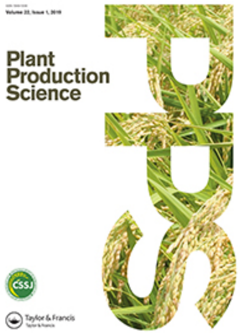

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REVIEW

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Research strategies for mechanised production of rice in transition from subsistence to commercial agriculture: a case study from Khammouan in Lao PDR

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ABSTRACT
Mechanised rice production has started to take place in response to rural labour shortage and increased labour cost in Khammouan province in central Laos where subsistence rice production is being replaced with commercial agriculture. This paper summarizes the results of recent findings of four mechanised items, combine harvester, seed drill, transplanter, and artificial grain dryer, and discusses research strategies for advancement of the mechanised rice production system. Combine and seed drill were considered to have good potential for reduction in production cost and hence the likelihood of farmer adoption. Synergistic effects of these four and other items are noted; for example, the adoption of combine harvesting service is associated with farmer's accessibility to drying facilities. Artificially dried grain has been shown to decrease broken rice component during the milling process, resulting in higher grain quality, and hence increased marketability. The proposed research strategies focus on the production of rice with reduced cost and increased grain quality for increased farmer adoption of contracting services available for mechanised rice production. The strategies include promotion of large size paddy fields to allow efficient use of machinery and reduced service fees. Other strategies which are discussed include identification of suitable rice varieties and other technologies that maximize in field machinery efficiency. The requirements of actors in the rice value chain working together for mechanised rice production are emphasised.

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Rice mechanisation; combine harvesting; drying facility; grain quality; value chain

1. Introduction

Kunihiro (2013) has shown the development pattern for agricultural mechanization across different regions and countries. He considers that Southeast Asia is in the 'growing' stage, and machinery population is increasing rapidly, but Laos is less advanced compared to most other countries in the region (Khamphoukeo, 2014). The rapid increase in machinery population is often related to a shift from subsistence to commercial agriculture (Kunihiro, 2013), and Laos should be considered to be in the early stage of development in terms of commercialization and mechanization. As is typical with early stage and introduction of mechanization, farm operations traditionally requiring high power inputs and low levels of control are mechanised (Rijk, 1999), and mechanised tillage, transport, water pumping, milling, and threshing have become available in Laos (Khamphoukeo, 2014). However, machinery with operations requiring high levels of control such as combine harvester is not well adopted in the country; for example combine harvester became available in about 1990 and 2000 in Thailand and Vietnam respectively and combine is used for most rice crops in these countries (Haefele & Gummert, 2015), while combine was not utilised in Laos until about 5 years ago and its use is still limited.

Rice crops occupy large areas of agricultural land, providing sufficient staple food for most people living in Laos. Rice is grown mostly for subsistence under rainfed conditions with limited input, and yield is affected by drought, flood and other biotic and abiotic constraints (Schiller et al., 2001). Grain exports from Laos are limited (US$7.7 million) to 3 percent of total agricultural exports (Nishimura et al., 2016). Nishimura et al. (2016) documented low labour productivity in the agriculture sector in general compared to most other sectors in Laos, and made a few suggestions such as the use of improved seeds and better usage of fertilizer to improve labour productivity. While these measures will help improve rice yield and as a result labour productivity to some extent, greater impact on the labour productivity may be achieved when the labour input is reduced greatly without reducing yield. Thus, mechanization is a key to improving labour productivity, reducing

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production cost and yet maintaining grain yield (Bunna et al., 2018; Xangsayasane et al., 2019c). Khamphoukeo (2014) described the extent of current mechanization practices in Laos, and mentioned that Viengkham Agricultural Machinery Centre that was developed in the 1980s as a result of the Government's recognition of the importance of agricultural mechanization could not be sustained. No systematic development in agricultural mechanization in Laos appears to have taken place since that time. However, in recent times with the shortage of rural labour to conduct manual work such as transplanting and harvesting of rice, the importance of mechanised rice production has again been given a high priority with the Government declaring mechanization to be a key policy to increase farmer income (Lao Ministry of Agriculture and Forestry, 2015). A few research and development projects have been working towards this goal in Laos.

