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A diagnostic on-farm survey of the potential of seed drill and transplanter for mechanised rice establishment in Central Laos and Southern Cambodia

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ABSTRACT

Due to labour shortages in rural areas, traditional manual transplanting is often no longer feasible and alternative rice establishment methods are required in Central Laos and Southern Cambodia. The work reported here evaluated the potential of a seed drill and transplanter by comparing yield of over 200 crops established by different methods including broadcasting in farmer's fields under their management in 3 seasons in Laos. In Cambodia, yield of rice established by drill planting was compared with farmers' practice by broadcasting in two early wet seasons. When mechanised and manual establishment methods were compared in each of 10 farms in the same season in Laos, drilled crops produced slightly higher yield compared with manual planting. Similarly in Cambodia, the technology package including drill produced slightly higher yield and higher gross margin despite lower plant density than that of the farmer practice based on broadcasting. On the other hand, mean yield established using drill was 26% lower than manually transplanted crops across all seasons and villages in Laos, indicating that possibly drills were used in fields unsuitable to them. Mean yield established using transplanter across all fields was 16% lower than manually transplanted crops. Hill density of crops established from transplanter was lower than that from manual transplanting, and yield increased with increased hill density. The labour requirement and hence establishment cost were greatly reduced compared to manual transplanting. The results show the economic advantage of mechanised rice establishment particularly of seed drills.

Abbreviations: WS: wet season; DS: dry season.

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Drill; transplanter; rice; crop establishment; mechanisation; plant density

1. Introduction

With limited availability of rural labour for manual crop production work, mechanisation offers an alternative option and is gradually taking place in different crop production processes in the Mekong region. Thus, land preparation is commonly done using two or four wheel tractors, and the combine has become quite common for harvesting rice crops in some countries such as Cambodia and Thailand (Department of Agricultural Engineering, 2016). However, mechanised planting is not common for rice in the region. Strategies for mechanised production of rice in SE Asia where subsistence agriculture is gradually replaced with commercial agriculture are developed recently by Fukai et al (2019).

The traditional planting method for rice is manual transplanting which requires, including pulling the seedlings from the nursery, about 25–50 people to complete

1 ha/day (Dawe, 2005). Broadcasting has become popular in some Mekong countries as it requires much less labour than transplanting (Fukai & Ouk, 2012). Experimental results show broadcasting can produce similar yield to transplanting in Laos (Mitchell, Fukai, & Basnayake, 2004). However, often crop establishment is rather slow and not uniform. This may be related to the uneven surface of paddies and also light cultivation after broadcasting which results in seeds positioned at different soil depths. The major problem associated with broadcasting is weeds, and with limited use of herbicides, farmers often revert back to manual transplanting (Fukai & Ouk, 2012). There are several mechanical planting methods practised or trialled in Laos and Cambodia such as drum seeder (Dalglish et al. 2016), seed spreader, seed drill and mechanical transplanter to overcome the problems associated with manual transplanting and broadcasting. The mechanical transplanter has been commonly used and has replaced manual transplanting in northern Asian

Table 1. The number of paddy fields tested under various establishment methods in different villages in Central Laos in three seasons.

Year	Villages	Total number of fields	Manual transplanting	Transplanter	Broadcasting	Seed drill	Drum seeder
2014/15 DS	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	
2015 WS	Hatkhamhieng	1				1	
	Tung	37	8	24	5		
	Paketue	5	5				
	Others	22			9	13	
	Total	65	13	24	14	14	
2015/16 DS	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
Three seasons	Total	226	53	64	65	28	16

DS: Dry season; WS: wet season.

countries. Its advantage is reduced labour requirement and faster speed of operation compared to manual transplanting. It is sometimes used for high-quality seed production of rice in Laos where manual transplanting is not feasible any more due to increased labour cost.

Another mechanised planting method that appears promising is seed drill, which is gaining popularity in Savannakhet, Laos, due to saving of labour cost compared to manual transplanting (Sengxua et al., 2019). Drill-planted rice area increased from 835 ha in 2015 to over 15,000 ha in 2016 (Jackson, Sengxua, & Wade, 2017). Recent work on the comparison of drill and broadcasting at three farms in Savannakhet showed that the drill produced higher mean yield (4590 vs. 3490 kg/ha; Jackson et al., 2017). Similarly, Kumar and Ladha (2011) showed a yield advantage of drill over broadcasting across Asia. Compared to broadcasting, the seed drill can provide better establishment and also drill-planted crops are easier for weed control (Kumar & Ladha, 2011). The performance of seed drill may be compared with broadcasting where direct seeding is already practised and with manual transplanting where it is still practised. Seed drill is used when the soil is rather dry, thus early in the wet season (WS), while the transplanter is used when the soil is saturated.

