than from shallow (2-3 cm) planting. Crop establishment decreased linearly with decrease in soil moisture content (Figure 7.14). The red point in each panel was obtained at the first time of drill planting when the soil was too wet for optimal drill operation. Examination of the linear regressions indicates that rice appears most sensitive to reduced soil moisture content; at 15% moisture content estimated establishment is 26% compared to 45-48% for other crops. The reason for this is being investigated, particularly whether hulls in rice restrict water flow resulting in lower moisture content of the kernel for a given soil moisture content.

The findings could have significant implications for farmers' planting practices, whether planting mechanically or manually. Deep planting in drier conditions is a common practice in many countries, and the use of a seed drill can make deep planting a readily achievable practice. The project plans to develop a strategy to promote deep planting under moisture-limiting conditions.

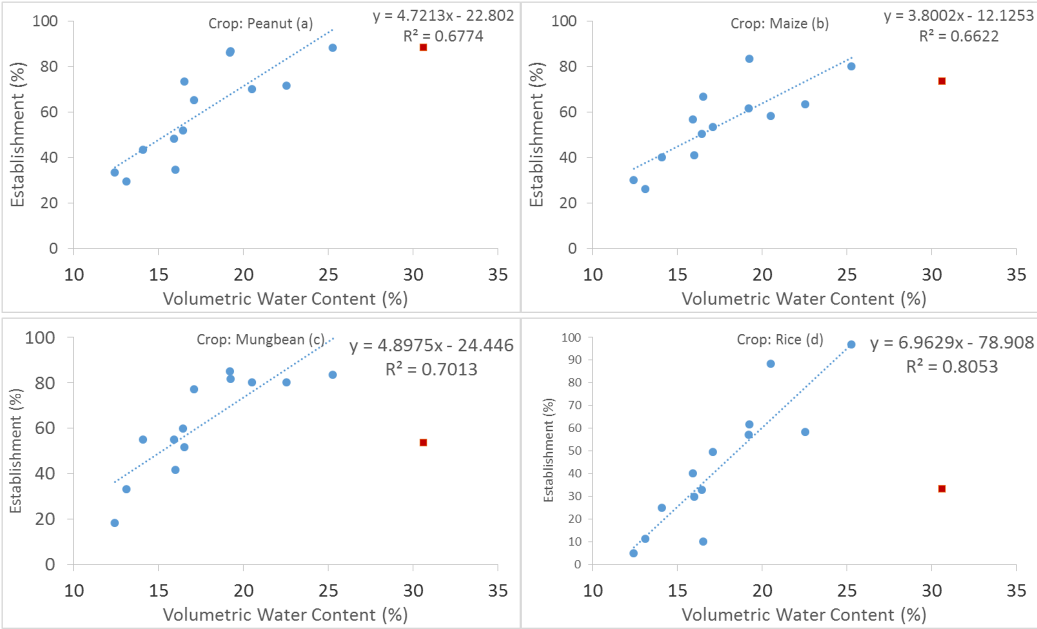


Figure 7.14 Relationship between seedling emergence and soil moisture content at the time of sowing

3d. Agronomic evaluation of planting machines and land preparation measures (1.3) – deep ripping

The use of machinery has contributed to the development of a hard pan in rice fields and this often affects growth of non-rice crops following rice, and hence the viability of diversifying rice-based cropping systems. In Cambodia, the project has demonstrated that deep ripping to around 35 cm soil depth to reduce the impact of the hard pan helped non-rice crops in the DS to produce 20-30% higher yield and also resulted in 20-40% higher water-use efficiency in maize and peanut (Table 7.12).

Table 7.12 Effect of deep ripping on grain yield, root depth, water use, and water-use efficiency of maize and peanuts

Effect of deep ripping

		Grain yield (kg/ha)			Root depth (cm)	
	Crops	Ripped	Non ripped	% increase	ripped	Non ripped
Maize	2	4586	3816	20.2	45	22
Peanut	3	783	606	29.1	15.5	11.8
		Water use (m3/ha)			WUE (kg/m3)	
		Ripped	Non ripped		Ripped	Non ripped
Maize		2572	3019		1.79	1.28
Peanut		1459	1505		0.51	0.42

The experiment and demonstration conducted in DS 2017 in Takeo confirmed that deep-ripped fields produced deeper roots and a yield advantage of 14-30% in maize, although water-use efficiency was similar at 1.70 and 1.63 kg/m^3 for ripped and non-ripped fields, respectively (Table 7.13). The rice crop in the WS following deep ripping in the DS did not appear to be affected by the disruption of the hard pan though the soils were still softer during the WS.

Table 7.13. The effect of deep ripping in DS prior to planting on maize growth and water use

	Treatment	Seedling emergence (%)	Maximum root depth (cm)	Water use (m^3/ha)	Grain yield (kg/ha)
Experiment	Ripped	78.7	26.1	5,637	9,572 (130)*
	Control	69.0	20.6	4,510	7,351 (100)
Demonstration	Ripped	75.6	23.7	(5,637)	9,041 (114)
	Control	75.0	21.1	(4,510)	7,905 (100)

* % of control grain yield indicated in brackets.

The effect of deep ripping for peanuts in EWS 2016 on the subsequent rice crop in WS 2016 and melon in DS 2016/17 was examined at the farm of Ouk Sombunthen in Trapeang Chak village, Trapeang Kranhung commune, Tramkak district, Takeo province. According to him, the rice crop was not affected by deep ripping, but the soils in the deep-ripped area were still softer in subsequent seasons. Nevertheless, the tractor did not sink in the deep-ripped area. Thus it appears deep ripping still had some positive effect. In another farm, rice yield was determined and was found to be not significantly affected by deep ripping of the field where peanuts were planted in the preceding EWS.

4a. Socio-economic evaluation of mechanization options (1.1, 1.4) – operation of combine contractors

In 2015, interviews were held with 16 contractors providing the services of different types of machinery to our target villages – combine harvesters, reapers, 4-wheel tractors, 2-wheel tractors, and threshers (Table 7.14). Of these contractors, 8 were farmers diversifying into the contracting business while 8 had non-farm businesses, though most also owned farms. These service providers were considered a key component of the mechanization value chain, directly linked to farmers. There were 7 combine contractors operating 11 combines. The combine owners resided in Kampong Trach of Kampot, Kirivong of Takeo, and Kanch Chreach in Prey Veng, all outside the districts of our target villages.

While a combine may be transported long distances across districts and sometimes provinces, small machinery such as reapers are used more locally. Combine contractors charge higher fees for WS crops where harvesting conditions are often not favourable (tall plants, lodged crops). The sole purpose of purchasing a combine was to develop a contracting business. Most combine owners took out a loan from a bank, private creditor, or relatives to buy the machine. The contractors sent their combines with machine operators to operate in the districts of Takeo, Kampot, and Prey Veng where the contractors lived and in other provinces, including Kampong Speu, Svay Rieng, Kampong Thom, Pursat, and Battambang. The reported investment costs, operating costs, and returns from providing various contract services are shown in Table 7.15.

Table 7.14. Ownership of various machines by 16 contractors interviewed in southern Cambodia

No.	Province	Combine	Reaper	4W tractor	2W tractor	Thresher	Water pump
1	Kampong Speu		1		1	1	1
2	Kampong Speu		1		1	1	
3	Kampong Speu		1		1	1	1
4	Kampong Speu		1		1	1	1
5	Kampot			1			
6	Kampot	1			1		
7	Kampot	2					
8	Kampot	2		1			3
9	Kampot	1			1		
10	Kampot				1		1
11	Takeo			1	1		
12	Takeo			1			
13	Takeo	2					3
14	Takeo	2				2	3
15	Takeo			1			3
16	Prey Veng	1					

Table 7.15 Costs and returns for provision of machinery services in southern Cambodia

Machine	Combine	Reaper	4W tractor	2W tractor
Year bought	2012-2014	2012-2014	2011-2014	2000-2014
Price (USD/unit) – new	28,000	2,200	24,000	2,400
– old	17,500	600	17,500	1,400
Working capacity (ha/day)	6	2.1	4	0.8
Labour-days/ha	4	1.3	2	1.5
Labour cost (USD/ha)	10.2	5.0	10.0	7.5
Fuel (l/ha)	18	2.6	14	13
Fuel cost (USD/ha)	16.0	3.1	10.7	12.6
DS contract fee (USD/ha)	72.8	54.2	45.0	62.5
DS gross margin (USD/ha)	46.6	46.0	24.3	42.4
WS contract fee (USD/ha)	111.3	n/a	n/a	n/a
WS gross margin (USD/ha)	92.1	n/a	n/a	n/a

The combine harvester and four-wheeled tractor required high capital investment, hence bank loans were necessary. Even second-hand machines were costly. Apart from this starting capital, operating costs included the operator’s labour, fuel, oil, repairs and maintenance, and use depreciation. The combine required the most labour on a per hectare basis. The unit labour cost was USD 10/ha for operating a combine or four-wheeled tractor and USD 5/ha for operating a reaper. The two-wheeled tractor was operated by the contractor’s family and had no cash cost. There was some variation between contractors of a given machine in the labour requirement and hence the labour costs. Fuel prices were fairly consistent across different locations, hence variation in fuel costs was due to the particular machine's fuel requirement, including differences between petrol and diesel. The combine required the highest fuel cost at USD 16/ha, followed by the hand tractor using petrol (USD 13/ha), the 4W tractor (USD 11/ha), and the reaper using petrol (USD 3/ha). No estimate was made of oil use, repairs and maintenance, or depreciation, nor of interest payments on loans.

The combine's working capacity averaged 6 ha/day, varying between 4 and 10 ha/day among the contractors. The reaper could harvest on average 2 ha/day ranging from 1.3 to 3 ha. Four-wheeled tractors could plough 4 ha/day, varying between 2 and 5 ha/day, but two-wheeled tractors could complete only 0.8 ha/day with a narrow range of between 0.5 and 1.3 ha/day.

The average contract fee for combine harvesting in the DS was USD 73/ha. Due to tall plant height and crop lodging of WS rice, which was unfavourable for combine harvesters, the harvesting contract fee was around USD 110/ha in the WS. Deducting the costs of hired labour and fuel, the contractors averaged a gross margin of USD 46/ha. However, this would have to cover additional running costs as mentioned above, as well as interest and principal payments for the loan.

The contract fee for land preparation was USD 45/ha for four-wheeled tractors and USD 62/ha for two-wheeled tractors, given the lower work rate of the latter. Deducting the costs of labour and fuel, the contractors obtained a gross margin of USD 24/ha from the large tractors and USD 42/ha from the small tractors.

Further analysis is needed to estimate the full costs and returns of contract operations, taking into account capital costs, transportation costs, and rates of utilisation.

4b. Socio-economic evaluation of mechanization options (1.1, 1.4) – combine contracting options

Use of combine harvesters is generally higher in southern Cambodia than in central Laos, but the usage varies greatly across villages in each country. Some factors that favour the use of combines are high wages, low labour availability, large farm size, low combine contracting fees, and the availability of drying facilities for grain of high moisture content harvested by combines. Combine contracting fees are higher in Laos than in Cambodia and also higher in the wet season (when most rice is grown) than in the dry season. Low fees in Cambodia are associated with the high number of operating days as combines operate across different seasons and locations. Limited availability of artificial drying facilities means higher risks of harvested paddy rice spoiling when rainfall interferes with drying processes, particularly for EWS rice in Cambodia and DS rice in Laos where there is a fair chance of rain at harvesting time. Thus, securing drying facilities is a key for wider use of combines. With the use of artificial drying, high physical grain quality is maintained, resulting in increased opportunity to market rice domestically and perhaps also to export. In the WS, drying is less of a problem as the weather at harvesting time is generally more favourable and the rice crops are mainly used for home consumption. The interrelationships among different players in the combine harvesting sector are summarized in Fig. 7.15 (Xangsaysane et al. 2016).

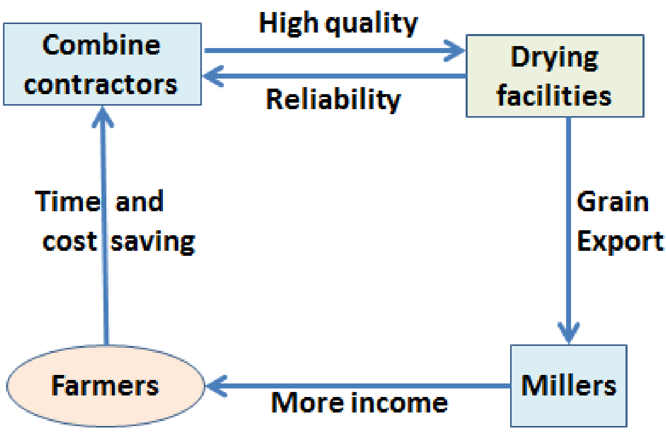


Figure 7.15 Interrelationship among combine contractors, farmers, millers, and drying facilities

The project has documented the activities of combine contractors in Cambodia, including the number of days a contractor operates in a year at different locations and in different seasons. This extended operating period has resulted in potentially large profits at relatively low contracting fees of USD 70-110/ha. This appears to contrast with the situation in Laos where the fee is much higher, often around USD 150-200/ha, and this appears to adversely affect the demand for combines in Laos. This high combine charge appears to be related to limited competition because only a small number of contractors are available, the short time period for payback of credit for purchase of combines, and the limited number of days per year combine contractors can operate in Laos. Combine adoption is likely to increase in Laos if the issues mentioned can be resolved.

Advantages and disadvantages of adoption of combine harvesting service are listed in Table 7.16. Combine offers large advantages over manual harvesting. This advantage is not just for direct financial gain by not employing labourers for harvesting, but also for the time saving the combine harvester service offers, as well as high head rice yield that combine harvested crops can offer when artificial drying facilities are available. A major consideration for combine contractor is how much combine can be used for harvesting within a year; this depends on how many days of service they can operate in wet season and dry season. Combine contracting service is more efficient if many growers in a village can use the service at the same time, so that travel cost can be minimized.

Table 7.16. Advantages and disadvantages for different characteristics of combine harvester (Values mentioned are modified from Xangsayasane et al. 2018 c). Fukai et al. 2018.

	Combine requirement/operation	Advantages	Disadvantages
Labour requirement	3-4 persons/ha	Lower than manual harvesting (about 30 persons/ha)	
Service cost	68-190 USD/ha depending on the yield and fee rate.	Lower than manual harvesting (272-286 USD/ha including threshing fees)	

Grain harvesting loss in the field, and harvested yield	Mean of 1.5% (range 0.1-5.1%).	Smaller than the manual harvesting when threshing and handling losses are considered, resulting in slight advantage in harvested yield.	
Paddy moisture content	High paddy moisture content requiring rapid drying	High head rice yield when paddies are dried properly	Sun drying exposes paddy to unfavourable weather conditions, reducing grain quality.
Time saving	3 to 5 ha/day depending on field size	Faster than manual harvesting (1ha/day with 30-35 persons)	May lose community interactions/relationship
Rice straw	Greater (>50%) quantity of straw remains in the field	Incorporate rice straw to the field and improve soil fertility	Loss of animal feed

4c. Socio-economic evaluation of mechanization options (1.1, 1.4) – planting machine options

Transplanter

Transplanter and manual transplanting cost in Central Laos is shown in Table 7.17.

Table 7.17. Cost (USD/ha) of transplanting by machine transplanter or manually at different villages in Central Laos (a) and breakdown of the cost (b). Xangsayasane et al. 2018b

a)

Village	Transplanter	Manual transplanting
Pakpung	$115	$298
Nongping	$159	$285
Pak-etue	$112	$209
Tung	$98	$193
Average	$121	$246

b)

Cost items	transplanter	Manual transplanting
Seed	$45	$56
Seed tray hire	$2	
Transplanter hire	$16	
Tray preparation/seedbed	$30	$24
Pulling seedlings		$48
Transplanting	$28	$118
Total	$121	$246

It is clear that transplanter requires less cost than hand transplanting; about half the cost of transplanting. The difference is about $125USD/ha. The variation in transplanter cost is partly due to hiring cost which may be high at Nongping $50/ha to low at $12/ha at Pak-e-tue to zero in the other places where the provincial Government provided free service or a project provided a transplanter free to farmers some years ago. It may be that the cost found in Nongping would be appropriate for the cost when transplanter contractor is considered. Large variation in hand transplanting is due mainly to labour cost (ranging $9/day at Pakpung to $5/day) and the number of people required to hand transplant (17-24 people to complete a hectare in one day).