The central Lao provinces of Savannakhet and Khammouan are considered as the most advanced in rice production and processing technologies in the country. Thus, these provinces have often been involved in rice research, development and extension projects and new technologies are disseminated to increase rice production and improve livelihood of farmers and others involved in the rice industry. Key rice mechanisation technologies for crop establishment, harvesting and grain drying have been trialled in these provinces, and major results published in the current Special Issue and elsewhere. Thus, mechanised operations have been compared with manual operations for seed drill (Sengxua et al., 2018; Xangsayasane et al., 2019a), transplanter (Xangsayasane et al., 2019a), combine harvester (Xangsayasane et al., 2019c; Xangsaysane et al., 2016) and flatbed dryer (Vongxayya et al., 2019; Xangsayasane et al., 2019b) in terms of grain yield, grain quality particularly head rice yield, and financial gain to farmers of adoption of contracting services for mechanised operations. This paper summarises the recent research achievements for mechanised rice production in this and other provinces in the country and suggests research strategies that would further enhance the mechanised rice production. The main objective of the present paper was to develop research strategies for establishment of mechanised rice production in areas where subsistence rice production is being replaced with commercial agriculture and mechanisation has just started to take place, using Khammouan Province in Laos as a case study.

2. Rice production and mechanization development in Khammouan

The central Lao Government defined Khammouan Province as a rice hub, and has selected the province to produce rice for national food security and also for export together with other ASEAN countries. Rice value chain development is regarded as a gateway to the local economic development. According to 2016 annual reports from different provinces in the country, wet season rice occupied an area of 80,380 ha in the province, with yield of 4.29 t/ha resulting in rice production of 345,000 tons. In the dry season, irrigated rice area was 9,040 ha with yield of 5.37 t/ha and production of 48,500 tons. The total production in Khammouan was about 10% of that of the whole country in that year. Of the total rice produced, about 82,000 tons or 20% was traded, including export to other provinces (about 7,400 tons of milled rice and 20,000 tons of paddy rice), and other countries (about 3,400 tons of milled rice and 1,600 tons of paddy rice).

The average farm size is about 2 ha per household and most farms are managed by families with the average family labour of just over two. Labour availability in rural areas has decreased recently as young people have moved out from rural villages to work in the industry sector, and this has encouraged the farmer to adopt mechanisation. Rice is the most important crop, and is mostly grown in rainfed lowlands in the province. The characteristics and issues in rainfed lowland rice production in the Mekong region were reviewed by Fukai and Ouk (2012), and the province is a typical rainfed lowland rice area in transition from subsistence to marketing agriculture (Cramb & Newby, 2015). Currently, there are 159 rice producer groups, 12 rice seed producer groups and 5 miller groups working together to develop the rice value chain in the province. While rice production for marketing purpose has increased in recent years, the low quality of local rice, high production cost, and limited marketing and trading opportunities are considered the main barriers for rice sector development in Khammouan.

The recent change in the number of each machinery type in the province is shown in Table1. The statistics were collected by the provincial government through all District Agriculture and Forestry Offices throughout the province. By 2015, most households had a handheld two-wheel tractor, and harvested rice was threshed mechanically, but the number of hand tractors and threshers increased further in the following 2 years. During this period, the number of most other machinery increased sharply. Thus, in 2015 there was a limited number of four-wheel tractors but the number increased by more than 50 fold and the popularity of ploughing with four-wheel tractor increased and continues to do so. The change in planting, harvesting and drying machinery will be described in the next section. One reason for the increased number of machinery items in recent years is the Government policy of

Table 1. The number of different types of machinery in Khammouan.

Items	2015	2017
Thresher	1055	1482
Small size tractor (2 wheel)	23,198	31,597
Medium size tractor (4 wheel)	28	1993
Seed drill (attached to hand tractor)	10	31
Seed spreader	2	25
Drum seeder	5	22
Transplanter	8	15
Combine harvester	2	24
Grain dryer	10	14

Source- Agricultural Extension and Cooperative of Khammouan

exempting import tax if the machinery cannot be produced in the country.