The objectives of this study were to examine yield and economic benefit from different establishment methods particularly transplanter and seed drill and identify advantages and disadvantages of each method. The approach adopted in the present work was that of farmer participation; thus, farmers

tested the transplanter and seed drill under their own management.

2. Materials and methods

2.1. Comparison of establishment methods in different villages in Central Laos

Yield comparison of crops established from seed drill, transplanter, manual broadcasting and manual transplanting was conducted mostly in four villages in the 2014–15 dry season (DS), 2015 WS and 2015–16 DS in Central Laos. In one season, drum seeder was also examined in two villages. The four villages were in Pakpung, Bolikhamxay province, and Paketue, Hatkhamhieng and Tung in Khammouan province. The soil type of the first three villages was clay loam while it was sandy soil in Tung village. All villages were located in lowland rice ecosystem, and some parts of the villages had access to irrigation water in DS for rice and other crops, the latter occupying higher toposequence positions. In each village, several farmers participated in the present work, and their fields were scattered across toposequence positions. In the three seasons, the number of fields harvested from crops established using transplanter was 64 and by seed drill 28, while the number of crops established from conventional methods of manual transplanting was 54 and broadcasting 65 (Table 1). These crops from different establishment methods were not necessarily grown under the same conditions, and the results here should be treated as those of a survey rather than of experiments.

Note that the numbers of fields used in DS and WS in each village were different, for example Pakpung village had no field in WS, whereas it provided the largest number of fields in both DSs while most fields in WS belonged to Tung village. However, on nine farms, crops were established using mechanised method as well as manual establishment method in the same season; hence, the crops in each farm were grown under similar growing environment and management, and hence, the yields achieved in these cases were considered more directly comparable to each other. For the comparison of seed drill and broadcasting, the yield result of an farm obtained in Ekxang village, Vientiane province in 2016 WS, was added as the 10th farm where mechanised establishment (5 fields) was compared with manual establishment (11 fields).

The rice crops used for the present work were also used for the determination of combine harvester efficiency reported by Xangsayasane et al. (2019).

In Central Laos, manual transplanting was the most traditional establishment method, but broadcasting has become common recently. Participating farmers in these villages had used mechanical 4-row Kubota transplanters (model SPW-48C); thus, the farmers were familiar with these three methods, and they decided which methods to use for their fields across toposequence positions available to them, and they prepared the land and established the crops as per their routine work. Land preparation was also a little more thorough for the use of mechanical transplanter compared with manual planting methods. While no record was made for the selection of toposequence positions for these three methods in DS and WS in each village, farmers in Central Laos tended to use broadcasting in lower toposequence positions in WS while no such preference appeared to exist in the DS.

As seed drill was new to the farmers who participated in the work, and the concept of seeding rice before the field was saturated was also a new concept to farmers: some had rather poor establishment as reflected in some yield results. The drill tended to be used more for upper fields and lighter soils available within the participating farmer groups, but no record of toposequence position was made. A four-row drill manufactured in Thailand (Ta Ngao company Thailand – model TSP R3), with four tynes and not suitable for zero tillage, was provided to each village for testing. The drill was mounted to a two-wheel hand tractor for planting rice. In the WS, soil was ploughed at the end of April to early May and the second ploughing was done in early-to-late May or after first rain, followed by harrowing before seeding under dry soil conditions. In the DS, soil was prepared in December under dry conditions and some farmers flooded the rice field and waited until the soil dried to field capacity before preparing the land and then

rice was seeded by seed drill. Dry rice seed was put in the seed box attached with seed drill and seeded under dry soil condition. After seeds germinated and seedlings were 5–10 cm in height, the field was irrigated in DS, while in the WS, the field was under rainfed condition. Post-emergence herbicide (Bispyribac sodium) was sprayed after rice seedlings were 5–10 cm in height.