The transplanter produced grain yield that was 8% (270kg/ha) lower that hand transplanting as shown in the agronomic evaluation section earlier, but this was partly due to farmers not experiencing the use of transplanters (eg use of small number of trays). It is expected that the difference in yield is likely to be reduced, and hence the economic benefit of hiring transplanter service would increase.

Some farmers who have transplanters have considered providing contract services, but the number of seedling trays required for this service would be quite large and rather costly (USD 1.60 per tray). If a transplanter is used for 15 days continuously in a season, the number of trays required would cost USD 3,000. In addition, the transplanter is delicate machine and requires frequent repairs and maintenance.

Advantages and disadvantages of transplanter are listed in Table 7.18. While it has a major advantage of labour saving and hence cost reduction compared with manual transplanting, it is quite costly compared with broadcasting. Thus, it can be used more for value-added rice production such as seed production. Tray cost as well as transplanter purchase cost is high for most rice growers. Thus, it is likely that the technology is more suitable for specialist growers, unless transplanter service is developed in large scale to reduce the rice production cost.

Table 7.18. Advantages and disadvantages for different characteristics of transplanter (Values mentioned are modified from Xangsayasane et al. 2018b). Fukai et al. 2018

	Transplanter requirement/operation	Advantages	Disadvantages
Labour requirement	3-4 persons/ha	Lower than manual transplanting (20-30 persons/ha)	Higher than broadcasting (1-2 persons/ha)
Service cost	110-150USD/ha	Lower than manual transplanting (190-300USD/ha)	Much higher than broadcasting (10-15USD/ha)
Seed tray requirement	Seedlings grown for transplanter use		Trays costly, and also labour required.
Seed requirement	60kg/ha	Less than broadcasting (120kg/ha)	
Use of young seedlings for transplanting	15 days old seedlings used.	Higher tillering, early maturity than manual transplanting (commonly 25-45 days old seedlings used)	Seedlings can be inundated; affected by golden apple snails
Weed control	Weed control between rows	Mechanical weeding feasible	
Plant density	Wide rows (30cm) and low density	Reducing the cost	Yield may be reduced.

Grain yield	Depending on plant establishment and growing conditions	With better establishment, yield may be higher than broadcasting.	Yield may be reduced by wide rows, inundation and golden apple snails

Seed drill

Economic analysis from the 8 sites in Cambodia in 2014WS and 2015WS indicated that the CARDI technology package obtained a gross margin of about USD 100 ha^{-1} higher than farmers' practice. As noted in Section 5, this comparison is the result of several differences in practices, not just the use of the seed drill. In a further rice seed drill demonstration in EWS 2017 in Cambodia, the results showed that the crop establishment was good and also the crop was easier for weed control. Plant density was slightly lower in the drill-seeded fields (Table 7.19). The average grain yield of four drill-seeded fields with Chul'sa variety was 3.81 t ha^{-1}, which was about 0.45 t ha^{-1} or 13% higher than with the farmers' practice (local varieties and crop establishment method).

Table 7.19. Comparison of seed drill based technology and broadcasting based farmer's practice for gross margin (GM) and its various components in Cambodia for early wet season (a) 2015 and (b) 2017. Xangsayasane et al. 2018b

	Land area (ha)	Plant density (/m^2)	Yield(kg/ha)	Input cost($/ha)	Income($/ha)	GM($/ha)
a) 2015						
Seed drill	0.13±0.01	409±52.3	4570±690	572±76	1142±172	570±153
Farmer	0.25±0.04	510±53.5	3060±580	432±55	766±146	334±138
b) 2017						
Seed drill	0.05±0.017	338±9.9	3810±260	476	952±64	476±64
Farmer	0.11±0.018	384±7.7	3360±150	433±7	839±37	406±37

Economic analysis of the four sites in 2017EWS also indicated that the CARDI technology package obtained a gross margin of about USD 100 ha^{-1} higher than the farmers' practice. The input cost was higher with the drill based technology (Table 7.20), but the total income was higher due to higher yield from the crop established with drill. Similar results to these are obtained from the work in 2018.

Table 7.20. Comparison of input costs for seed drill based technology and broadcasting based farmer's practice in Cambodia for (a) 2015 and (b) 2017. Xangsayasane et al. 2018b

a)

	Input costs ($USD/ha) Seed drill	Broadcast & Farmer practice
seed price	60	57
land preparation	89	85
Fertilizer	112	88
Irrigation	93	51
Planting	31	13
Weeding	106	60
Harvesting	74	71
Other	8	8
Total	572	432

b)

2017			Input costs - Seed Drill			Input costs - Broadcast & Farmer practice (avg of 4)		
No	Item	Unit	Quantity	Unit Price($USD)	Total $USD/ha	Quantity	Unit Price($USD)	Total $USD/ha
1	seed price	kg	100	0.6	60	163	0.4	61
2	land preparation	ha	1	112.5	113	1	112.5	113
	Fertilizer							
3	Urea	kg	75		36	65		31
4	KCl	kg	50	0.6	30	95	0.6	57
5	DAP	kg	50	0.6	30	50	0.6	15
6	Irrigation	L(3time)	45	0.9	39	19	0.9	13
7	Planting		1	31.0	31	1	12.5	13
8	Weed control(herbicide)				50			44
9	Harvesting		1	88	88	1	88	88
Total					476			433

The seed drill appears promising as long as the planting condition is favourable. In Savannakhet province, the area of rice established by seed drill has increased rapidly over 2015 and 2016 to probably over 15,000 ha. This was achieved by innovative farmers positively engaging in the use of the seed drill. They have often become contractors, thereby extending the use of the technology to other smallholders in nearby villages. The areas where the use of drills are spreading have sandier soils than the areas in Khammouan and Bolikhamxay where the project was concentrated, which could be a factor causing the difference in usage. Availability of a seed-drill manufacturer in Savannakhet has also helped the rapid spread of the drill in the province. This would be a positive factor for the use of drills in Khammouan and Bolikhamxay.

In addition to utilizing seed drill for rice establsihment, seed drills can be used for some other crops such as mungbean, peanut, and corn. This increases the usage of a seed drill considerably and provides more options to farmers; for example, peanuts may be considered too labour-intensive for hand planting and therefore may not of been an attractive option previously, but the drill could make peanuts a viable option.

Advantages and disadvantages of seed drill are listed in Table 7.21. A major advantage of drill is low cost compared with manual transplanting. However, weeds are a major issue with drill planting as with other direct seeding methods. Another key point determining drill adoption is whether the area has established broadcasting as a standard method without severe effect of weeds; in these areas adoption of drill may be reduced, although in dry conditions drill is likely to do better than broadcasting.

Table 7.21. Advantages and disadvantages for different characteristics of seed drill (Values mentioned are modified from Xangsayasane et al. 2018b). Fukai et al. 2018.

	Drill requirement/operation	Advantages	Disadvantages
Labour requirement	2 persons/ha	Lower than manual transplanting (20-30 persons/ha)	Similar or slightly higher than broadcasting (1-2 persons/ha)
Service cost	50-60USD/ha	Lower than manual transplanting (190-300USD/ha)	Higher than broadcasting (10-15USD/ha)
Soil moisture requirement	Dry- moist soil, but not saturated	Early planting	Missing opportunity due to early season rain
Seed requirement	40-50kg/ha	Less than broadcasting (120kg/ha)	
Weed control	Weed control between rows	Mechanical weeding feasible	More weed problem than transplanted crops.
Soil type requirement	Not strongly compacted soil	Sandy soils	Poorer establishment in heavy clay soils
Grain yield	Depending on the establishment, weed levels and other growing conditions	Yield can be higher than manual planting methods, particularly under dry establishment conditions.	Yield may be lower than manual planting under poor establishment and weedy conditions.

5a. Dryers – in mills (2.2)

Three rice milling plants in Phnom Penh were selected for the observation of rice cracking and broken rice % during drying and milling. These mills used different dryers with the capacity ranging from 15 to 30 tons, but they used the same Vietnamese dehusker. A mill which received paddy with the smallest cracking (4.7%) produced the lowest broken rice (18.4%) or the highest whole grain of 81.6%), while another mill which had a high cracking rate from the beginning (5.8%) ended up with high broken rice (28%) or low whole grain (72%) (Table 7.22). The drying process more than doubled the cracked grain % in all mills, while development of cracked grain was small during the milling process. While the initial condition of paddy delivered to the mill appears important for determination of the subsequent broken rice %, it is difficult to modify the commercial operation of mills, and hence Activities 2.2.2- 2.2.5 were not conducted. However, the project staff discussed mill operation frequently in 2017/2018 and hence a good understanding of their drying and milling operation practices have been obtained.

Table 7.22. The change in grain moisture content (%), fissured grain (%), and whole grain (%) at 5 different stages in 3 rice mills and the mean and standard error (±) across mills in Phnom Penh area. Bunna et al. 2018b

	Before drying	After drying	After storage	Brown rice	White rice
a) Moisture content (%wb)					
Mill A	28.5	14.8	14	15.3	13.8
Mill B	28.7	14.2	14	13.6	13.1
Mill C	29.3	14.1	14.1	13.1	12.4
Mean	28.8±0.14	14.3±0.12	14.1±0.01	14±0.38	13.1±0.23
b) Fissured grain (%)+					
Mill A	4.7	4.6	13.8	8.3	9.7
Mill B	6.2	19.1	20.3	8.4	14.8
Mill C	5.8	12.9	20.1	13.3	12.8
Mean	5.6±0.27	12.2±2.42	18.1±1.24	10±0.95	12.4±0.86
c) Whole grain (%)					
Mill A				92.7	81.6
Mill B				87.6	80.8
Mill C				88.1	72
Mean				89.5±0.94	78.1±1.78

+ Fissured grain (%) for brown and white rice was determined as percentage of whole grain

5b. Flatbed dryers in Laos – comparison with sun-drying (2.3)

Physical grain quality of milled rice and head rice yield are important characteristics for marketing of rice. In addition to combine harvesting reduc the risk of poor rice quality and reduc the labour requirement for drying, the project has demonstrated that artificial drying using flatbed dryers has an advantage because the rice milling quality improves compared to sun-drying.

<u>On-farm comparison</u>

Our flatbed dryers in Central Laos were used on a total of 22 occasions for determination of physical grain quality of milled rice when rice was harvested by combine. It takes about 11 hours to dry combine-harvested paddy with 28% moisture content to about 16% level. In addition, it takes about 1 hour to load the dryer and another 1 hour to unload. Paddy harvested by combines was also sun-dried by placing the grain on plastic sheets for a day or two. There were 26 batches of sun-dried paddy. The comparison between artificially and sun-dried paddy is shown in Table 7.23. Head rice was significantly higher at 45% when the flatbed dryer was used compared with sun-drying (36%). The effect was consistent between WS and DS, although there was a significant interaction effect reflecting a smaller drying method effect in the DS. The variation in head rice recovery was accounted for mostly by the variation in broken rice. Milled rice was slightly but significantly higher in paddy dried using the flatbed dryer (62.9 cf. 60.7%).

Table 7.23. Comparison of rice milling quality of combine harvested rice dried using flatbed dryer (F) or sun (S) drying and mean (M) in villages across 3 seasons in Laos. Xangsayasane et al. 2018a.

	Brown rice (%)			Mill rice (%)			Broken rice (%)			Head rice recovery (%)		
Season	F	S	M	F	S	M	F	S	M	F	S	M
2014-15DS	77.3	76.9	77.1	64.2	62.4	63.3	19.7	24.4	22.1	44.5	37.9	41.2
2015WS	75.6	75.2	75.4	62.6	60.0	61.3	12.9	24.4	18.7	49.2	35.6	42.4
2015-16DS	75.1	74.8	75.0	61.7	59.7	60.7	20.8	25.2	23.0	41.0	34.6	37.8
Mean	76.1	75.4	75.8	62.9	60.7	61.8	17.5	24.8	21.2	45.3	35.7	40.5
LSD5%S			1.37**			2.23*			1.61**			2.17**
LSD5%D			ns			1.82*			1.31**			1.77**
LSD5%SxD			ns			ns			2.28**			3.07**
CV%			2.46			4.93			10.22			7.34

S= season; D= drying method; ** significant at p<0.01; *significant at p<0.05

Harvesting time and grain quality experiments

Experiments in Laos in the first three seasons show the large benefit of early harvesting as well as the advantage of the use of artificial dryer over sun-drying (Table 7.24)

Table 7.24. Head rice recovery in Experiments 1, 2 and 3 when rice was harvested 3 times during ripening, and dried using sun drying and artificial dryer (sun dried only in Experiment 1) in Laos. Xangsayasane et al. 2018a.

	Head rice recovery (%)				
	Seasons				
	14WS	14-15DS		15-16DS	
Harvesting time	Drying method				
(Days after flowering)	Sun	Dryer	Sun	Dryer	Sun
25	31.1	52.2	27.4	46.9	37.2
30	25.3	na	Na	na	na
35	Na	36.1	26.1	34.4	31.5
45	7.1	8.2	8.4	17.0	8.0
Mean	21.2	32.2	20.7	32.8	25.6
LSD5% (Time)	5.9**		2.1**		2.5**
LSD5% (Method)			1.71**		2.04**
LSD 5% (TxM)			2.96**		3.53*

na = not available, *=significant at p<0.05, **=significant at p<0.01

In WS 2016, an experiment in Laos examined head rice yield of paddy harvested by combine at three different times and dried either by flatbed dryer or sun-drying using either a nylon net commonly available or a proper plastic tarpaulin sheet (Figure 7.16). Higher head rice yield was obtained when paddy was dried with a flatbed dryer, and head rice yield exceeded 50% when the crop was harvested at 25 days after flowering and the grain artificially dried. The use of a nylon net or tarpaulin did not make much difference in head rice yield; the advantage of the tarpaulin was that it can be used to cover the grains quickly in case of rain, although it would cost more to purchase than the nylon net.

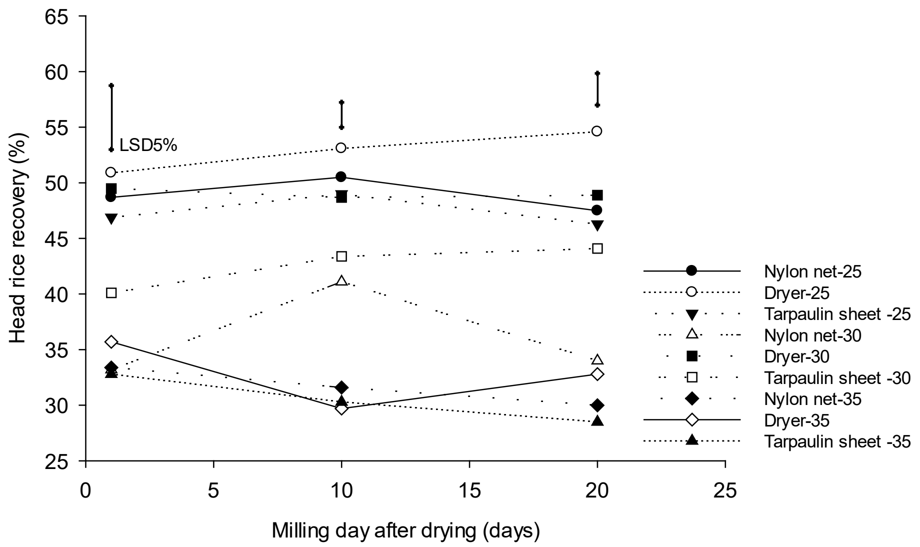


Figure 7.16 Change in head rice recovery as milling was delayed after drying time for 9 harvest time (25, 30 and 35 days after flowering) and drying method (nylon net, flatbed dryer and tarpaulin) treatments. LSD (5%) bars are also shown. Experiment 4 conducted in 2016WS in Laos. Xangsayasane et al. 2018a.