3. The advantages and disadvantages of four mechanisation items examined in Khammouan

Key aspects of four mechanisation items; seed drill, transplanter, combine harvester and artificial dryer are discussed in this section. The information provided is partly derived from recently published research results obtained in the province and neighbouring provinces, and also from many interviews held with farmers familiar with machinery contracting services, machinery contractors providing services to farmers, and millers who have all been actors in the development of the rice value chain over the last 5 years in the province. Adoption of these key items by farmers is taking place through the use of contracting services rather than owning the machinery. The contracting service is available in parts of the province for combine and artificial dryer but is limited for seed drill and transplanter.

3.1. Seed drill

Xangsayasane et al. (2019a) described the major advantages of two-wheel tractor mounted drill (Ta Ngao company Thailand – model TSP R3) over manual transplanting to be labour saving and cost reduction, although it is more costly compared to establishing crops by broadcasting (Table 2). The drill also required less seed (40 to 50 kg/ha), particularly compared to broadcasting where the standard rate is 120kg/ha, it uses dry seed for planting under dry soil conditions, is easy to use and manage, and plants are established in rows which results in ease of weeding compared with broadcasting. Rice seed planted with drill are placed at depth where soil moisture is more available than on the soil surface, and this may help achieve better establishment and reduce weed problems compared with crops established by broadcasting. However, proper land preparation is important for even establishment of the drill-seeded crops and for weed control. On the other hand drill is not suitable for planting in heavy clay soils, under wet soil conditions, and in fields that have weed problems. Yield was similar to manual planted crops in the same farms, but was lower than manual planting methods in different farms (Xangsayasane et al., 2019a). Some farmers consider the plant density of a drilled crop is too low with 25 cm row spacing, and they practise double planting by seeding first in one direction and seed again at right angle to the first planting line or a second time in the same direction.

Another aspect of the drill is that the time of planting is an important issue; it should be used early in the season when the soil is still not water saturated. Farmers are traditionally familiar with hand transplanting when the soil is wet and saturated, but this soil condition is already too late for drill seeding. While the current model available in Laos is not suitable under water-saturated conditions, prototypes have been developed for the use under flooded conditions (Yamamoto, 2007).

The number of seed drills in Khammouan Province increased from 10 to 31 in 2017 (Table 1). The number is increasing rapidly with the sale of new drills in two machinery shops in Thakhek, the Provincial capital

Table 2. Advantages and disadvantages for different characteristics of seed drill (Values mentioned are modified from Xangsayasane et al., 2019a).

	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.

Table 3. Advantages and disadvantages for different characteristics of transplanter (Values mentioned are modified from Xangsayasane et al., 2019a).

	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

where some 30 drills have been sold in 2018. In Hatkhamhiang village in Khammouan, the village head ranked the farmer's preferences for different planting methods and believed the seed drill was the most popular for upper fields in the wet season, as dry direct seeding using drill early in the wet season can reduce the risk of crop failure. However, in the dry season where field water level can be controlled readily, risk of submergence of seed/seedlings is very low, and hence farmers prefer transplanting as they believe they will achieve higher yield. Due to the affordability (USD 300) of seed drills, they are items that the farmer may wish to own. Some may become contractors and charge fees of around $50–60/ha. Thus, they can provide a rather quick return on investment if sufficient numbers of farmers are willing to adopt their service.

Considering the points noted in Table 2, the 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. It should be noted that in neighbouring Savannakhet province, drill use spread rapidly in 2015–2016 to over 15,000 ha (Clarke et al., 2018), although the early commencement of the 2017 wet season reduced its use in that province.