Fertiliser was applied in the DS at about 100–150 kg of NPK mixed fertiliser (15–15–15)/ha but the rate was variable among the farmers in WS. Rice was harvested by combine in most fields but some fields were harvested manually, grain weight for the whole field and grain moisture content determined, and after the paddy field area was calculated, grain yield was determined and adjusted to 14% moisture content. Varieties used in this work were mostly high yielding, photoperiod insensitive varieties TDK8 and VTE450-2 and mildly sensitive RD15.

In order to determine yield components, crops from different establishment methods were cut from an area of 1 m² in 23 and 22 fields in 2014/15 DS and 2015/16 DS, respectively. Crops were harvested manually, and grain yield and total biomass determined and harvest index estimated as grain yield/total biomass. The number of hills was determined for transplanted crops. For all crop establishment methods, 10 panicles were randomly selected and filled and unfilled grain number counted, and filled grain percentage calculated. Sample of 1000 grain was taken and weight determined. Panicle number/m² was estimated as grain yield/(filled grain number per panicle × 1000 grain weight).

2.2. Yield responses to hill density in transplanter established crops

In 2016/17 DS, a small trial was conducted without replications at the Rice Research Centre in Central Laos to demonstrate the tray number – hill spacing effect on grain yield. The Kubota 6-row NSPU-68 CMD transplanter was used. One field (about 2100 m²) was divided into four sections (each section was 480 m²) to test the effect of hill spacing when the rice crop was established with a transplanter. Row spacing was always 0.3 m, but the hill spacing varied from 0.14 to 0.21 m, where 0.16 m was often used for DS crops and 0.18 m for WS crops. The number of seedlings per hill would be the same (5/hill). The number of trays used varied from 250 to 188 trays/ha. The growing media used in the seed tray had the ratio of soil and burned rice husk of 1:1 (50% fertile soil from river bank and 50% burned rice husk). The hill number was counted and grain yield determined at maturity.

In 2017/18 DS, an experiment with randomised complete block design was conducted with five treatments of number of trays with three replications. The various

treatments were generated using different seedling numbers per hill for 150 and 200 trays, and 300 and 350 trays/ha. A field with size of 30 × 40 m was used for this experiment with each plot dimension of 1.8 × 40 m. In this experiment, the field area with uniform appearance was selected, and 1 m² area was harvested along a line perpendicular to row direction across the whole field, before whole plot was harvested by combine as was conducted in the first season. From the 1-m² area, panicle number was counted and grain yield was determined. In both years, yield was adjusted to 14% moisture content.

2.3. Economic evaluation of farmer adoption of planting machine contracting service in Laos

The economic benefit to farmers of adoption of planting machine contracting service over manual planting is estimated here. Contracting service for transplanter and seed drill has commenced recently in Central Laos where farmers pay to hire the planting machine. The hiring fees that the machine owner charges would cover the depreciation and maintenance costs of the machinery. Operation cost may be included in the hiring cost or may be met separately by the users, i.e. farmers, as in the case of transplanter service. The cost of adopting transplanter contracting service was estimated by interviewing people in four villages who have used a transplanter regularly. The cost included hiring transplanter, as well as the costs for producing seedlings in trays and associated labour cost, and the costs for operators of transplanter, labourers and fuel charges associated with running the transplanter. At the same time, the cost for hiring labourers for pulling and bundling seedlings and manual transplanting was estimated in the same villages. The cost of hiring a seed drill was provided by

Table 2. Grain yield (kg/ha) and as percentage of hand planting (%) of crops established from drill or transplanter compared with manual transplanting or broadcasting within the same farm and in the same season.

Farmer no.	Manual transplanting	Drill	%
1	3562	3359	94.3
2	2234	2863	128.2
3	3427	3505	102.3
Farmer no.	Manual transplanting	Transplanter	%
4	2791	3227	115.6
5	2812	2435	86.6
6	5371	3327	61.9
Farmer no.	Broadcast	Drill	%
7	3167	3178	100.3
10	2636	3137	115.2
Farmer no.	Broadcast	Transplanter	%
8	1383	2681	193.9
9	2783	3201	115.0
6	4476	3327	74.3

Each farmer is numbered from 1 to 10; farm 10 was in Ekxang village, Vientiane. Yield was estimated from the whole field.

farmers who have used a drill regularly in Savannakhet Province. The time required for planting 1 ha of rice fields for a transplanter, seed drill, broadcasting and manual transplanting was also estimated from the information provided by farmers who used the various rice establishment methods.