A further experiment in Laos in DS 2016/17 showed that sun-drying only in the morning improves head rice yield to be as good as that of paddy dried with a flatbed dryer (Table 7.25.)

Table 7.25. The effect of drying method (sun drying with tarpaulin sheet or nylon net or use of dryer) and duration (5 or 10 hours in the sun drying and 12 hours in dryer) on head rice recovery of rice crops harvested at 25, 30 and 35 days after flowering. Experiment 5 conducted in 2016/17DS in Laos. Xangsayasane et al. 2018a.

Time of harvesting	Tarpaulin		Nylon		Dryer	Mean
	5	10	5	10	12	
25	48.9	43.6	45.7	44.1	44.7	45.4
30	35.0	28.4	49.5	44.8	44.4	40.4
35	24.7	17.0	37.3	22.8	43.1	29.0
Mean	36.2	29.7	44.2	37.2	44.1	38.3
LSD5% (Time)						1.5**
LSD5% (Method)						1.8**
LSD 5% (TxM)						3.4**

**=significant at p<0.01

The large effect of time of harvesting can potentially have a large impact on the way farmers and combine contractors harvest, particularly where rice is intended for the market where higher head rice % attracts a premium price. Further information on the optimal time of harvesting is required, together with improved understanding of the factors determining physical grain quality. Genotypic variation and the effect of drought on grain quality are being investigated in Australia (see section 6b).

5c. Dryer – flatbed dryer options (2.3)

The farmer group in Pak Peung is currently only paying the marginal cost (electricity, fuel, labour) for drying grain with the flatbed dryer. However, the group charges some farmers from outside the village 3,000 kip/sack to use the drier to cover some of the ongoing costs. A preliminary economic evaluation of using the flat-bed drier suggests that a small price premium (35-40 kip/kg of paddy) would be required to cover the 3,000 kip/sack drying fee. Interviews with a local medium-scale mill purchasing from the group showed that the mill was already paying a 300 kip/kg premium to the group, offsetting the additional cost of drying and increasing farmer profit. If the group had to buy the drier, however, the fee would not cover the full cost.

Advantages and disadvantages of the use of flatbed dryer used in the project are listed in Table 7.26. While advantages of flatbed dryer over the sun drying are well demonstrated, a 4 ton flatbed dryer has the limitation in capacity to dry- 4 ton drying takes overnight. Larger capacity flatbed dryer has become more common and has shown to be more economical for combine harvested paddies that require quick drying. In one of the villages where 4 ton dryer was prepared in the project, the village group decided to send paddies to a large mill with columnar drying, indicating the limitation of the 4 ton dryer. They could be used in a small scale operation, but would have limitation for large scale operations.

Table 7.26 Advantages and disadvantages for different characteristics of 4 ton flatbed dryer (Values mentioned are modified from Xangsayasane et al. submitted a). Fukai et al. 2018.

	Dryer requirement/operation	Advantages	Disadvantages
Labour requirement	1-2 persons/4 ton	Lower than manual sun drying	
Service cost	50-100USD/4 ton	Possibly similar to sun drying and also columnar drying	Possibly similar to sun drying and also columnar drying
Grain quality	Head rice yield	Higher than sun drying (45% versus 36%)	
Chance of spoilt grain	Rain event high for dry season crops	Lower than sun drying	
Operation time	Can use at any time with electricity	Can dry during raining	

6a. Physical properties of rice (2.4) – variety differences and storage

Glutinous rice quality in relation to harvest and drying method and storage period

The result from Rice Research Centre with VTE450-2 shows that HRY is greatly reduced under sun-drying compared with forced air drying (Table 7.27), but in forced drying method, storage for 4 months or longer resulted in lower HRY (Figure 7.17).

Table 7.27. Milling quality of VTE450-2 rice produced in dry season 2015-16 harvested by hand and its response to drying methods and storage duration. Vongaxayya et al. 2018.

Factors	BR (%)	MR (%)	HRY (%)	Broken rice (%)	MC (%)
Drying methods (a)					
Sun drying	77.75 a	63.38 b	34.36 b	29.02 a	14.36 a
Forced air drying	78.22 a	65.65 a	50.61 a	15.04 b	13.94 a
Storage periods (b)					
0 month	79.19 a	65.60 ab	44.34 a	21.26 b	13.89 b
2 months	78.46 ab	65.90 a	44.28 a	21.62 b	14.14 b
4 months	76.20 c	62.29 c	40.26 b	22.02 ab	14.79 a
6 months	78.10 b	64.26 b	41.06 b	23.20 a	13.79 b
F-Test					
Drying (D)	Ns	*	**	**	Ns
Storage (S)	**	**	**	*	**
D x S	Ns	Ns	**	**	Ns
CV (a) %	1.34	2.14	5.49	8.86	4.51
CV (b) %	1.02	2.21	4.05	6.67	3.08

BR (brown rice); MR (milled rice) HRY (head rice yield) Broken rice MC (grain moisture content)
Ns= not significant,*; ** = significantly different at p≤0.05 and 0.01, respectively
Means followed by different letter(s) are significantly different by LSD at p≤0.0 (split plot design)

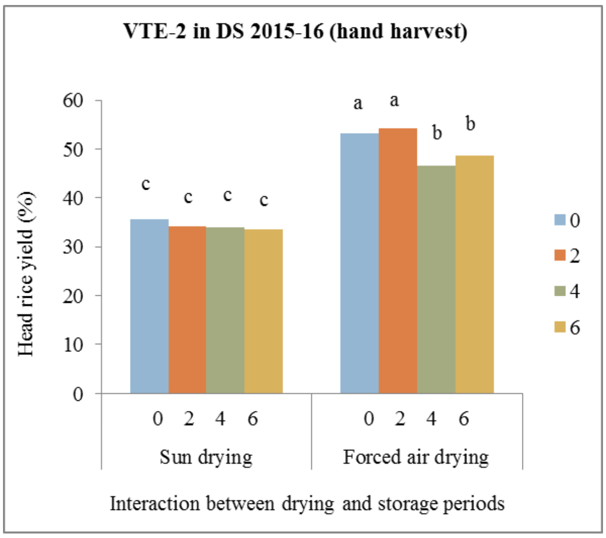
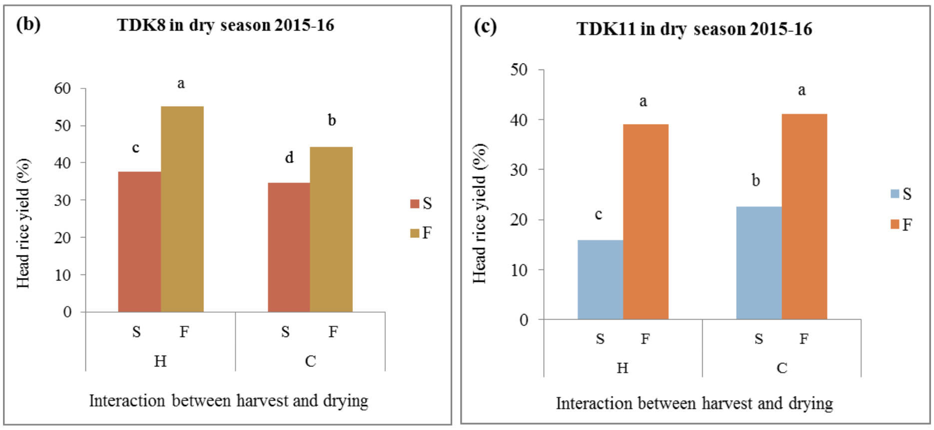


Figure 7.17. Interaction between drying methods and storage period on head rice yield of VTE450-2 produced in dry season 2015-2016 and stored during 2016 wet season. Vongxayya et al 2018.

While hand harvesting and combine harvesting resulted in similar HRY, TDK8 generally had higher HRY than TDK11 particularly under sun drying (Figure 7.18).



S= sun drying; F= forced air drying

Figure 7.18. Interactions between harvest methods, drying methods on head rice yield of TDK8 produced in wet season 2017(a) and dry season 2016 (b) and DS 2016 of TDK11(c). Vongxayya et al. 2018.

While artificial drying was useful to increase head rice yield, other methods that farmers can readily apply have been tested. Results of one such experiment is shown in Figure 7.19. It appears that at least in two varieties tested, drying in room temperature for 6 hours would increase head rice yield greatly.

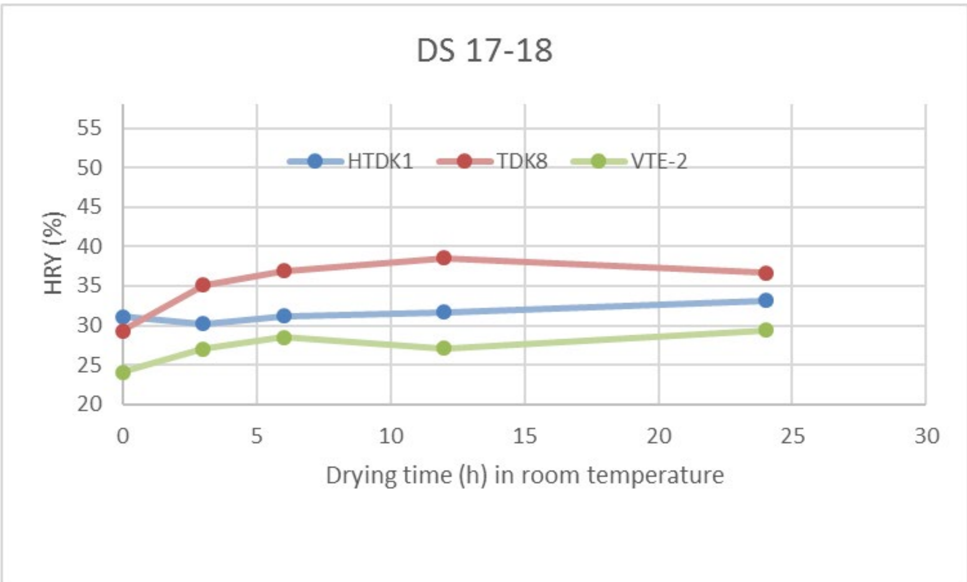


Figure 7.19. The effect of drying time at room temperature on head rice yield of three glutinous rice

Varietal variation in head rice yield was conducted in 4 seasons (2 wet and 2 dry seasons) at Rice Research Centre in Vientiane. The experiments in the first two seasons were not replicated while the last two had two replications. The results of the last season (2019 DS) are shown in Table 7.28. Genotypic variation in HRY was highly significant with the value ranging from 46.1% to 17.0%. While genotypic variation in brown rice was also highly significant, the range was rather small (80.1-74.9%). Thus, genotypic variation in HRY was determined mostly during milling and not during dehusking process. There was large variation in milled rice, and thus degree of milling (brown rice-milled rice)/brown rice varied greatly, and those with larger degree of milling resulted in lower HRY (r=-0.648**, n=30). Broken rice was higher in varieties with lower HRY, but broken rice was not correlated with degree of milling.

There was significant correlation (r=0.456*, n=24) for head rice yield of genotypes common in 2019DS and 2018WS where experiments had replications. Based on ranking (1 the highest HRY) for the 4 seasons, HST, TDK1, TSN7, TSN8 and VTE450-2 were the top HRY varieties. In WS (2 seasons), the best varieties were TSN3, XBF1 and TDK1 while in DS (2 seasons), TDK6, HST and TDK8 were the best varieties.

Table 7.28. Comparison of milling quality of 30 varieties in dry season 2019

No	Variety	% MC	% Brown	% MR	% BR	% HRY
1	TDK6	14.3 ab	79.42 ad	65.13 a	18.99 kl	46.14 a
2	TDK3	14.05 ae	79.51 ac	65.17 a	19.51 jl	45.66 a
3	NTN1	14.6 a	79.30 ad	63.11 b	18.39 l	44.72 ab
4	XBF2	13.65 dh	79.19 ae	65.88 a	24.62 fl	41.26 ac
5	PNG4	14.00 bf	78.42 cg	62.11 bd	21.99 hl	40.11 ad
6	HSV	13.80 bg	78.73 bf	63.46 b	26.05 fl	37.41 be
7	XBF1	14.15 ad	78.88 fh	62.89 b	25.74 fl	37.15 be
8	TDK8	13.3 gh	77.26 gh	57.71 ij	21.16 il	36.54 ce
9	TSN1	14.00 bf	75.97 ij	57.69 ij	21.33 il	36.35 ce
10	15LH066	13.75 bh	80.11 a	59.00 fi	22.73 gl	36.27 ce
11	TDK1	13.55 eh	77.83 fh	59.78 eg	25.70 fl	34.08 cf
12	HTDK1	13.6 dh	78.12 eh	60.26 ef	27.51 dj	32.75 dg
13	TDK37	14.00 bf	78.65 bf	63.52 b	30.84 bf	32.68 dg
14	TSN7	13.75 bh	79.39 ad	58.28 hi	26.34 fl	31.93 eg
15	VTE-2	14.25 ac	78.07 eh	57.95 hj	26.10 fl	31.85 eg
16	PNG5	13.95 bf	78.64 bf	61.11 ce	29.63 ch	31.48 eg
17	PNG1	13.75 bh	79.75 ab	57.54 ij	26.44 ek	31.10 eg
18	TSV	13.70 ch	77.80 fh	63.10 b	32.28 af	30.82 eh
19	TSN8	13.45 fh	78.8 bf	58.48 gi	28.30 di	30.28 ei
20	15LH110	13.50 eh	77.77 fh	56.49 jk	27.98 di	28.50 fj
21	TDK5	14.15 ad	77.67 fh	62.57 bc	34.44 ae	28.13 fj
22	TDK11	13.25 gh	77.98 fh	60.04 ef	32.53 af	27.51 fj
23	TSN9	13.55 eh	78.11 eh	60.81 de	34.88 ad	25.93 gk
24	TSN3	13.6 dh	78.08 eh	56.03 k	30.39 bg	25.64 gk
25	VTE-1	13.20 h	79.43 ac	62.05 bd	38.93 a	23.12 hl

26	TSN10	14.05 ae	77.07 hi	59.31 fh	36.33 ac	22.99 il
27	TSN2	13.80 bg	74.90 j	54.05 l	32.65 af	21.49 jl
28	TSN6	14.15 ad	75.99 ij	48.37 n	27.15 dj	21.22 jl
29	15LH163	13.45 fh	78.24 dh	57.91 hj	38.28 ab	19.64 kl
30	TSN4	13.75 bh	75.27 j	51.6 m	34.58 ad	17.01 l
	Variety	**	**	**	**	**
	Prob	<0.01	<0.01	<0.01	<0.01	<0.01
	LSD	0.56	1.17	1.49	8.03	7.72
	CV (%)	2.02	0.74	1.23	14.03	11.95

MC= moisture content, BROW= brown rice, MR= milled rice, BK= broken rice and HRY= head rice yield
ns, *, ** = not significant, significant at $p<0.05$ and $p<0.01$, respectively.
Means followed by the same letter(s) are not significantly different at $p<0.05$ by LSD

6b. Physical properties of rice (2.4) – varietal differences in broken rice and head rice yield under fully aerobic and stressed conditions (at Gatton, Queensland)

In the first year of aerobic rice study, water stress was commenced at 84 and 94 days after sowing for the first and second sowing. Mean flowering time under irrigated conditions varied from 82 to 129 days but most plants flowered by day 90. Thus these varieties were at the flowering to early grain-filling stages by the time stress was applied. There were significant interaction effects between water availability and genotypes for grain yield, broken rice (%), and head rice yield. Mean yield under irrigated and 1-week stress conditions are shown in Table 7.29. One week of withdrawing irrigation affected all varieties severely, and mean grain yield decreased from 8.3 to 2.7 t/ha. Broken rice was generally small under aerobic conditions (7.1%) but doubled with 1 week of withholding irrigation water. Head rice yield decreased correspondingly, and genotypic variation in HRY was most strongly related to broken rice. Those genotypes which had high HRY (>71%) were Sherpa, Cypress, Baru, Amaroo, and Lemont, and these varieties had only 2-3% broken rice. Some of these maintained high HRY under 1-week stress while others were more affected by the stress. Several Australian varieties produced yield exceeding 9 t/ha under well-watered aerobic conditions, but all were affected by water stress severely. Sherpa appears to be most adapted to the aerobic conditions while Doongara, commonly grown in aerobic conditions in Northern Queensland, appears to have high broken rice % and correspondingly low HRY.