3.2. Transplanter

According to Xangsayasane et al. (2019a), the transplanter saved labour cost with only 3–4 labourers/ha/day compared to 20–30 people required for manual transplanting, and it saved seed with a rate of only 60 kg/ha compared to broadcasting (Table 3). Because of the large labour cost for preparing seed trays and transplanting, the cost of establishing rice crops from transplanter is much higher than broadcasting (Xangsayasane et al., 2019a). The rice plants perform well due to the use of younger seedlings, and rice is planted by row resulting in ease of weeding. However, it requires experienced people for preparing seed trays and driving the machine, and is not suitable for lower fields where seedlings may be readily inundated and golden apple snails attack young seedlings.

One issue noted is that in some cases transplanter planted crops have low plant density resulting in low yield. This may be related to wide row spacing of 30cm common with the transplanter, and also the use of fewer trays because of the their limited availability. The number of trays used per hectare in some cases may be too small for maximum yield (Xangsayasane et al., 2019a). Trays are rather expensive and often farmers are attracted to reduce the number of trays used in the field. On the other hand, low plant density reduces the cost associated with seed and also tray preparation, and new transplanters with even lower plant density are being developed in Japan (Yamamoto, 2007).

Transplanters are often used by seed producers who require transplanted crops but can be challenging to operate, and with the greater number of people (3–4 people/ha) required for its use, their economic merit appears less than that of seed drill. The number of transplanters in the province has increased only slightly in recent years (Table 1).

3.3. Combine harvester

In the province, 24 combines (Kubota DC70) are now available compared to 2 in 2015 (Table 1), and they are mostly operated by contractors. When the fees are based on 10–20% of the crop produced with a yield of 2.3–3.2t/ha (Table 4), the charge is in the range of 69–190USD/ha (Xangsayasane et al., 2019c). While combine service fees have become cheaper in Laos including Khammouan from

Table 4. Advantages and disadvantages for different characteristics of combine harvester (Values mentioned are modified from Xangsayasane et al., 2019c).

	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

over 200 USD/ha in 2014 to around 150 USD/ha, they are still expensive compared to neighbouring countries, for example Cambodia (Bunna et al., 2018). This high combine charge appears to be related to limited competition because of only a small number of contractors available, low combine harvesting efficiency particularly due to small field size (Xangsayasane et al., 2019c), the short time period for payback of credit for purchase of combines, and the limited number of days per year that combine contractors can operate in Laos.

The combine contracting saves time and the cost of labour where typically 30 people are employed to manually harvest 1 ha of land (Xangsayasane et al., 2019c). Combine harvested crops do not require the additional threshing process as it is in-built in the combine harvester, and this again saves further time and cost. Economic analysis indicates large benefits to farmers adopting combine harvesting contracting service, particularly in areas with high labour cost (Bunna et al., 2018; Xangsayasane et al., 2019c). Their study also indicated that combine harvested grain yield was similar to hand harvested yield and grain harvesting loss was about 1.5% of the total yield, which was less than the total loss for manual harvested crops when the losses during threshing and handling of paddies was included. Grain quality of combine-harvested crops is as good as that of manually harvested crops when harvested paddies are dried properly (Bunna et al., 2018, 2019; Vongxayya et al., 2019). Often combine harvested crops are dried artificially while manually harvested crops are sun dried, then higher head rice yield is obtained in combine-harvested crops (Vongxayya et al., 2019), paving the way for improved grain quality and marketing.

The combine contracting business appears profitable according to the high daily return estimated from harvesting 3–5 ha per day (Xangsayasane et al., 2019c). Data for combine harvesting of over 300 paddy fields in Khammouan and Bolikhamxay provinces (Xangsayasane et al., 2019c) indicated that combine harvest 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. Improving combine harvesting efficiency is one way to reduce the cost of operation and increase profitability for contracting service providers (Xangsayasane et al., 2019c). Lodged crops also reduced combine harvesting efficiency, and this was a greater problem in crops established by broadcasting compared to hand transplanting or mechanised (transplanter or seed drill) planting (Xangsayasane et al., 2019c), an observation also made by Farooq et al. (2011). This is another example of the synergistic effects of mechanisation on several aspects of production.

Increased availability of drying facilities will also improve adoption of combine contracting service, and this is discussed in the section below. The spare time created through the introduction of machinery has contributed to further increase in on-farm agricultural productivity.