2.4. Seed drill demonstrations in Southern Cambodia

In Cambodia, drills developed previously at CARDI (Cambodian drill seeder) were used for demonstrations in villages each year. Subsequent to the first seed drill demonstration in WS 2014 when rainfall was unusually low, 16 farmers in Trapeang Chak village, Trapeang Kranhung commune, Tramkak district, planted almost 30 ha with the seed drill. Farmers in the village normally establish rice from broadcasting, but the dry conditions meant that it was very difficult to establish a crop from broadcasting.

In 2015, nine field demonstrations were carried out in early wet season (EWS) in Takeo and Kampot. The objective was (1) to determine the differences between broadcasting (farmer practice) and use of seed drill on rice yield in the rainfed lowland area with some supplementary irrigation and (2) to compare the economic benefit between the two methods by recording production cost. All field demonstrations were divided into two plots and each field consisted of (1) CARDI technology package including the use of Cambodian seed drill and (2) farmer practice including broadcasting. The nine field demonstrations (two in Prey Kabas district, five in Tramkak district and two in Bateay Meas district) in two provinces were conducted using Chul'sa variety. Plant density was determined 3 weeks after planting. Similarly, four pairs of fields were compared in 2017 EWS.

3. Result

3.1. Comparison of various establishment methods in villages in Central Laos

3.1.1. Comparison of establishment methods on the same farm

On 10 farms where crops were established using mechanised method as well as manual establishment method in the same season, the number of fields in each crop establishment method varied from 1 to 26, but it was mostly 2–5. For all 5 cases with drill planting, yield of drill established crops was comparable to that of manually transplanted (94–128%) and also broadcasted (100–115%) crops (Table 2). Mean yield of transplanter planted crops varied from 2435 to 3327 kg/ha among five farms where yield was compared with either manual transplanting (62–116%) or

broadcasting (74–194%). Farmer number 6 produced much higher yield when the crop was established from manual transplanting (5371 kg/ha) or broadcasting (4476 kg/ha) than from transplanter (3327 kg/ha). On the other hand, farmer number 8 produced much lower yield (1383 kg/ha) when the crop was established from broadcasting.

3.1.2. Comparison of different establishment methods across villages and seasons

Yield results obtained from different establishment methods, conducted under farmer's management and in over 200 fields in several villages across two DSs and one WS, show that the highest mean yield was obtained for crops established by manual transplanting and yield reduction in drill-planted crops was 26% and transplanter-planted crops was 16% (Table 3). However, there was rather large variation in yield for each establishment method with coefficient of variation varying from 27% in drill-planted crops to 36% in drum seeder. The effect of different establishment methods varied between the seasons and across villages. Thus, the transplanter-produced yield as high as that of manual transplanting in the WS when it was used only in Tung village. Among direct seeding methods, mean yield in drill-planted crops was lower than broadcasting (2743 vs. 3368 kg/ha), but they produced similar yield in WS. Drills were used in fewer fields, but they produced similar yield to manually transplanted crops in Tung village in mostly sandy soil fields while lower yield in

Pakpung village. At maturity, crops lodged only under broadcasting, but this did not affect crop yield.

In general, Hatkhamhieng produced higher yield and Tung lower yield than other villages. On the other hand, Pakpung produced the highest yield in manually transplanted crops among all villages, and rather poor yield was achieved from mechanised planting.

3.1.3. Yield components of crops from different establishment methods

The number of fields sampled for the determination of yield components varied from 3 to 9 in 2014/15 DS and 3 to 11 in 2015/16 DS for the 4 different established methods (Table 4). In both DSs, transplanter-established crops had about 40% fewer hills than manually transplanted crops, and panicle number/m² was also lower in transplanter-planted crops. Larger number of grain/panicle compensated for the fewer panicles in 2014/15 DS resulting in similar grain yield. However, in 2015/16 DS, larger panicle size could not fully compensate for the fewer panicles, and the yield was lower. In the 2014/15 DS, drill produced slightly higher yield than other crop establishment methods, but the number of panicles was rather small. In 2015/16 DS, drill produced the fewest panicles and yield was the lowest. Thus, in both seasons, panicle number was smaller in the crops with mechanised establishment methods compared with manually planted crops. However, the number of filled grain/panicle tended to be larger in the

Table 3. Grain yield mean and standard error of crops established from five different methods in three seasons in several villages in Central Laos.