Table 7.29. Broken rice %, head rice yield and grain yield of 20 Japonica varieties grown under well-irrigated aerobic conditions and with 1-week water stress

Variety	Flowering time (days)	Broken rice (%)		HRY (%)		Grain yield (t/ha)	
		Irrigated	Stressed	Irrigated	Stressed	Irrigated	Stressed
Tachiminori	82	9.6	21.1	64.0	43.0	8.75	3.58
M205	84	5.2	6.1	68.8	57.2	6.63	3.00
Doongara	86	10.8	19.1	60.1	46.2	9.19	2.41
Sherpa	84	2.4	10.6	72.6	53.0	9.88	4.76
Cypress	86	2.5	19.7	71.9	48.0	10.81	3.12
Jefferson	85	8.8	19.1	64.0	46.0	7.66	4.38
Baru	85	2.6	9.5	71.8	57.6	9.48	2.17
Namaga	86	4.9	12.1	70.0	56.7	7.03	2.91
Calrose	85	4.3	8.1	69.3	59.8	4.38	3.06
Amaroo	88	2.4	13.2	72.1	48.5	7.49	3.52
Kyeema	90	2.9	10.9	69.9	58.0	9.72	2.41
Bengal	88	3.4	20.3	70.4	45.2	8.81	2.54
Lemont	90	3.2	12.1	71.1	59.5	8.14	5.01
IR62266	92	12.8	12.5	58.3	53.8	6.46	1.82
IR64	92	25.4	13.6	45.2	53.7	5.42	1.66
Topaz	99	3.4	14.1	69.6	57.4	8.94	3.37
YRL39	115	7.9	12.2	61.7	58.4	9.1	2.27
Viet 1	97	6.1	22.0	70.2	49.0	7.85	1.4
Teqing	105	12.4	11.2	60.3	63.2	12.59	3.34
Takanari	129	11.7	15.6	56.5	53.5	7.75	1.41
Mean	**92**	**7.1**	**14.2**	**65.9**	**53.4**	**8.3**	**2.9**

In the second year, detailed studies of 4 varieties show that genotypic variation in head rice yield was related to the variation in bran as well as broken rice while variation in husk component was small. Milling duration of 30 seconds may be sufficient for some varieties but not so for others, while all varieties responded well to increased assimilate supply when plant density was reduced to half (by thinning) at flowering.

7a. Value adding (2.6) – packaging and storage of milled rice

The effect of packaging brown and milled rice for three varieties (black rice, TDK8, and Kainoi) under vacuum and nitrogen conditions showed that the vacuum and nitrogen methods were effective in maintaining good quality when grain was stored for longer than 3 months. Similarly at UQ, a high quality of the popular Lao variety TDK8 was maintained after 4 months of storage when grain was sealed with vacuum, nitrogen gas, or CO_2. The work in Laos and Australia has shown rapid deterioration of glutinous grain quality after a period of 3 months storage. However, this could be reduced if the grain was stored under high nitrogen concentration in a package. This would have wide application for maintaining high quality glutinous grain for a longer period.

7b. Value adding (2.6) – green and brown rice

Rice yield increased with delay in harvesting, and most varieties reached full maturity at 35 days after flowering (Table 7.30). At 20 days after flowering when most grain shows green colour, yield was about 50% the final maturity yield in non-glutinous varieties, but the percentage was higher in glutinous lines (TDK8 and YRW4). When grains were harvested earlier RVA results show peak viscosity and final viscosity were lower, suggesting possible improvement in texture of brown rice.

Table 7.30. Yield of 8 rice varieties in control treatment

Variety	Yield (t/ha)				
	15 DAF	20 DAF	25 DAF	30 DAF	35 DAF
Doongara	3.39$^{a\ A}$	5.22$^{b\ A}$	7.38$^{c\ B}$	7.87$^{c\ BCD}$	8.28$^{c\ B}$
Koshihikari	3.13$^{a\ A}$	4.55$^{ab\ A}$	5.31$^{b\ A}$	8.51$^{c\ D}$	9.22$^{c\ BC}$
Langi	3.75$^{a\ A}$	4.99$^{a\ A}$	7.22$^{b\ B}$	7.57$^{bc\ BCD}$	8.76$^{c\ B}$
Reiziq	3.34$^{a\ A}$	4.95$^{ab\ A}$	5.15$^{ab\ A}$	6.19$^{b\ AB}$	8.26$^{c\ B}$
Sherpa	3.80$^{a\ A}$	5.72$^{ab\ A}$	7.28$^{b\ B}$	8.12$^{bc\ CD}$	10.62$^{c\ C}$
Tachiminori	4.18$^{a\ A}$	5.35$^{b\ A}$	5.77$^{b\ AB}$	7.18$^{c\ ABCD}$	9.06$^{d\ BC}$
TDK8	3.23$^{a\ A}$	5.18$^{b\ A}$	5.43$^{b\ A}$	5.73$^{b\ A}$	5.87$^{b\ A}$
YRW4	3.28$^{a\ A}$	4.34$^{a\ A}$	6.29$^{b\ AB}$	6.53$^{bc\ ABC}$	7.68$^{c\ B}$

Note: -Figures in the same row with the same small letters (a, b, c, d) are not significant different at p = 0.05

-Figures in the same column with the same capital letters (A, B, C, D) are not significant different at p = 0.05

8a. Agronomic evaluation of innovative cropping systems (3.1) – rice/non-rice systems

In both Cambodia and Laos, the project has tested innovative cropping systems and has demonstrated the potential for higher income with the new systems. This was the case with the addition of non-rice crops in the DS, partly because of reduced water requirement compared to rice production. Non-rice crops are grown after WS rice in lowland areas with the availability of some irrigation water in both Laos and Cambodia, but often irrigation water is limited, causing crop failure or reduction in yield. Seed drills can be used to establish non-rice crops and this can produce more stable rice/non-rice double-cropping systems. Thus the project used seed-drills to plant non-rice crops after the rice harvest to evaluate the feasibility of this system. For example, at Trapeang Chak in Takeo, where a single rice cropping system is dominant, two farmers successfully used seed drills to plant mungbean using limited pond water available in DS 2015/16, thus increasing the cropping intensity. Peanuts were also successfully planted using seed drills in two villages in Tramkok in Takeo in DS 2015/16. Without a seed drill, planting these crops was thought to be too time-consuming, hence the farmer grew maize. However, peanuts can be more profitable, and the use of the seed drill appears promising for the development of profitable double-cropping systems.

<u>Water requirements of rice and maize in the dry season</u>

Experiments at RRC in Vientiane showed the irrigation water requirement was much higher for rice (1,280-1,490 mm depending on crop duration) than in maize (370-580 mm depending on time of planting) under standard irrigation conditions. The irrigation water requirement for rice could be reduced by about 150 mm without affecting grain yield. The greater water requirement in rice was due to its longer growing duration, higher water loss through deep percolation and seepage, and lower plant transpiration efficiency. Work at UQ shows transpiration efficiency is two times higher in maize than in rice.

Seed drill demonstration in Laos

Use of the seed drill for non-rice crops was demonstrated mostly with mungbean in Laos. In Pakpung, the drill was successfully used for good establishment of maize and peanuts by the village chief, but the weed problem was severe in these fields. Use of appropriate herbicides would have saved the crops. The possibility for crop diversification using drill-planted mungbean continued in Hatkhamhiemg and Tung villages in Khammouan. Peanut was planted in Ekxang village in Vientiane Province where currently a single crop of WS rice is practised. The yield of peanut planted by seed drill was 1.20 to 2.26 t/ha in Ekxang. See section 10 for the analysis of economic benefit.

CARDI technology – seed drill for non-rice crops

Comparison of grain yield from crops grown in DS 2015/16 under farmers' practice and under CARDI technology, including the use of the seed drill and recommended varieties, in Takeo (4 farmers with mungbean) and Kampot (4 farmers with maize) shows much higher yield for mungbean under CARDI technology but not for maize. However, labour productivity would have been higher in the CARDI maize plots, considering the reduced time required to plant maize by seed drill compared with hand dibbling.

In DS 2016/17, nine field demonstrations were carried out in O'saray and Trampeang Kranhung communes, Tramkok district, Takeo province, with the objective to determine the differences in mungbean and maize yield between hand-sowing and drill-seeding. All field demonstrations were divided into 2 plots, one with the CARDI Technology Package, including planting with the Cambodian seed drill, and one with farmer practice, including hand-sowing. The results of five field demonstrations for mungbean clearly show that, by using the CARDI technology, mungbean grain yield was more than double that of the farmer practice (Table 7.31). However, as noted earlier, the CARDI package differed in other respects from farmer practice and these other factors may also have affected the yield comparison.

Table 7.31. Comparison of mungbean yield from CARDI technology using seed drill and farmer practice in DS 2016/17 in Tram Kok District in two communes

No	Commune	Village	Farmer	Dry yield (kg/ha)	
				CARDI	Farmer
1	O'saray	Stoeng	Sin Kea	500	250
2	O'saray	Stoeng	Yon Tern	480	242
3	O'saray	Stoeng	Sem Chrel	366	233
4	Trapeang Kranhung	Trapeang Chak	Chhim Gnet	480	200
5	Trapeang Kranhung	Trapeang Chak	Ouk Sombuntan	750	285
		Mungbean Mean		515	242

The results of four field demonstrations with waxy maize show that the mean fresh yield of maize planted by seed drill (9.0 t ha^{-1}) was similar to the mean yield with farmer practice

(9.5 t ha^{-1}), despite the farmer practice using hybrid seed and more chemical fertilizer (Table 7.32). However, the farmers were happy to adopt the seed drill and they shared the information with other farmers in the region. They clearly understand that replacing hand planting with the seed drill was more profitable because of saving time and labour costs.

Table 7.32 Comparison of maize yield obtained using CARDI technology including seed drill and farmer practice in Tram Kok District in DS 2017

No.	Commune	Village	Farmer	20 cobs weight (kg)		Fresh yield (t/ha)	
				CARDI	Farmer	CARDI	Farmer
1	Tram Kok	Trpoam Chok	Pum Khouen	4.60	4.80	9.44	10.00
2	Tram Kok	Trpoam Chok	Oun Ouen	4.20	4.50	9.15	8.85
3	Tram Kok	Trpoam Chok	Sin Yan	4.30	4.40	9.37	8.66
4	Tram Kok	Trpoam Chok	Khev Nhun	3.70	5.00	8.06	10.42
			Mean	4.20	4.68	9.01	9.48

Intensified rice/non-rice cropping systems

Planting a non-rice crop after WS rice depends mostly on economic considerations. It is common, particularly in Laos, that farmers refrain from growing a non-rice crop in lowland areas because of the problem of finding markets for the produce. Another factor is the availability of irrigation. For example, in EWS 2017 we observed that mungbean in Steung village and many other non-rice crops in Trapeang Chak village in Tramkok Commune in Tramkok District were grown when there was good rainfall in January and irrigation water was available. It appears that crop diversification is occurring in this part of Takeo province, but there is season-to-season fluctuation in growing non-rice crops, depending on earlier rainfall. In 2017/18season, good rainfall resulted in increased rice-rice double cropping.

Some farmers have learned to use the limited available water effectively to diversify and intensify their cropping systems. For example, Mr Ouk Sombunthen was a typical rainfed lowland rice farmer in southern Cambodia, where commonly only one crop of rice is grown each year and drought is a major problem. He started to work with the project in the middle of 2014 when the wet season was very dry and most farmers failed to grow a rice crop, whether from broadcasting seed or hand-transplanting. He used a seed drill that the project provided and encouraged others to use it. While he was not successful, some farmers harvested rice crops established from the drill. In the following EWS, he was successful in using the seed drill and the produced 1.6 t/ha with the help of water available from his small pond, when no other crops could be hand-planted. He realized the advantage of mechanized planting and used the transplanter in the main wet season, producing a rice yield of 3.1 t/ha. Use of seedlings grown in trays for the transplanter requires less water than seedlings grown in a field nursery. He then used the seed drill in the following dry season to successfully grow mungbean. Thus, the adoption of mechanisation – a seed drill and rice transplanter with supplementary irrigation from a pond – could help him to grow three crops a year. Mr Sombunthen saw the seed drill and rice transplanter as a solution to the current labour shortage and a way to intensify cropping systems to improve the livelihoods of smallholders. In two typical rainfed lowland villages with no canal irrigation but with ponds in Takeo has shown that the addition of a crop is feasible in some years. Thus in Tramkok commune 3 crops may be planted, and the other 2-2.5 crops in one year.

8b. Agronomic evaluation of innovative cropping systems under different water availability conditions (3.1) – rice-rice systems

Double cropping of high-quality rice varieties (Cambodia)

Sequential planting of the high-quality variety Phka Rumduol Prang was compared with the Chhul'sa variety at CARDI (Table 7.33). Acceptable yields (3.6 t/ha) were produced if the crops were planted by November 20. Later planting led to substantial yield loss in both varieties. Thus, while Phka Rumduol Prang behaves like Phka Rumduol when sown at the usual time in June-August, it can be planted as late as mid-November. The crops seeded in late November-early December (Blocks 5 and 6) were damaged by insects and mice, but the flowering date was unlikely to have been affected. The results in Table 7.33 also show that Phka Rumduol Prang matured earlier by 5-7 days in October-November planted crops, while the yield was 10% lower than Chhul'sa. Considering the high quality of Phka Rumduol Prang, the yield penalty would be considered small, and this variety could be used in October- November planting. A major problem is that it would attract insects and rodents as it matures at a time when no other rice varieties would be growing. Thus, a community-wide adoption of the variety may be required to minimize this problem.

Table 7.33. Comparison of Phka Rumduol Prang and Chul'sa rice varieties sown at 10-day intervals in October-December, 2015 at CARDI

Time of planting	Duration to 100% flowering (days)		Duration from sowing to harvest (days)		Yield (t/ha)	
	PRDP	Chhul'sa	PRDP	Chhul'sa	PRDP	Chhul'sa
Oct 21	69	75	92	97	3.31	3.67
Oct 31	68	79	93	100	3.92	4.16
Nov 10	71	79	92	98	3.10	3.97
Nov 20	69	76	91	98	3.56	3.58
Nov 30	71	79	100	106	2.50	2.02
Dec 10	74	78	95	97	0.56	2.00
Mean	70	78	94	99	2.83	3.23

In order to demonstrate the potential to increase the profit from double cropping of high quality rice, Phka Romdoul (PRD) was planted early (in early May) and harvested early (early November) in WS 2016, and then Phka Romdoul Pran (PRDP) and Chhul'sa were planted in early December as the DS 2016/17 crop. The latter crops were planted with a drum seeder or seed drill and harvested on 25 February 2017. The yield and net income are shown in Table 7.34. While yield was higher for Chhul'sa, the grain price was lower than for PRDP and hence the estimated net income was 29% higher for PRDP (USD 643/ha cf. USD498/ha). The estimated net income for the preceding WS was USD 779/ha in both cases and hence the annual income was USD 1,421/ha for PRDP compared with USD1,276/ha for Chhul'sa. The advantage of PRDP is likely to be enhanced if it is planted in mid-November according to the previous experimental results. It can be noted that there was no significant difference between the drum seeder and seed drill for either variety.