3.4. Grain dryer

Artificial dryers are used to dry paddy rice harvested either by combine or manually, and they are particularly useful for dry season crops which could encounter rain after harvesting. In the WS, drying is less of a problem as the weather at the time of harvest is generally more favourable, and the rice crops are mainly used for home consumption. Sun drying is particularly problematic for combine harvested, threshed paddy as it is not readily dried in the rice field as is often the case with manually harvested rice where panicles and stem are still intact.

With the use of artificial drying, high physical grain quality is maintained (Table 5), resulting in increased

Table 5. Advantages and disadvantages for different characteristics of 4 ton flatbed dryer (Values mentioned are modified from Xangsayasane et al., 2019b).

	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	

chance of marketing (Vongxayya et al., 2019; Xangsayasane et al., 2019b). 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 (Vongxayya et al., 2019; Xangsayasane et al., 2019b) . The importance of using artificial drying was recognised particularly when crops were harvested early during the ripening phase and grain moisture content was still high (Bunna et al., 2019). With sun drying, the paddy needs to be turned over every 2 hr or needs to dry in thin layers of 2 cm or less to maintain high head rice yield. If paddy harvested by combine is to be sundried, sufficient land area is required and fine-mesh plastic net may be used. However, this can be risky especially in the dry season crop. Tarpaulin sheets could be used to protect the grain from rain (Xangsayasane et al., 2019b).

The total number of dryers available in the province is limited but the number increased slightly between 2015 and 2017 (Table 1). There are several vertical columnar dryers (capacity >20 tonnes) available in a few large mills. Currently, several flatbed dryers of 4 ton capacity provided by different development projects are not commonly used in Khammouan. While flatbed dryer is not commercially available in Laos, it is commonly used to improve grain quality in Vietnam (Truong et al., 2011). It appears 4 ton dryer is less competitive (costing around 50USD to dry 3–4 tons of paddy) against larger (20 ton) flatbed dryer or the high volume columnar dryers installed in mills (Nguyen-Van-Hung et al., 2019). Thus, once the high- capacity dryer is installed, the smaller capacity flatbed dryers may not have much opportunity for use.

There is a strong link between the farmer's decision to use combine harvesting and the availability of facilities to dry paddy, hence village heads and/or millers need to ensure that the grain can be dried properly. This is an example of the synergistic effect of the use of different machinery items; the introduction and use of one type may be promoted by the availability of another.

4. Research strategies towards the development of mechanised rice production from a plant scientists' perspective

Based on the findings mentioned in the previous section, the following points are considered as research strategies for rapid progress in adoption of mechanised rice production in the province. Improved adoption of mechanised rice production could be achieved through reduction in machinery service charge or production of value added products so that the farmers adopting the services are making financial gain. These goals may be achieved through the advancement of technologies, policy interventions or better dissemination of information to the farmers. Research strategies that are particularly relevant to plant scientists are described here.

4.1. Identification of intervention points in the rice value chain

It is important to understand the rice value chain and actors involved in the value chain for identification of appropriate intervention points that could help increase adoption of mechanised rice production. Figure 1 shows rice value chain framework that operates in the province in relation to mechanised rice production. Farmers prepare land, plant and manage rice crops, and may harvest them manually or mechanically. In subsistence agriculture, manually harvested grains are sun dried in the field, threshed and locally milled for home consumption (orange lines in Figure 1). With the introduction of combine harvesting, high- moisture paddy may be dried artificially in the mill and result in high-quality grain suitable for market (blue lines).