Table 7.34. Yield and net income from Chhul'sa and PRDP rice varieties established with drum seeder and seed drill in DS 2016/17

	Yield (t/ha)		Estimated net income (USD/ha)
	Drum seeder	Seed drill	
Chhul'sa	4.781 a	4.722 a	498
PRDP	3.391 b	3.909 b	643
Mean	4.086	4.316	
LSD at 5%	0.22 **		

Note: Means followed by the same letter(s) are not significantly different at p<0.05 by LSD

<u>Ratooning in flood-prone areas</u>

In Laos, the project has successfully demonstrated the ratooning rice option for development of intensified and more stable cropping systems in a few villages where flooding is a recurring problem. In Navang village in Khammouan, we had a successful small-scale testing of ratooning in one year, ratooning crop yielding 2.8 t/ha, although it was abandoned because of brown plant hopper infestation in the following year. In Pakpung village in Bolikhamxay, ratooning was successfully demonstrated by one farmer. Ratooning of DS rice was not successful in the village head's field, but the group leader was successful in his second attempt in his second-lowest field. The DS crop was harvested in May and cut to about 10 cm height in June while water was still available. Nitrogen was applied; the crop was in the booting stage when visited and appeared quite successful (Photo 7.5). Normally these bottom fields were used only for cattle grazing, and harvesting two rice crops in one year would be beneficial to the farmer.

In Photo 7.5 Group leader in Pakpung village, Bolikhamxay, was happy with successful ratooning in wet area

<u>Rice cropping systems for flood prone areas</u>

In addition to ratoon cropping mentioned above, rice cropping systems suitable in flood prone area are considered. One would be to plant photoperiod sensitive varieties such as RD6 if flood recedes early enough, or quick maturing varieites such as TDK11 perhaps using drum seeder. Cold tolerance may be required as booting stage may coincide with the cool weather. Another option would be plant quick maturing varieties early in wet season using seed drill. The severe flood event in Laos in 2018 suggests these options are worthy of testing. Flood- prone areas also need to be identified; recent improvement in satellite technology could be utilized.

9a. Variety improvement (2.5, 3.2) – rice

The multilocation trials in three seasons have identified promising rice varieties, including a line from Cambodia. One genotype (IR07 L167) from Cambodia performed well in ARC. Lao breeding lines RGD10033-77-MAS-327-43-B and RGD10033-77-MAS-327-42-B performed well in ARC while IR87638-10-1-1-1 produced the highest yield at Pakcheng (Table 7.35).

Some varieties, particularly OM varieties (imported from Vietnam), appear to possess quite good milling (head rice yield exceeding 50%) and eating qualities (aroma) (Table 7.36). Varieties with high HRY had lower broken rice percentage; those with HRY>50% had broken rice <16%.

Table 7.35 Grain yield of 19 varieties tested at three field stations across two seasons in Laos

Variety	Yield in WS 2015WS				Yield in DS 2015/16				Mean
	ARC	XBF	PC	Mean	ARC	XBF	PC	Mean	
Chhul'sa	3.05	2.88	2.62	2.85	3.35	4.64	2.47	3.49	3.17
TR07 L 167	3.78	3.64	1.90	3.11	3.00	4.89	2.36	3.42	3.26
IR 07 L 1674-3B–8–2–2–8–2-4	2.49	3.74	2.22	2.82	3.15	4.35	2.23	3.24	3.03
IR 03 L148	3.16	3.14	2.59	2.96	3.11	3.91	2.60	3.21	3.08
IR 04 N 155	3.42	2.96	2.38	2.92	3.43	4.78	2.39	3.53	3.23
IR 87638–10–1–1-1	3.38	2.84	1.96	2.73	2.52	4.71	1.97	3.07	2.90
IR 87761–55–3–1-1	3.63	4.15	2.36	3.38	2.73	4.09	2.37	3.07	3.22
OM 9916	2.99	3.52	2.26	2.92	2.60	3.97	2.27	2.95	2.93
RGD 10033-77- MAS–327–43-B	4.14	3.86	2.84	3.62	3.26	4.03	2.86	3.38	3.50
RGD 10033-77-MAS-327-42-B	3.88	3.80	5.59	4.42	3.06	3.88	2.60	3.18	3.80
OM 4900	3.34	2.94	1.99	2.76	2.68	4.77	2.00	3.15	2.95
OM 6162	3.36	3.06	2.34	2.92	2.89	3.84	2.35	3.03	2.97
IR06L164	3.34	3.48	2.53	3.12	2.94	4.13	2.54	3.20	3.16
IR83415-B-SDO3-3-AJY1	3.44	3.22	2.01	2.89	2.73	4.11	2.03	2.96	2.92
RD 15 (control)	3.97	3.49	0.00	3.73	1.31	1.62	0.14	1.02	2.38
Xebangfai 2 (control)	4.09	3.36	2.25	3.23	1.97	2.99	2.26	2.41	2.82
PNG 1 (control)	2.79	3.44	1.76	2.66	2.38	2.70	1.77	2.28	2.47
VTE 450-1 (control)	3.90	3.53	2.00	3.14	1.82	2.31	1.96	2.03	2.59
PC26			2.22	1.43	2.06	3.45	1.88	2.46	1.95
Mean	3.45	3.39	2.43	3.03	2.68	3.85	2.16	2.90	2.97
CV (%)	11.5	13.4	24.8		11.5	12.5	24.7		
P value	0	0.04	0.005		0	0	0.095		

Table 7.36 Milling quality of 21 lines including 18 lines tested in multi-location trials

Country	Name of variety	% brown rice	% milled rice	% hulls	% bran	% brok-en	% head rice	Remarks
Cambo	Chhul'sa	79.5	63	20.4	16.5	13.9	49	
Cambo	TR07 L 167	77.9	65.9	22	12	21.8	44.1	
Cambo	IR 07 L 1674-3B-8-2-2-8-	76.2	64.7	23.7	11.5	28.6	36.1	
Cambo	IR 03 L148	77.6	65.7	22.3	11.9	14.3	51.4	
Cambo	IR 04 N 155	78.7	67.6	21.2	11	20.6	46.9	
IRRI	IR 87638-10-1–1-1	78.9	66.6	21	12.3	15.1	51.5	
IRRI	IR 87761-55-3-1-1	77.9	64.6	22	13.3	20.9	43.6	slight
Vietnam	OM 9916	78.4	67.4	21.5	11	15	52.3	aroma
Thailan	RGD 10033-77- MAS-	77.3	65	22.6	12.2	10.8	54.2	
Thailan	RGD 10033-77-MAS-327-	71.8	60.6	28.2	11.1	10	50.6	
Vietnam	OM 4900	77.8	67.3	22.1	10.5	15.8	51.5	aroma
Vietnam	OM 6162	78.1	67.1	21.8	10.9	18.3	48.8	slight
Cambo	IR06L164	79	65.2	20.9	13.7	20.4	44.8	slight
Cambo	IR83415-B-SDO3-3-AJY1	79	63.8	20.9	15.2	21.1	42.6	
Thailan	RD 15 (control)	75.2	62.7	24.7	12.4	12.3	50.4	aroma
Laos	Xebangfai 2	77.7	63.2	22.2	14.4	18.8	44.4	slight
Laos	PNG 1	77.1	65.2	22.8	11.9	12.5	52.7	
Laos	VTE 450-1 (control)	77.1	62.8	22.8	14.2	23.5	39.2	
Laos	XBF2	78.2	68	21.7	10.1	14	54	aroma
Laos	TDK8	75.6	63.3	24.3	12.3	19.4	43.8	
Thailan	RD6	75.6	62.6	24.3	12.9	15.9	46.7	aroma

Thus, the breeding program has made excellent progress, and several promising lines have been identified (Table 7.37). Black rice line TDK10403-B-B-B-5-3 appears particularly promising with quick maturity and high yielding for black rice. TDK10405-B-B-B-92-2-1 is also promising as quick maturing, high yielding rice, similar yield and maturity time to the quick maturing parent Till13. Breeding lines from crosses that were made at the beginning of the project have reached to observation yield trials in 2018WS where maturity dates were determined. There were 8 short maturity lines and 13 aroma lines which matured less than 110 days, while maturity date of some parents are 114-117 days (TDK8), 108 days (TDK5), 120-121 days (TDK11), 124 days (VTE450-2), 121 (IR64), 134-138 days (KDML105), and 120 days (RD15). TDK5 is suitable for cooler areas, and this project has shown to be quick maturing in Vientiane. Seed of some of these quick maturing lines as well as other promising lines (30 quick maturing lines, 16 aroma lines, and 8 black rice lines) were being multiplied for the replicated yield trials in the next season. It is particularly exciting that we have found promising lines that mature in less than 110 days, as they can be used to provide flexibility in different cropping systems.

Multi-location trials for early maturity has identified several lines (RGD10033-77-MAS-327-43-B, Chulsa, IR07 L167) that are high yielding including IR07 L167 which is also quick maturing. It is noted that this line from Cambodia matures in about 100 days over there, but in 124-133 days in Laos. This difference may be related to the use of younger seedlings for transplanting and higher temperature in Cambodia. It is also pointed out that some lines may be mildly photoperiod sensitive and this could delay flowering in WS in Laos where daylength is longer than in Cambodia in summer. In DS when daylength effect would be minimum, temperature is much lower in Laos, slowing down the reproductive stage development, possibly resulting in longer time to flower in Laos in both DS and WS.

Table 7.37. Summary of the current status of the rice breeding activities in Laos

Type of activities	Traits	Rice type	Stages	Status	Number of Lines
Variety selection	Early maturity	Glutinous and non-glutinous	4-year multiplication trials completed	IR07 L167 from Cambodia 124-133 day maturity, yield up to 4 t/ha. IRRI, Thai and Vietnamese varieties also promising	
Germplasm development	Early maturity	Non-glutinous	Observation yield trial of promising lines 2018	TDK8/Till4 (TDK10477)	5
				B6144 / TDK8 (TDK10478)	5
				TDK5/Till4 (TDK10492)	2
				Till4 / TDK11 (TDK10493)	8
				Till4 / TDK1 (TDK10494)	6
				TDK11/IR64 (TDK100496)	2
				B6144/VTE450-2 (TDK100497)	6
				B6144/TDK11 (TDK10498)	6
				TDK5/TSN1 (TDK10500)	2
				TDK5/TSN1 (TDK10500)	2
			Yield observation	128 -147 day maturity, 3100 to 4201 kg/ha	9
	Aroma and medium amylose	Non-glutinous	Observation yield trial of promising lines	IR64/KDML105 (TDK10484)	7
				Til13/KDML105 (TDK10485)	3
				KDML105/LG715 (TDK10486)	8
				Till8/RD15 (TDK10487)	14
				KDML105/LG13302 (TDK10488)	17
				KDML105/LG5448 (TDK10490)	8
	Black rice	Glutinous	Observation yield trial of promising lines 2018	TDK1/LG13259 (TDK10464)	5
				TDK1/LG715 (TDK10465)	3
			Yield observation	127-145 day maturity and 1900-2700kg/ha	8

9b. Variety improvement (2.5, 3.2) – non-rice crops in Laos

In each of two DS waxy maize experiments at ARC, Laos, there was highly significant variation in yield and yield components. The average yield (husked ear weight) for two seasons of the 6 highest-yielding waxy maize varieties ranged from 6,486 to 8,924 kg/ha. The six varieties were ARC 15, Waxy Maize 30, SLWB, Waxy Maize 165, Waxy Maize 168, and KKU-VN. None of these varieties were early maturing; most were of medium maturity. They can be used as parent materials for improving yield of early-maturing varieties.

The peanut yield trials have shown significant differences (P<0.01) among varieties and seasons, and significant interaction between varieties and season. In the DS most varieties were of medium to late maturity (120-130 days) while in the WS only 93-103 days were required to mature. Varieties were very late maturing in DS 2016. Local varieties were in the earlier maturing group (Red VTE, Red LPB, and White XY), with 93 days to mature in the WS and 120-124 days in the DS. Varieties V78 and Thainan9 both had small grain size, while KK6 and KK84-7 had the largest grain size. The highest yielding varieties were KKU40, V78, and KKU60 in DS 2016, and KK84-7, V78, and Thainan9 were WS 2015 and DS 2016. When averaged over 3 seasons, the highest yield was obtained from V78 (Vietnam), KKU40, and KS2 (Thailand), with 1,926, 1,867 and 1,781 kg/ha respectively. V78, KKU40, and Thainan9 are good for grain consumption, while KKU40, KS2, KK5, KK6, KK84-7, and KK84-8 are good for boiling fresh pods.

For mungbean, there was also a highly significant difference ($P<0.01$) between varieties and crop seasons, and a significant interaction between variety and season. Almost all early maturing varieties had first harvesting in less than 70 days. Generally all varieties produced low yield, mostly less than 1,000 kg/ha (from 97 to 864 kg/ha). It seems that mungbean did not develop well in the DS; WS2015 was better than DS2015 and DS2016. This could be because of the difference in weather conditions but it is noted that irrigation was not sufficient in the DS. The average yield over three seasons was highest for OMX19 (718 kg/ha). The highest yield in DS 2015 was for OMX19 (865 kg/ha) and VC3890A (820 kg/ha). VC6497-59A and VC5610-151-1 produced good yields in WS 2015 and DS 2016, while they produced low yields in DS 2015. DXVN7 had better yield in the DS than the WS. OMX19 and VC6368 are promising varieties for mungbean.

9c. Variety improvement (2.5, 3.2) – non-rice crops in Cambodia

The results of 29 on-farm adaptation trials of CM1 maize in three villages in DS 2016 show that CM1 produced a marginally larger number of cobs and hence total income than the farmers' variety; most farmers preferred the newly released CM1 variety.

The peanut trial in Ta Deng Thmei village in Kampong Speu in DS 2016 showed no significant yield difference among 12 lines, but the Cambodian lines matured 10 days earlier than ICRISAT lines. Results of two multi-location trials of peanut conducted in Kampong Speu and CARDI in DS 2017 show that days to flowering, days to maturity, pod yield, kernel yield, kernels/fruit, and 100 kernel weight had significant genotypic variation, but not for the number of fruits per plant. Lines FD ICGV03169, SB11, and PS7 are the earliest flowering at 26 days, maturing at 113 days after planting. PS7 at the CARDI site produced the highest fruit and kernel yield, with the largest kernel weight (440 mg), followed by PR 12 (Table 7.38). Genotype by environment interaction was significant in all tested traits, except number of fruits/plant and number of kernels/fruit. The three lines FD ICGV03169, SB11, and PS7 were identified as promising.

Seed multiplication of the three promising peanut lines has continued from EWS to WS (180 m^2 each), but heavy rainfall affected plant growth, and only limited amount of seed was obtained. They were used for pre-on-farm trials in around 20 locations in Kampot and Takeo after harvesting WS 2017 rice, and based on 10 trials successfully completed, 3 lines were further selected. Based on farmer's preference one line (SB11) was released as CAP1 (Cambodian Peanut 1) in 2018. Seed was further multiplied for additional on-farm trials in 2019.

Table 7.38 Genotypic differences in days to maturity, fruit yield, and kernel yield of the 12 peanut lines tested in DS 2017

No.	Genotype	Day to 50% flower (days)	Day to mature (days)	Fruit yield (kg/ha)	Kernel yield (kg/ha)	Fruit/plant	Kernel/Fruit	100 kernel weight (g)	Fruit yield (kg/ha)		Kernel yield (kg/ha)	
									K. Speu	CARDI	K. Speu	CARDI
1	FD ICGV 99029	32	124	2,626	938	24	2	37	1,656	3,595	242	1,635
2	FD ICGV 99030	31	124	2,692	848	25	2	41	1,871	3,513	348	1,347
3	FD ICGV 99032	31	124	3,076	911	26	2	41	1,776	4,375	373	1,450
4	FD ICGV 99036	32	125	3,431	1,352	31	2	41	2,632	4,230	787	1,918
5	FD ICGV 99053	28	113	3,235	1,754	28	2	41	2,076	4,394	651	2,857
6	FD ICGV 99054	30	124	2,949	1,042	27	2	39	1,819	4,080	569	1,515
7	FD ICGV 03169	26	113	2,876	1,662	24	3	38	1,596	4,156	579	2,745
8	SB 11	26	113	2,957	1,915	31	2	41	1,580	4,333	621	3,209
9	PS 7	26	113	3,616	2,284	26	2	44	1,714	5,519	837	3,731
10	PR 27	28	113	2,751	1,569	22	2	42	1,440	4,061	308	2,830
11	PR 41	27	112	2,217	1,159	29	2	36	1,201	3,233	242	2,077
12	PR 12	27	112	3,421	1,778	27	2	40	1,597	5,245	410	3,146
Mean		29	117	2,987	1,434	27	2	40	1,747	4,228	497	2,372
Genotype (G)		1.2**	0.6**	692**	423**	ns	0.1**	2.2**				
Environment (E)		0.5**	0.2**	282**	172**	2.7**	ns	ns				
G x E		**	**	*	**	ns	ns	**				

10. Socioeconomic analysis of intensified and diversified production systems (3.3)

Mechanisation has been used mostly to save labour, which constitutes its major economic contribution. There are, however, examples from the project where the use of machinery has also enabled crop intensification and diversification. Some of the economic benefits of such intensification and diversification are listed here.

(a) Mechanised planting

Crop intensification and diversification may be achieved as a direct result of the use of mechanized planting, providing a positive return to farmers. For example, drill-seeding saved a rice crop planted in a dry spell in the wet season in Takeo, Cambodia. In Ekxang village in Laos, where some irrigation water is available in the DS but not sufficient to grow rice, no crops had been grown. Our work with a farmer has shown that the addition of drill-seeded peanuts in the DS after WS rice resulted in a gross income close to USD 150 from an area of 800 m^2. The cost of purchased seed was about USD 20 and the cost of irrigation water was about USD 3, but these would be reduced greatly if seed was sourced from the farm and the amount of irrigation was reduced – the farmer irrigated his peanut and maize crops every few days, whenever the soil surface became dry, and this resulted in apparent over-irrigation. Another farmer planted 600 m^2 of peanuts in the DS by dibbling and produced 130 kg of pods which would have grossed about USD 100.

The result of economic evaluation of intensified and diversified system is shown here with the assumption of additional mungbean crop per year planted with seed drill using the data obtained in the Takeo example. Mungbean yield varied among farmers and seasons shown in section 8 the agronomic evaluation of innovative cropping system. The mean yield of 515 kg/ha obtained in 2016/17DS was used for this analysis. The current on-farm gate price is about 4000 riel/kg or 1USD/kg, and hence the income from this crop would be 515USD/ha. Cash cost for mungbean production was estimated in our previous project in Cambodia to be 179USD/ha, hence providing the net cash return of 336USD/ha.

Drills and transplanters also save time compared with hand transplanting, which is still common in both countries; pulling seedlings and transplanting are time consuming (about 35 people are required to plant a hectare in one day), and the saved time could be used for other crop production activities. This change may also affect men and women differently, as discussed with regard to the use of combine harvesters.

(b) Use of dryers

Dryers can also contribute to crop intensification. This can be seen in the example of our group leader in Pakpung village planting rice as he harvested rice, as he had access to the dryer and hence did not need to avoid rainy days for harvesting. As he grew photoperiod-insensitive rice varieties and had access to irrigation, he could plant at any time of the year although he has not done so, as he has vegetable garden to look after which is the main source of the family's income. Thus dryers in this case provided flexibility in rice cultivation.

(c) Use of combine harvesters

The combine harvester is used to achieve a timely harvest. The importance of a timely harvest is highlighted through the project's work on the effect of proper time of harvesting during ripening on harvest grain loss and loss of grain quality. As the rice crop is harvested in a timely manner, a new crop can be planted on the same land sooner than with hand harvesting, although we have not yet observed such a case.

Another point is that the time saved by the use of machinery can be reallocated to crop intensification or diversification. For example, employing a combine harvesting service has resulted in very little time being required for harvesting rice, hence more time has become available to grow another crop or pursue other livelihood activities, thereby intensifying and diversifying household livelihoods, even if the crop is not planted on the same plot as the rice crop just harvested.

8 Impacts

Impacts of some of the project outputs have become apparent in the increased use of machinery, enlargement of paddy fields, and adoption of new varieties that the project has been engaged in developing or promoting. Interactions between the various technologies can also be noted, such as enlarged fields promoting the mechanisation of various operations, and the use of combine harvesters promoting the use of dryers for grain of high moisture content.

Impact has been achieved in two ways – first, through direct interaction with farmers and district officers and, second, through the central and provincial governments. These higher levels of government in Laos have promoted technologies such as agricultural mechanization and new varieties to which the project has contributed. Project results are continuously provided to MAF and the provincial government, particularly in Khammouan. Project outputs and recommendations were supported by the provincial government for the use of machinery and enlarging fields as well as the use of VTE450-2 and XBF2 rice varieties that the project is strongly promoting.

The understanding of factors associated with use of combine harvesters that the project has generated, such as the involvement of millers and land developers, has resulted in identifying policy intervention points that could be accepted by policy makers. Based on the understanding of the interrelationships, the project has assisted implementation of mechanized rice production in Central Laos. The project has cooperated with the Khammouan Provincial Government, particularly the Extension Group, and the largest impact of the project is seen in this province where the number of combine harvesters has started to increase and larger paddy fields are being promoted. Recently, the Khammouan Government has decided to provide credit to farmers who wish to enlarge their fields. In addition, their Extension Group obtained a set of 11 machines, including combine harvester, 4W tractor, and a transplanter for demonstration of mechanized rice cultivation in Nongping village, Gnommalad District. Their services have been well utilized by the farmers in the village and nearby areas in 2016 and 2017.

8.1 Scientific impacts – now and in 5 years

Scientific impact may be seen in the evaluation of rice grain quality, particularly in head rice yield. One aspect is the realization that varieties may differ in their milling requirement and the current uniform milling method may not express the best milling quality of some varieties. In some countries, harvested paddy is thoroughly cleaned before milling, while in others harvested paddy may be tested directly for milling quality. In the latter case, grain yield (t/ha) multiplied by head rice yield (%) would produce milled rice that can be marketed, while in the former case, the actual milled rice weight will be less than the values indicated from grain yield and head rice yield.

8.2 Capacity impacts – now and in 5 years

An International Workshop on Mechanization was held in Vientiane in November 2015, and in Cambodia in November 2016. Project members and others attended the workshop and gained considerable knowledge on the scientific and operational aspects of combine harvesting, mechanical planting, and grain drying from international and national scientists working in the field.

Four scientists from Laos and Cambodia visited UQ for 2 weeks in September 2016 to learn more on data analysis and paper writing. The impact of this visit was seen in their excellent presentations at the International Mechanization Workshop in Cambodia.

A number of group meetings have been conducted, particularly when UQ team members visited the countries (Fukai 21, Bhandari 4, Cramb 1, Newby 4, and Mitchell 6 times), and they provided assistance to project membrs for improved understanding of various topics within the project. Jono Newby resided in Vientiane and was able to assist the Lao group continually. We also held annual meetings in each country, and project scientists presented their project results and future plans.

Excellent capacity development can be seen by our scientists receiving awards; Phetmanyseng Xangsayasane IRRI Alumni Outstanding Scientist as well as ASEAN Outstanding Rice Scientist awards; Ouk Makara ASEAN Outstanding Rice Scientist award and Chay Bounphanousay IRRI Alumni Outstanding Scientist award.

Table 8.1 lists the formal training received by postgraduate students through the project. Mr Malik Nawaz, who commenced his PhD four years ago, has made good progress in his study of grain quality of glutinous rice, and seven papers have been published recently in reputable international journals, and received his PhD in 2018. Similarly, Ms Vongxayya has obtained her Master's degree after publishing a paper in an international journal.

Table 8.1. Formal training received by postgraduate students through the project

Name	Institution	Degree	Years	Topic	Funding source
Malik Nawaz	UQ	PhD	2014-2018	Grain quality of glutinous rice	Australian Government and the project
Khamtai Vongxayya	Khon Kaen Uni.	MSc	2015-2018	Grain quality of glutinous rice	Khon Kaen University and project
Houn Sereivuth	RUA, Cambodia	MSc	2017-	Grain quality of non-glutinous rice	RUA and project
Vilayphone Sourideth	UQ	PhD	2013-	Water use efficiency of rice and maize	Australian Government and project
Ohnmar Myint	UQ	PhD	2016-	Drought and rice grain quality	Australian Government and project
Sinh Chao	UQ	PhD	2017-	Green and brown rice	Australian Government and project
Hongjing Liu	UQ	MFood	2016	Rice grain quality	UQ and project
Cai Yuhong	UQ	MFood	2016	Rice grain quality	UQ and project

In addition, several undergraduate students in Agronomy and Agricultural Engineering from the Royal University of Agriculture conducted their thesis experiments in Cambodia. Experimental costs were met by the project.

Machinery provided by the project, such as seed drills, a combine harvester, and flatbed dryers, are likely to be used by other research projects through NAFRI and CARDI.

8.3 Community impacts – now and in 5 years

Seed drills

Project impact is also seen in the adoption of seed drills. In Laos, the project allowed farmers in the target villages to use its seed drills to plant their crops. The project also influenced the Namgnep1-Hydropower Company to purchase 5 seed drills to be used in a resettlement program. Similarly, the Khammouan Development Project purchased 3 seed drills and one has been provided to farmers. Thus, as a direct result of the project, 10 seed drills have been purchased in Khammouan and Bolikhamxay, Laos. A number of rice fields in our target villages and nearby areas were planted by seed drill in WS 2017, but the extent of drill use is not known at this stage. The number of seed drills in Khammouan Province increased from 10 to 31 in 2017. In Hatkhamhiang village in Khammouan, the village head ranked the farmer's preferences for different planting methods as shown in Table 8.2. He believed the seed drill was the most popular for upper fields in the WS, but not in the DS.

In Cambodia, subsequent to the first demonstration in WS 2014, 16 famers in Trapeang Chak village, Trapeang Kranhung commune, Tramkak district, planted almost 30 ha with the seed drill. Dry conditions in WS 2014 meant that two farmers failed to produce any yield, but over 10 t of paddy were produced from the remaining 14 farmers with a mean yield of 0.35 t/ha. Apparently about 80% of farmers in the village tried to plant rice by broadcasting and all these crops failed, indicating the usefulness of the seed drill under drought conditions. The crop establishment was better than broadcasting and also weed control was less of a problem. In WS 2015, 16 famers in Takeo province planted almost 10 ha with the seed drill and 7 farmers produced over 32 t of paddy with a mean yield of 3.1 t/ha. In WS 2016, 17.5 ha of rice was planted by seed drill outside the project area in Takeo. More recently, in WS 2017, three newly-designed seed drills were provided to three farmer groups in Cambodia. In addition to the project areas of 4 ha in O'Saray, 7 ha in Trapeang Chak, and 3 ha in Kampot, as well as 2 ha of maize in Kampot, IRRI borrowed our drill and planted 10 ha in Trapeang Chak. IRRI and other projects are keen to use our drill further for rice or other crops. Thus there is evidence of widening impact of the project's work on seed drills.

Table 8.2 Assessment of farmers' preferences for rice planting methods in wet and dry seasons by head of Hatkhamhiang Village, Khammouan Province

Farmers' ranking	Wet season (upper field)	Wet season (lower field)	Dry season
First	Seed drill	Volunteer rice	Drum seeder
Second	Drum seeder		Broadcast
Third			Hand transplanting
Fourth			Seed drill

It is expected that the use of the seed drill will spread quickly in Laos, particularly in Khammouan where it is available commercially and many farmers have been exposed to the technology. In early 2018, about 30 seed drills were purchased by farmers from a machinery shop, and the project provided a leaflet on how to use seed drill. Our economic analysis also supports this view. It should be noted that in neighbouring Savannakhet, seed drill use spread rapidly in 2015-2016 to perhaps several thousand hectares, although the early commencement the wet season in 2017 has reduced its use in that province.

Transplanters

The impact of project outputs in relation to the transplanter appears limited so far, partly because of the initial high purchase cost of transplanters as well as the requirement of a large number of seedling trays. Project farmers who had transplanters and were provided with trays by the project are continuing to use the transplanters, particularly for seed production for which they receive a higher price. Some farmers who have transplanters have started to provide contract services, but their viability is not known at this stage. As indicated in Section 7, transplanter service has become available in the Nongping village area in Khammouan, and several farmers are willing to pay the contracting fee of 400,000kip/ha.

A lot of transplanters have been sold recently in Vientiane, and thus its use is likely to increase in the near future.

Deep ripping

After the project work highlighted the advantage of deep ripping, all paddy fields in CARDI have been deep-ripped recently. As this had not been done for many years, the hard pan was getting stronger all the time, and the topsoil layer had become very shallow. There is also interest outside of CARDI in deep-ripping, and some farmers are keen to learn the technology.

Combine contracting services

In Central Laos, large paddy fields are being created, and combine contracting services are increasing rapidly. In Khammouan, 24 combines are now available compared to 2 at the commencement of the project, and in Bolikhamxay the first combine became available in 2017. In Vientiane, the number of machinery also increased since the commencement of project from 2 to the present number of 15, but dryer number has not increased causing as a bottleneck for the adoption of combine service. These combines are operated by contractors and their services are spreading quickly in these provinces. For the first time in 2016-2017, large areas of rice in 3 of our target villages were harvested by combine. Combine service fees have become cheaper in Laos, probably due to increased competition among service providers; the fee was often over USD 200/ha at the commencement of the project but much lower fees have been charged in the past year.

However, many farmers in Laos and Cambodia are reluctant to use combine harvesting services as often there is no grain drying service available to handle the high-moisture paddy that results from harvesting by combine. Thus, the development of a drying service is a major requirement for wide adoption of combine harvesting. Drying services may be provided by mills or villagers, though it is likely that mills have an advantage in providing this service.

It is expected that combine harvesting services will spread rapidly for the remaining parts of the three provinces of Central Laos (Khammouan, Bolikhamxay, and Vientiane), considering the economic benefit to both contractors and farmers, following the example of neighbouring countries (Thailand, Cambodia, and Vietnam). Combine contracting services have been expanding during the project period and this is expected to continue in the near future.

Use of combine harvesters depends on decisions by at least three different groups (farmers, millers, and combine contractors). A mechanism is required to ensure that all actors involved in combine harvesting will work together for the common goal of developing mechanized rice production so that everyone benefits in the long term. The combine contracting business appears profitable and further development of the business is encouraged. The current combine contracting fees in Laos are expensive, partly because of short-term credit the contractor has signed on for. Increasing the credit term will assist in lowering fees, thus further promoting the use of combine harvesting. There is strong link between the farmer's decision to use combine harvesting and the availability of facilities to dry paddy, hence villages and/or millers need to ensure that the grain can be dried properly. Among several methods available to reduce the combine service fees, field amalgamation is one option that can be achieved by cooperation among combine contractors, farmers, and field amalgamation and land levelling service providers who would use 4-wheel tractors. Field enlargement will be of direct benefit to combine contractors who will be able to harvest rice more efficiently.

We have also made suggestions regarding the long-term policy for mechanization. For example, consideration could be given to establishing a mechanization promotion board to be run by the private sector to foster machinery businesses and establish a mechanization technology center for training mechanization specialists. This will help further the adoption of mechanized cropping.

<u>Enlarged fields</u>

Some farmers have amalgamated fields, realizing that larger fields are more efficient for various machinery operations, including combine harvesting. Farmers near our project areas in two villages started to enlarge their fields after seeing the benefit of enlarged paddies in our project activities. In Bolikhamxay District, NamGnep Hydropower is developing 11 ha of rice fields, and the project is assisting their field layout as well as crop establishment using seed drills. Often the implication of enlarged paddies is a change in the establishment method, as hand-transplanting may no longer be practical in such a large field. While the advantage of large paddy size is well demonstrated by the project, and it was promoted by the Khammouan Provincial Government, the correct method of paddy enlargement and land levelling needs to be conveyed to 4WT contractors.