As shown in Xangsayasane et al. (2016), with the availability of drying facilities, farmers have a better chance of adopting combine service, and the grain will have higher quality and hence increase the chance of marketing. The high-value grain will then provide higher return to the farmers. A mechanism is required to ensure that all actors involved in combine harvesting

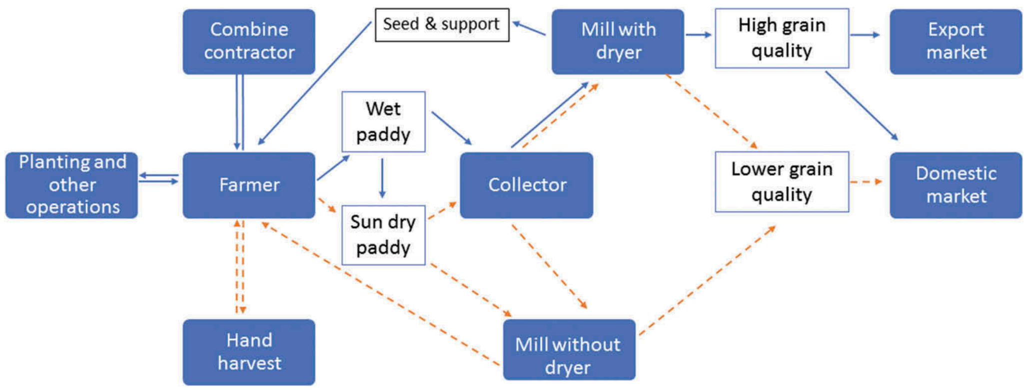

Figure 1. Rice value chain and grain quality depending on traditional (orange arrows) or mechanised (blue arrows) harvest. Solid boxes represent actor or process in the value chain, while outlined boxes represent product. In general, farm operations are the responsibility of the Provincial Agriculture and Forestry Office (PAFO) while commercial operations of machinery and mills are the responsibility of the Provincial Office of Investment and Commerce (PoIC).

will work together for the common goal of developing mechanised rice production so that in the long term everyone benefits.

In the province, 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). The Provincial Government can develop policies that will assist different actors in the value chain; for example, promotion of good agricultural practice (GAP) for farmers and good manufacturing practice (GMP) for millers to improve rice grain quality.

4.2. Reduced contracting service charges

Reduced contract service charges may be achieved through improved machinery operation efficiency in the field. One main issue here is the small lowland rice field size that is common in Khammouan and elsewhere in Laos and neighbouring countries. The effect of field size on combine harvesting efficiency was investigated recently, and results indicate that the efficiency increased with the field size (Xangsayasane et al., 2019c). Increased efficiency in larger fields will then allow the reduction in service fees which would in turn improve combine adoption by farmers. After observing the benefit of enlarged paddies, some farmers have amalgamated fields, realizing that larger fields are more efficient for various machinery operations, including combine harvesting. This is in line with Kunihiro (2013) who showed an association between mechanisation and farm size, and the advantage of mechanised rice production in larger farms. Similarly, combine harvesting efficiency is greater in crops with reduced lodging. The development of non-lodged crops and increased field size may be considered a good target for the pathway to increased field combine efficiency, reduced fee charges and increased adoption of combine harvesting service.

The farmers may receive long-term credit for field enlargement. Realizing the importance of large field size, the Khammouan Government has decided to provide credit for amalgamation of up to 70 ha/year encouraging farmers to amalgamate the fields. The combine fee structure may be changed so that larger paddies are charged less per ha or fees are charged based on the quantity of paddy rather than the area harvested. There are also areas which have not been cropped, but are converted to rice fields in the province. It is important to make sure that these newly developed fields are sufficiently large and levelled and have shapes that are compatible with the requirement of mechanisation to ensure high-field operation efficiency.

4.3. Technology development to maximise the benefit of mechanisation

The benefits of mechanisation vary greatly depending on the conditions where the machinery is used. For example, the benefit of a combine harvester to a contractor was greatly enhanced when it was used to harvest large rice fields (Xangsayasane et al., 2019c). Some conditions are related to socio-economic factors such as labour availability and cost, and the cost of purchasing the machine. The full benefit of mechanisation may not be realized until optimal conditions are created to maximise the benefit of mechanised rice production.

4.3.1. Rice variety improvement

Improved machinery operation efficiency may be achieved through the use of rice varieties suitable for

Table 6. Variety characteristics required for mechanised rice production.

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

particular mechanisation items. Plant adaptation to mechanised agriculture is a path that will improve the efficiency of mechanised agriculture (Rijk, 1999).

Some variety characteristics required for mechanised rice production are shown in Table 6. Tall and long-duration varieties tend to lodge, particularly when they are broadcast, and this makes combine harvesting inefficient (Xangsayasane et al., 2019c). 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. While drill-planted and transplanted crops lodge less, the use of broadcasting is increasing in Laos. As the broadcast crops are prone to lodging, lodging-resistant varieties are required. While combine harvested crops may not have large harvest loss (Bunna et al., 2018; Xangsayasane et al., 2019c), this may not always be the case particularly if varieties tend to shatter, and shattering resistant varieties would be useful to reduce combine harvesting loss in the field. Morphological variation contributing to shattering resistance is well known for japonica type rice (Okubo, 2014).

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-quality grain. One way to solve the problem is the use of photoperiod-sensitive varieties that can be planted over a long period while still flowering and maturing at about the same time that maximises grain yield, grain quality and field operation. Unlike neighbouring Thailand and Cambodia where photoperiod sensitive varieties are commonly used (Ouk et al., 2006; Rajatasereekul et al., 1997), most varieties developed recently in Laos are photoperiod-insensitive (Sipaseuth et al., 2009), and the introduction of photoperiod sensitive varieties that flower after the peak rainy period could be quite important for crops planted early with drills, and this change may result in more stable yield leading to further adoption of seed drill.

These new varieties with increased flexibility in planting time, less lodging, and high-quality grain would maximise the potential impact of mechanisation particularly in respect to utilisation of seed-drills and combine harvesters. On the other hand, row spacing of these mechanised planters is rather wide particularly transplanter planted crops (Xangsayasane et al., 2019a), hence varieties that spread quickly to occupy the inter-row space are required to suppress weeds and provide early vigour, leading to higher yields.

4.3.2. Land preparation and weed control

Similar points may be made for land and crop management to enhance the value of mechanisation. Land levelling is required to achieve good establishment from mechanised planters and the advantages of laser land levelling were discussed by Nguyen-Van-Hung et al. (2019). One research issue is the development of appropriate weed control measures that are widely applicable to the rainfed lowland rice ecosystem. Drill-planted or other direct seeded rice crops are often more affected by weeds than 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. For drill planted crops, a mechanised weeder that can be mounted on two-wheel tractor would be useful. Yamamoto (2007) described the development of such a weeding device. Another method available is to rotate transplanted and direct seeded crops. Thus, a combination of crop management and judicial use of herbicide is likely to minimize the weed issue.

4.4. Promotion of value-added products through mechanisation

One aspect that has emerged as a result of the work on mechanisation is an opportunity to develop high-quality grain products. In order to improve grain quality for marketing, uniformity of production is required. Compared with manual operations, machinery reduces farm-to-farm variation and this would result in more uniform rice products, and thus good grain quality control may be more readily achieved in mechanised rice production. The introduction of machinery can provide opportunity for large-scale commercial rice production, and this could lead to more uniform grain quality.

Introduction of artificial dryer improves head rice yield (Vongxayya et al., 2019; Xangsayasane et al., 2019b), and this would improve marketability of the rice grain. While combine harvesting may not provide better head rice yield compared to hand harvested crop (Bunna et al., 2019), combine harvested paddies are often dried artificially to minimize the risk of grain being spoilt with rain events which may occur when sun drying, and the artificial drying improves head rice yield (Vongxayya et al., 2019; Xangsayasane et al., 2019b).

As shown in Figure 1, mills with dryer are in a good position to direct farmers for quality rice production. Realizing the importance of seed used to produce high-yield grain and head rice yield, millers may provide high-quality seed to farmers under contract so that farmers are guaranteed a premium price for their combine harvested paddy. This scheme is currently promoted under the guidance of the Provincial Government.

4.5. Plant scientists working together with value chain actors

As shown in the example of interrelationship between farmers and millers mentioned above, and between farmers and combine contractors mentioned elsewhere, this paper has demonstrated various links that exist among different actors along the value chain. As also indicated earlier, different groups in the rice value chain including PAFO and PoIC may work together to improve the rice industry in the province. For plant scientists, it is important to understand the roles that different groups play, and work with them appropriately to realise the impact of the research work.