Figure 8.1 below shows the interrelationships among different groups in relation to paddy field enlargement, indicating that farmers receive little direct benefit from amalgamation of paddies if they incur the cost of amalgamation. This relationship shows that farmers are financial losers, whereas land developers and combine contractors are financial winners. The project suggested ways to rectify this situation by altering the combine fee structure (i.e., larger paddies are charged less per ha) and by the farmers receiving long-term credit for field enlargement. Recently the Khammouan Government has adopted this suggestion and is providing credit for amalgamation of up to 70 ha/year, hence it is likely that the adoption of field amalgamation will be accelerated. After the advantage of large paddy size was demonstrated by the project, field amalgamation was promoted by the Khammouan Provincial Government particularly in Nongping village where mechanized rice production is demonstrated through Provincial Extension group.

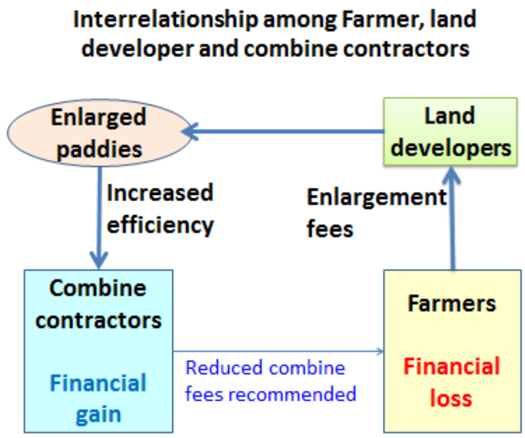


Figure 8.1. Interrelationship among farmer, land developer, and combine contractor

Flatbed dryers

The project successfully demonstrated the advantage of flatbed dryers for production of high physical quality of grain and labour saving in Central Laos. Flatbed dryers may be used in a commercial operation; the flatbed dryer in Pakpung village in Bolikhamxay is used for non-project members in the village and nearby. They appreciate the usefulness of the artificial dryer in case of rain soon after harvesting, whether by combine or manually. Because of the availability of combine harvesters for the first time in DS 2016/17 in the area, our dryer was used 11 times for drying of 1,040 bags (35 kg each). The electricity fee for the season was 1.3 million kip. It was again used 5 times in WS 2017, drying 221 bags (35 kg each). The fee for this service was USD 20/load (3-4 tonnes or about 1 ha equivalent). While millers in the area appreciate the higher quality of artificially dried paddy, the premium paid by millers appears rather small currently. Dryer services are likely to become more competitive as combine harvesters become popular and artificial drying is required, particularly on wet days when sun-drying is not possible. Commercial drying service is likely to grow also when rice becomes more commercialized and the value of higher head rice yield is more appreciated. While our attempt to install small 4-tonne flatbed dryers in villages in each country had merit, larger flatbed dryers could be installed in medium-sized mills where they see the merit of artificial dryers but are not able to afford more expensive vertical dryers with higher efficiency. However, flatbed dryers may not be viable in areas where vertical dryers are already installed in mills, if their capacity can keep up with the demand. Furthermore, given that one combine can harvest around 4 ha per day, there will be problems with congestion of flatbed driers once the use of combines increases. Economic analysis suggests that when the fixed costs of the drier (depreciation, interest, housing) are considered, the business case for small size driers may not be strong without support from development projects.

Grain quality under storage

The work in Laos and in Australia has shown rapid deterioration of glutinous grain quality after 3 months of storing. However, this could be reduced when the grain is stored under high nitrogen concentration in a package. This would have wide application for maintaining high glutinous grain quality for a longer period.

8.3.1 Economic impacts

Varieties

Participating farmers have become aware of new varieties of rice and other crops that the project has been working with. This includes waxy maize CMB1 and high-quality Phka Romdual rice in Cambodia, and XBF2, XNF3 and VTE450-2 rice in Laos. Some of the farmers have continued to use these new varieties after first testing them with the project. In our target villages and surrounding areas and beyond, newly released VTE450-2 and XBF2 varieties have become popular. It is likely that the project's effort to promote these varieties has contributed to this. This will have large economic impacts in the future at the community and national level as farmers and others in the industry realize the excellent value of these varieties, which are likely to be widely adopted. Seed of these rice varieties was produced through government agencies and a large number of farmers use them; they are planted on perhaps one quarter of the rice area in some districts.

Benefit of combine harvesting to farmers

With the increased labour cost for hand harvesting, combine harvesting has become an attractive option in many locations in SE Asia. Without spending the time for hand cutting, collecting, sun-drying in the field, and carrying dried paddy to a threshing service, the farmer who uses combine harvesting can reduce the cost of growing rice substantially and increase labour productivity. The financial gain with reduced labour cost can be seen in Table 8.3 and Table 8.4. In the Cambodian case (Table 8.3), the harvesting cost is reduced from 185 to 110 USD/ha. In the estimation for Laos, we used two levels of yield (as we found in farmers yields in Vientiane) and two levels of fees (20% fees more common in Laos but fees are decreasing and hence 10% as often found in Cambodia). Net return to farmers is higher for combine contracting service compared with hiring workers for manual harvesting in all cases. With high yielding of 3230 kg/ha and 10% fees, the net return to farmer's labour approaches 10USD/day. The financial benefit is smaller if the fees are 20% as is often the case in Laos but still 17% higher than hand-harvesting with hired labour. (The high net return for hand-harvesting with family labour is because the calculation ignores the opportunity cost of family labour.) The net return to labour was also 37% higher with combine harvesting. It should be noted that the scale of the benefit will depends on the yield, local wage rate, combine fees, threshing fees, drying costs (whether sun-drying in field or artificial drying), labour required for stacking and hauling hand-cut crop before threshing, grain losses, and effects on grain quality. One consideration is how the saved time is spent; often the time will be used for other activities that generate additional income or save on costs. combine-harvested paddy.

Table 8.3. Estimation of cost, time and labour required for each operation for combine harvesting and manual harvesting (USD/ha). Bunna et al 2018b

No	Activity	Combine harvester		Manual harvesting		
		Unit price (USD/ha)	Time (hour)	Labour required	Time (hour)	Unit price (USD/person/day)
1	Harvesting	100	3	25	8	5
2	Field collection	0	0	5	5	5
3	Threshing	0	0	5	4	5
4	Cleaning	10	8	2	8	5
	Total	110	11	37	25	185

Table 8.4. Budgeted net returns to farmers for hand- and combine-harvested rice for the yield of a) 3,230 kg/ha and b) 2,280kg/ha in Laos. Xangsayasane et al. 2019.

a) Yield 3,230kg/ha					
Measure	Units	Hand-harvesting		Combine- harvesting	
		Family Labour	Hired Labour	10% fee	20% fee
Yield	kg/ha	3,230	3,230	3,230	3,230
Farm gate price	USD/kg	0.3	0.3	0.3	0.3
Gross income	USD/ha	969	969	969	969
Input cost (not including harvesting and family labour)	USD/ha	214	214	214	214
Contract-harvesting fee	USD/ha	0	0	96.9	193.8
Hand-harvesting cost (USD 7/day)	USD/ha	0	238	0	0
Threshing fee (5% of paddy)	USD/ha	48	48	0	0
Net return per ha	USD/ha	707	469	658	561
Total family labour input (from land preparation to harvesting)	days/ha	102	68	68	68
Net return per day of family labour	USD/day	6.79	6.89	9.68	8.25
b) Yield 2,280kg/ha					
Measure	Units	Hand-harvesting		Combine- harvesting	
		Family labour	Hired Labour	10% fee	20% fee
Yield	kg/ha	2,280	2,280	2,280	2,280
Farm gate price	USD/kg	0.3	0.3	0.3	0.3
Gross income	USD/ha	684	684	684	684
Input cost (not including harvesting and family labour)	USD/ha	214	214	214	214
Contract-harvesting fee	USD/ha	0	0	68.4	136.8
Hand-harvesting cost (USD 7/day)	USD/ha	0	238	0	0
Threshing fee (5% of paddy)	USD/ha	34	34	0	0
Net return per ha	USD/ha	436	198	402	333
Total family labour input (from land preparation to harvesting)	days/ha	104	68	68	68
Net return per day of family labour	USD/day	4.19	2.91	5.91	4.90

Financial aspects of combine contracting business

The detailed survey of contractors operating 48 combines in southern Cambodia gave the following mean values. A combine is used for 51 days/year, harvesting 214 ha/year. It operates for about 11.6 hours/day. The fees are USD 105/ha in the WS and USD 70/ha in the DS. This would result in a gross income of close to USD 19,000/year and a gross margin of about USD 13,000/year (before deducting capital costs). Harvesting takes only 1.5 hours/ha under favourable conditions and 2.7 hours/ha under unfavourable conditions. The project identified that lodging and small paddy size were some of the factors reducing combine efficiency.

Economic analysis shows a large effect of paddy field size on the contractor's gross margin (Table 8.5). Thus, in the case of the low fee of about 10% of the grain harvested (as in Cambodia) and yield of 3230kg/ha, the daily return would increase by USD 145 or 60% with enlarged paddies. In the case of the typical fee in Laos (20%), the gross margin would increase by almost USD 290 or 55%. In both cases, the improved combine harvesting efficiency resulting from enlarged paddy fields will increase the contractor's profit greatly, enhancing the viability of the combine-harvesting service. Relative increase is even higher when yield level is lower.

Table 8.5. Daily return to combine contractor from yield levels of 3,230kg/ha and 2,280kg/ha, small and large paddy fields, and two fee charge rates of 10 and 20%. Units are all USD. Xangsayasane et al. 2019.

	Yield 3,230kg/ha				Yield 2,280kg/ha			
Combine efficiency	3.5ha/day		5ha/day		3.5ha/day		5ha/day	
Fees	10%	20%	10%	20%	10%	20%	10%	20%
Revenue/day	339	679	484	970	239	479	342	684
Labour ($10 x 5.7)	57	57	57	57	57	57	57	57
Fuel/day	50	50	50	50	50	50	50	50
Daily return	232	572	377	863	132	372	235	577

The analysis indicates that the combine contracting business in Laos is currently viable, with possible further improvement. It appears that the combine owner is able to meet the credit repayments, despite the short term of the loan, by charging farmers a relatively high fee. The cost of a standard model combine is about USD 35,000, including an initial USD 3,000 instalment, with a 3-year payback period. With a daily net return over operating costs (fuel and labour) of USD 500, a total of 70 working days is required to meet the full repayment, which could be achieved in about one year in Laos. If competition forces down the fee to the equivalent of 10% of the total product, a longer period would be required to meet the repayment schedule, but the operation is likely to still be viable.

While there is likely to be significant economic benefit at the farm and community level with the adoption of combine harvesting and enlargement of paddies, these changes are likely to interact with other practices that the project is working on, such as mechanized planting, artificial drying, deep-ripping of compacted soils, and the development of new cropping systems.

8.3.2 Social impacts

Increased mechanisation will have some negative impact on poorer households that have depended on wages for transplanting and harvesting. Often this labour comes from beyond the target village and is not captured in baseline surveys. The surveys showed wide variation between using family labour over a longer period and hiring additional labour to complete the task in a more timely fashion. The move to mechanised rice production would change the gender dynamics, warranting deeper investigation.

Various social impacts are already being seen and are likely to increase. One impact is due to the time-saving nature of mechanization such as the use of the seed drill or transplanter to replace hand-transplanting, and the use of the combine harvester instead of hand-harvesting. The saved time can be used for other activities both on and off-farm (or taken as increased home-time), which is a major social impact due to mechanization. The social impact is not only due to the availability of extra time but also to a reduction in the drudgery and effort required, as manual work is typically harder (e.g., pulling rice seedlings and hand-transplanting in flooded fields under the hot sun) than the work involved in operating machines. Thus the available time is of higher quality and family members can be more productive, whether or not the time is directly used in income-earning activities.

Table 8.6 shows how men and women used the time saved due to the use of combine harvesters in Laos. Improving crop production and increasing livestock production were common responses from both men and women. Men more frequently mentioned off-farm work, while women mentioned home-based activities like vegetable gardening and weaving for household use. Both men and women also appreciated simply having time to rest.

Table 8.6 The use of time saved by men and women due to use of combine harvesters; surveyed in Khammouan, Central Laos in 2016.

Impact of combine harvesters on save time

Activities	No. answer	No. answer
Improve agriculture production	9	8
Fishing for home consumption and sell	4	0
Taking care of livestock and increase number of livestock	13	7
Prepare for next season of rice growing	4	2
Off-farm work	7	2
Have time to take a rest	6	7
Weaving for home consumption	0	8
Vegetable garden	0	7
Taking care of kids at home	0	3
Cooking for family member	0	1
Other (build house, attend social event, housework)	2	2
N/A	1	1

Women, who have traditionally spent more time hand-harvesting rice than men, now have considerably more time to spend on alternative activities. Thus, the use of combines is having a significant impact not only on livelihoods but also on the traditional activities that women and men undertook in the farm household. Similarly, the manual work of transplanting rice has traditionally been mainly the responsibility of women. Hence the mechanisation of planting as well as harvesting has had a large impact on women's roles in particular. If the household employs a contractor for drill-seeding or mechanical transplanting, more time will be available for both women and men. If they operate the seed drill or transplanter themselves, the operation will be done mostly by men, although women may spend more time preparing the seedling boxes and tending seedlings for the transplanter. The mechanisation of these activities has had a large impact on women's roles within the household and community, impacting on their health, welfare, and alternative employment opportunities.

8.3.3 Environmental impacts

No impacts have been noted. However deep-ripping of paddy soils, which the project is working on could have an impact on water balance in nearby areas. The general expectation would be that deep-ripping would increase infiltration of rainwater into the soil and hence reduce surface soil runoff from the field, reduce Fe toxicity in the field, and also reduce flooding in the area surrounding the field. The project will monitor any change in water balance as a result of deep-ripping.

The increased use of direct seeding may result in increased use of herbicides to overcome weed pressure, a process that is occurring apart from the project's activities. Farmers generally have limited exposure to the safe use of agro-chemicals. The project is investigating whether proper land preparation prior to drill-seeding can replace or reduce the use of herbicides.

8.4 Communication and dissemination activities

Field days

Four farmers' field days were conducted in Cambodia as listed in Table 8.7. At these field days, more than 40 farmers participated from nearby villages and observed new technologies being developed in the field; project scientists provided key information about the technologies. Then farmers were interviewed about their views and a report written up to summarize farmer's perspectives of the technologies.

In addition, the project conducted a number of field demonstrations each crop season in Cambodia to compare CARDI technologies and farmer practice. Participating farmers took a positive role in working with the project, particularly in the target villages. In Laos, the project also continuously interacted with participating farmers in the target villages and strong stakeholder engagement was achieved. The interaction with farmers helped the project refine the technologies, and further tests are being conducted with farmers. Rice millers and local machine dealers have also attended field days.

In Laos, a farmer field meeting was held at Pakpung Village, Bolikhamxay, in December 2014 for demonstration of a transplanter, seed drill, and field amalgamation. In the same village another field day was held in April 2015 for combine-harvester demonstrations. Two further meetings were held in Laos in October 2016 where 45-70 people attended, mostly farmers and village heads, and heard about the project outputs and government recommendations about the outputs. In Ekxang Village, Vientiane Province, a workshop on mechanization was held with the participation of 20 people.

Table 8.7 Field days held in Cambodia

Date	Location	Main topics	Comments from participants
12/8/2015	Steung, Takeo	Seed drill	Broadcasting more common than hand transplanting in 2014WS, but most used broadcasting in EWS. About 50% used mechanised and 50% hand harvesting in WS but most used machinery in EWS harvesting. Farmers considered labour saving and good weed control as major advantages of seed drill.
3/12/2015	Trapeang Chak, Takeo	Transplanter	About 40% of farmers own 2W tractors purchased mostly in 2012-2013. Broadcasting increased recently to about 70% in WS. Combine service use only 12%. Farmers acknowledged labour saving and weed control nature of crops established using transplanter.
25/5/2016	Chum Kiri District, Kampot	Waxy maize and cropping system	Most farmers grew waxy maize and many grew rice and mungbean in DS, and rice and mungbean in EWS. CM1 maize variety favoured by farmers. WS rice-DS non-rice-EWS rice sequence preferred, but not practised currently.
6/3/2017	Trampeang Chak, Takeo	Seed drill for mungbean and waxy maize and cropping systems	Intensified cropping system possible with supplementary irrigation. The number of 2W tractors had increased in last few years. Half of paddies harvested by combine. About 30% farmers grew DS crops (mostly vegetables) and EWS crops (watermelon, less water required). Drill-seeder favoured, broadcasting least favoured.