In addition plant scientists need to be innovative and to identify intervention points where research outputs could greatly affect the value chain. Once the requirements of farmers and rural communities, as well as those of other stakeholders and local Government are known, it is the task of plant scientists to come up with the suggestion that would provide information that meet the requirements of stakeholders that improve the overall activities of the value chain. An example mentioned in this paper is the amalgamation of a number of small rice fields for improvement of machinery efficiency.

4.5.1. Working with appropriate farmers groups

An example of farmers groups is seed producers group, which has played a key role in the research results obtained in the province and mentioned in the paper. It is important to select a group that has a strong leader and its main activities match with the objectives of the work that the scientist is going to conduct. This was also pointed out in another project in Laos (Fukai et al., 2017). Often farmers are willing to participate in a research project and spend many hours with project staff discussing the research and development issues of importance. Their involvement in field operations often creates much useful information, and villagers provide good feedback to the scientist. These farmers' groups have good experience in rice growing and often include the leading farmers in the local area, and their views can shape the future activities of the scientist.

4.5.2. Identifying stakeholders associated with farmers' group

They would include grain collectors, millers, combine and other contractors, and the local Government (Figure 1). Appropriate rice value chains need to be considered, and the importance of rice production quantity and quality meeting the marketing demand is clearly required. Millers or grain collectors may be willing to provide high-quality seed and other inputs to farmers (Figure 1) and they may guarantee to buy back the paddy that farmers have produced at a premium price as these agribusiness people realize the benefit of high-quality seed and other support to farmers for production of high-quality grain.

4.5.3. Working with the local government

The local authority works with local people to help improve their livelihoods. They are influential in setting up appropriate policies and providing resources to selected groups and individuals. They are often well connected to the central Government and international donors that provide funds to the province. Continued dialogues with the local Government are essential for conducting appropriate research that could have direct impact on farmers and local communities. Research results could be readily implemented through the Government agencies or with their initiative through other groups such as NGOs if they are available.

The research results shown in the previous section were obtained in cooperation with the Khammouan Provincial Government 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 through the provision of Government credit to farmers. In working with the local authority, the scientists could also make suggestions regarding the long-term policy for mechanisation. One such case was the promotion of amalgamation of small fields, and this has resulted in the local Government providing incentive. Similarly, the Government has developed mechanisation extension project where different mechanisation items have been provided to a village in the province and tested by many farmers to determine appropriateness of different items in their production environment.

The MAF annual meeting in 2018 certified the use of mechanisation as a suitable method to reduce the investment cost and increase profitability of farmers. Consideration could be also given to establishing a mechanisation promotion board to be run by the private sector to foster machinery businesses and establish a mechanisation technology center for training mechanisation specialists. This will further help the adoption of mechanised cropping.

4.5.4. Dissemination of information

This is important for the outcome of any research project, and the results shown in the previous section and in the original technical papers have been well disseminated. One such method is organisation of workshops with farmers and other stakeholders, as was the case of the mechanisation work reported here such as seed drill technique, field size for mechanisation, combine harvesting efficiency and drying technique. In addition, information has been provided to farmers directly in several topics on a number of occasions. The topics included land amalgamation, the number of seed trays required for 1ha, seed drill, sun-drying method, the alternate wetting and drying technique, and golden apple snail control.

Another method is the production of leaflets; in relation to the mechanisation work here, three sets of leaflets were produced: (1) Paddy size and factors affecting combine harvesting efficiency, (2) Crop establishment method and (3) optimum time of harvesting rice and drying method, and 3,000 copies were distributed to farmers and PAFO. A factsheet on the operation of seed drill was produced and distributed to machinery shops that sell seed drill to ensure that the farmers will have correct information when they purchase seed drill.

In conclusion, it is critical that to promote the development of mechanised agriculture for commercialisation, that all actors in the rice value chain are engaged.

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