<u>Government meetings</u>

In Laos, we also participated in provincial and district government meetings where our project results were presented. In 2016, workshops on mechanization for rice production (seed drills, combine harvesting, and drying) were held in Gnomalad and Nongbok Districts, Khammouan Province, with a total participation of 120 people. In November 2017, a workshop on field amalgamation technique and mechanization for rice production was held in Gnomalad with the participation of 63 people including villagers and DAFO and PAFO staff. Leaflets (500) on techniques of rice-field enlargement, time of harvesting and drying, crop establishment methods, and seed production techniques were provided to the farmers and farmer groups.

<u>International workshops</u>

An International Workshop on Mechanization was held at NAFRI in Vientiane in November 2015. About 30 people from 5 countries attended and exchanged information on mechanization, particularly seed drills. Annual project meetings were held in Vientiane and Phnom Penh in November 2015. On both occasions, project members and non-members discussed the progress of the project and future activities.

A second International Workshop on Mechanization was held at CARDI in Phnom Penh in November 2016. About 47 people from 7 countries attended and exchanged information on mechanization, particularly combine-harvesting and grain-drying.

Fukai made a presentation of the project activities at the Crop Science Society of Japan meeting and also at BIOTEC in Bangkok, Thailand. Fukai and Ohnmar attended TropAg 2017 to present work on varietal variation in head rice yield. Phetmanyseng presented a paper at a workshop on Agricultural Development and Cooperation in Laos with Korea, NAFRI, 2017, and also at the KEI-RAC-LASS-VASS workshop, Siem Reap, Cambodia, October 19, 2017. Phetmanyseng also presented a paper on Rice Breeding and Mechanization for Value Addition in Laos at International Seminar on Promoting Rice Farmers' Market through Value-adding Activities, June 6-8, 2018, Kasetsart University, Thailand.

We displayed a number of posters to disseminate information of project activities on the occasion of the CARDI 18th anniversary meeting where the Minister of Agriculture, Forestry and Fisheries attended. On another occasion, the Minister visited and inspected our work on seed drill.

9 Conclusions and recommendations

9.1 Conclusions

The project has worked with strong farmers' groups during the whole period to determine the advantages and difficulties of mechanising crop production and improving grain quality in the context of different cropping systems in Central Laos and Southern Cambodia. Continuous dialogue between the groups and the project team has been established, providing effective communication, including good feedback on the project's activities. These farmers' groups have good experience in rice growing and often include the leading farmers in the local area, and their views have shaped the activities of the project, with in the overall aims. Positive impacts of the project have already been noted, particularly in Khammouan, Laos, where the project has worked effectively with the provincial government.

The project has found varying benefits of mechanization in terms of crop productivity and the incomes of smallholders and contractors. A positive effect was found, particularly with the use of combine harvesters, seed drills, and artificial dryers. Uptake of these machines is largely influenced by socio-economic conditions. For example, provision of combine contracting services is increasing, particularly in areas where labour availability is limited relative to the area of rice fields to be harvested, grain-drying facilities are available, and fees are around 10% of the paddy harvested. Similarly, the seed drill is likely to be adopted in areas where hand-transplanting is still practised and early planting in the wet season is acceptable to the farmer. Artificial drying services are likely to be adopted where large mills with high-capacity dryers can produce a high volume of quality rice for marketing, or where rice is marketed and high grain quality is appreciated. The project has demonstrated the usefulness of the flatbed dryer in terms of improving grain quality, particularly head rice recovery. Small flatbed dryers may have a role to play in some villages, while another option is the use of large flatbed dryers or vertical dryers attached to mills, if they are accessible to the farmers.

However, the benefits of mechanization varied greatly, depending on the conditions where the machinery was used. For example, the benefit of a combine harvester to a contractor was greatly enhanced when it was used to harvest large rice fields. Some conditions are related to socio-economic factors such as labour availability and cost, and the cost of purchasing the machine. Similar points may be made for crop management to enhance the value of mechanization. Land levelling is required to achieve good establishment from mechanized planters. Drill-planted rice crops are often more affected by weeds than hand-transplanted rice. Land preparation needs to be thorough to reduce the weed problem or herbicide technology is required for the sustainable production of direct-seeded rice crops, including drill-planted crops. Other factors affecting mechanisation are biological, such as the use of rice varieties with a high incidence of lodging, reducing the efficiency and effectiveness of combine harvesting.

9.2 Recommendations

Some factors appear particularly important in determining progress with mechanization. The full benefits of mechanization may not be realized until these are properly assessed and optimal conditions are created. In addition to socio-economic factors, the following physical and biological factors affecting machinery efficiency and usage require further research.

1. Physical characteristics of fields
    a. Field size (larger machinery including combine harvesters and 4W tractors)
    b. Land levelling (seed drill, transplanter)
    c. Soil moisture (seed drill, transplanter) – the occurrence of optimal conditions may be predicted with accurate forecasting at the beginning of wet season
    d. Soil texture (loam to clay-loam for transplanter and sandy soil for the current type of seed drill)
2. Weed control
    a. Land preparation method (seed drill, but also broadcasting)
    b. Use of herbicide (seed drill, but also broadcasting)
    c. Alternating planting techniques, e.g., hand planting for several years then change to direct seeding (seed drill but also broadcasting)
    d. Development and testing of mechanised weeder
3. Breeding rice varieties for mechanised agriculture;
    a. New plant type
        i. For combine harvesting – short plant type; lodging resistance particularly under broadcasting; reduced bulkiness, increase HI; Shattering resistance (particularly old indica varieties).
        ii. For drill seeding or transplanter – seedling's ability to emerge from soil depth (seed drill); seedling's ability to spread quickly to fill in initial gaps when planted drill and transplanters; intermediate plant height (80 to 100 cm) for weed competitiveness,
    b. Photoperiod sensitivity aromatic with submergence tolerant (early planting by seed drill) for Laos;
    c. Photoperiod insensitivity of aromatic rice for Cambodia

One aspect that has become clearer is that rice varieties have a strong influence on the efficiency of machinery operation (Table 9.1). The impact of varietal differences on combine harvesting efficiency is noted in this report. Tall and long-duration varieties tend to lodge, particularly when they are broadcast, and this makes combine harvesting inefficient. In addition, long-duration varieties tend to have more stem and leaf biomass and a low harvest index, and this bulkiness of the crop reduces combine efficiency. The use of seed drills tends to promote early planting before the fields are wet, and this often results in the rice plants flowering at the peak of the rainy period, reducing fertilization and also causing difficulty in harvesting, drying grain, and maintaining high grain quality. One way to solve the problem is the use of photoperiod-sensitive varieties that can be planted over a wide period while still flowering and maturing at the appropriate time. This could be quite important in Laos where most varieties developed recently are photoperiod-insensitive. While drill-planted and transplanted crops lodge less, the use of broadcasting is increasing in both Laos and Cambodia more than other establishment methods. As the broadcast crops are prone to lodging, lodging-resistant varieties are required. These new varieties with increased flexibility in planting time, less lodging, and high-quality grain would enhance the value of seed-drills and combine harvesters. On the other hand, row spacing of these planters is rather wide, hence varieties that spread quickly to occupy the inter-row space are required to suppress weeds and provide early vigour, leading to higher yields. The variety aspect would be a suitable research project for Laos and Cambodia, considering that well-qualified and respected rice breeders are available in NAFRI and CARDI.

Table 9.1. Variety characteristics required for mechanised rice production. Fukai et al. 2018.

Characteristics required	Type of operation	Note
Lodging resistance, reduced canopy bulkiness	Combine harvesting	Particularly broadcasted crops
Shattering resistance	Combine harvesting	Particularly old indica varieties
Photoperiod sensitivity	Seed drill	Avoiding flowering at peak rainy period from early planting
Seedling's ability to emerge	Seed drill	Seed may be planted at depth in moist soil
Canopy spread	Seed drill, transplanter	Filling initial gap quickly, weed control

One key aspect of the impact of mechanization is that grain quality can be improved, and this can have profound effect on rice marketing. A common problem the rice industry is encountering is poor grain quality, particularly large broken rice during milling. This results in lower head rice yield, and difficulty in marketing the rice grain. Mechanization particularly combine harvesting allows good control of rice product, using artificial grain dryer. The project has demonstrated this scenario, but this aspect can be further exploited with the help of millers or other agribusiness people willing to invest in dryers. Millers can further support farmers to ensure the rice product is of high quality. Farmers, agribusiness and Government require good cooperation to achieve the goal of improved rice marking. Such scheme is illustrated in Figure 9.1.

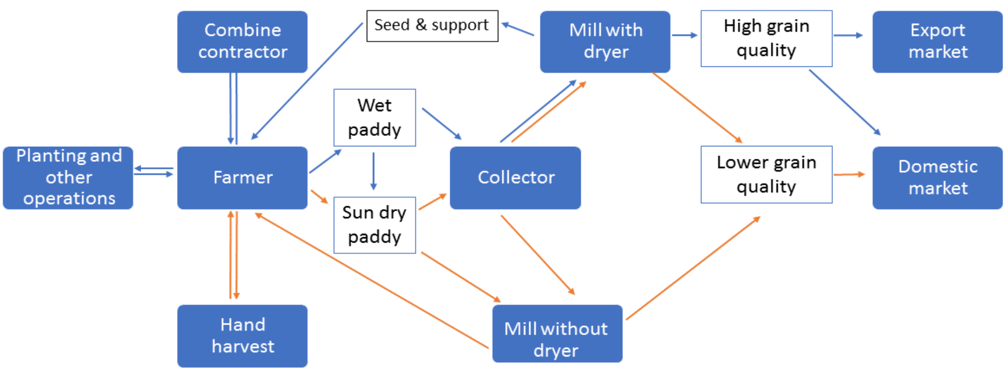


Figure 9.1. Rice value chain and grain quality depending on traditional (orange arrows) or mechanised (blue arrows) harvest. Solid boxes represent actor or process in the value chain, while outlined boxes represent product. In general, farm operations are the

responsibility of the Provincial Agriculture and Forestry Office (PAFO) while commercial operations of machinery and mills are the responsibility of the Provincial Office of Investment and Commerce (PoIC). Fukai et al. 2018.

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Conference publication

16. Ohnmar Myint, Peter Snell, Jaquie Mitchell and Shu Fukai (2017) Head Rice and Grain Yield of Diverse Rice Cultivars grown under Aerobic and Water-deficit Conditions. Poster presented in TropAg. Brisbane, 20-22 November 2017
17. Fukai S and Mitchell J (2017) Development of rice varieties for multiple abiotic-stress tolerance in the Mekong region and Australia. Paper presented in TropAg, Brisbane, 20-22 November.
18. Xangsaysane P, Phongchanmysai S, Vongsayya M, Bounphanousay M, Bounphanousay C and Fukai S. 2017. Agricultural Mechanization Innovation for Rice production in Laos. Paper present in workshop on Agriculture Development and Cooperation in Laos with Korea. June 22, 2017, NAFRI
19. Xangsaysane P, Phongchanmysai S, Vongsayya M, Bounphanousay M, Bounphanousay C and Fukai S. 2017. Improving Rice Quality and Cost reduction by Agricultural Mechanization in Central part of Lao PDR. Paper present in KEI-RAC-LASS-VASS workshop, SIEM REAP Cambodia, October 19, 2017.

Leaflets produced in Laos

20. Crop establishment
21. Field size and combine harvesting
22. Time of harvesting and drying

Reports (excluding papers/draft papers mentioned above)

23. Cambodia- village survey (Sareth)
24. Cambodia- contractors activities (Sareth)

25. Cambodia- combine (Sareth) Analysis of machinery contractors (Updated in Dec 2016).
26. Cambodia- AFS Report 1 Progress Report of Agronomy and Farming System Activity, August, 2014 – December, 2015.
27. Cambodia – AFS Report 2 Progress Report of Agronomy and Farming System Activity, January – May 2016, Activity AFS3: Innovative Cropping System
28. Cambodia- AFS Report 3. SEED DRILL (AFS1) AND TRANSPLANTER FIELD DEMONSTRATIONS FOR RICE SEED PRODUCTION (AFS2) Jan-September 2017 (Shu made comments and is waiting for the revised version).
29. Cambodia- PB Report. Progress report PB division (2017DS)
30. Laos. Rice breeding report
31. Laos. Maize breeding report
32. Laos. Mungbean and Peanut Breeding
33. Farmer field day in Kampot – Assessing cropping systems
34. Farmer field day in Takeo- assessing cropping systems
35. Farmer field day in Takeo – Assessing transplanter machine
36. Farmer field day in Takeo- assessing seed drill
37. Impact of the adoption of combine harvesters on smallholder livelihoods and lifestyle in Nongbok District, Lao PDR
38. REHYDRATION OF RICE KERNEL (Khamtai)
39. Effect of deep ripper on plant establishment and grain yield of non rice crop (maize and mungbean) (Sinath)
40. Soil moisture requirement for establishment of four different crops (Veasna)
41. Farm household survey – Farming practices, various sources of income and mechanisation adoption (Sareth)
42. Comparison of milling quality of improved rice varieties in central Lao in dry and wet season 2018 and DS 2019 (Khamtai).
43. Cambodian Peanut 1 (CAP1) (Kynet)
44. CARDI Breeding group Final (Sophea)

Further publications

Leaflet produced in Laos- How to use seed drill.

Conference presentations

Ohnmar Myint, Jaquie Mitchell, Peter Snell and Shu Fukai (2018). Head rice yield and grain yield of rice varieties in response to water deficit under aerobic conditions. Oral presentation at the 5th International Rice Congress in Singapore October 2018.

O. Myint, J. H. Mitchell, P. J. Snell and S. Fukai (2019). Head rice yield of rice varieties in response to aerobic condition and water deficit during reproductive stage. Presented in 2019 Australian Agronomy Conference, Wagga Wagga.

Phetmanyseng Xangsayasane, Sengthong Phonchanmysay, Khamtai Vongsayya, Malivanh Bounphanousai and Shu Fukai. (2018). Rice Breeding and Mechanization for Value Addition in Laos. International Seminar on Promoting Rice Farmers' Market through Value-adding Activities. Kasetsart University, Thailand. June 6-8, 2018.

Phetmanyseng Xangsayasane, Sengthong Phongchanmixay, Khamtay Vongxayya, Chay Bounphanousay, Jaquie Mitchell and Shu Fukai. 2018. From research to current status - mechanized rice production for improving quality and cost reduction in Lao PDR. Paper presented in the 5th International Rice Congress. Singapore. October 2018.

11 Appendixes

11.1 Appendix 1:

Leaflets produced in Laos are attached here (Lao version was distributed).

Crop establishment

Crop establishment Oct 17 2016-Eng.pub

Field size and combine harvesting

Field size and combine harvesting Oct 15 2016-En.pub

Time of harvesting and drying

Time of harvesting and drying Oct 15 2016.pub

Reports available

27. Progress Report of Agronomy and Farming System Activity, January – May 2016, Activity AFS3: Innovative Cropping System.

28. AFS Report 3. SEED DRILL (AFS1) AND TRANSPLANTER FIELD DEMONSTRATIONS FOR RICE SEED PRODUCTION (AFS2) Jan-September 2017

29. Progress report PB division (2017DS)

31. Maize breeding (Laos)

32. Laos. Mungbean and Peanut Breeding

33. Farmer field day in Kampot – Assessing cropping systems

34. Farmer field day in Takeo- assessing cropping systems

35. Farmer field day in Takeo – Assessing transplanter machine

36. Farmer field day in Takeo- assessing seed drill

37. Impact of the adoption of combine harvesters on smallholder livelihoods and lifestyle in Nongbok District, Lao PDR

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42. Comparison of milling quality of improved rice varieties in central Lao in dry and wet season 2018 and DS 2019 (Khamtai).

43. Cambodian Peanut 1 (CAP1) (Kynet)

44. CARDI Breeding group Final (Sophea)