	Mean of three seasons across all villages			Mean of wet season across all villages		
	Yield (kg/ha)	Number of fields	% Relative to manual transplanting	Yield (kg/ha)	Number of fields	% Relative to manual transplanting
Broadcasting	3368 ± 126	65	90.7	2659 ± 258	14	86.6
Drum seeder	2372 ± 215	16	63.9			
Manual transplanting	3714 ± 153	53	100	3069 ± 245	13	100
Drill	2743 ± 139	28	73.9	2692 ± 193	14	87.7
Transplanter	3100 ± 124	64	83.5	3073 ± 243	24	100.1
	Hatkhamhieng			Paketue		
Broadcasting	3689 ± 333	9	93.5			
Drum seeder	3568 ± 153	4	90.5			
Manual transplanting	3944 ± 206	14	100	3513 ± 445	5	100
Drill	3162	1	80.2			
Transplanter	4404 ± 368	2	111.7	2997 ± 246	5	85.3
	Pakpung			Tung		
Broadcasting	3476 ± 147	40	80.3	1745 ± 326	5	60.8
Drum seeder	1974 ± 155	12	45.6			
Manual transplanting	4328 ± 456	11	100	2868 ± 196	11	100
Drill	2638 ± 301	9	61	3073 ± 218	4	107.1
Transplanter	3117 ± 227	19	72	3037 ± 166	38	105.9

Mean grain yield for all three seasons and wet season alone from all villages as well as yield for all seasons in four villages are shown. The number of fields harvested as well as mean yield (%) relative to that of transplanting is also shown for each establishment method. Yield was estimated from the whole field.

Table 4. Grain yield and yield components (determined from 1 m² samples from each field) of crops established from different methods in two dry seasons in Central Laos.

(a) 2014/15 DS								
Crop establishment methods	Number of fields	Grain yield (kg/ha)	Hills (m ²)	Panicle number (m ²)	Filled grain number/panicle	Filled grain (%)	1000 Grain weight (g)	HI
Broadcasting	9	3430	na	169	71	81	28.5	0.49
Manual transplanting	3	3500	43	201	56	93	30.9	0.50
Drill	5	4100	na	140	99	78	29.4	0.51
Transplanter	6	3670	27	139	95	87	30.2	0.55
(b) 2015/16 DS								
Broadcasting	11	3634	na	325	38	62	30	0.47
Manual transplanting	5	5247	38	386	45	84	31	0.42
Drill	3	2213	na	167	44	81	30	0.37
Transplanter	3	4249	24	225	60	78	32	0.35

na: Not available.

mechanically established crops. Among the yield components, mean weight of grains varied least.

3.2. Yield responses to hill density in transplanter established crops

The 2016/17 DS resulted in about 10% yield loss when about 200 trays were used per hectare compared to the maximum yield which was obtained at 250 trays/ha (Table 5). This was associated with more than 30% loss in hill density. The results of the second DS also suggested a similar magnitude of yield loss when the tray number range was extended to 350–150 trays/ha. While the results based on whole plot sampling did not show a significant effect of the number of trays used, the treatment effect on grain yield from manually harvested 1 m² area was larger and significant ($p < 0.05$). The lowest tray number treatment showed 20% yield reduction compared to that with the 300 and 350 trays/ha treatments. However, panicle number sampled from the 1-m² area was not significantly affected by the number of trays/ha. The yield response to tray number

Table 5. Effect of the number of trays used on hill spacing, hill density and grain yield in two dry seasons.

Trays used (ha)	Hill spacing (m)	Hill density (m ²)	Yield (kg/ha)	Panicles (m ²)
2016/17 DS				
250	0.14	23.8	4500	na
229	0.16	20.8	4210	
208	0.18	18.5	4040	
188	0.21	15.9	4080	
2017/18 DS				
350	Na	Na	3430 (4650ab)	(318)
300			3220 (4690a)	(319)
250			3260 (4250abc)	(306)
200			3150 (4080bc)	(295)
150			3110 (3730c)	(271)

Values in brackets in 2017/18 DS were obtained from 1 m² samples. Different letters following numbers indicate significant differences among number of trays used.

was almost linear in both years, and the regression was significant in the second year (Figure 1).

3.3. Economic evaluation of farmer adoption of planting machine contracting services in Laos

Adoption of contracting services for transplanter and associated costs is compared with manual transplanting cost in Central Laos (Table 6). It was clear that the adoption of a transplanter service incurs less cost than manual transplanting in all villages, about half the cost of transplanting. However, the transplanter option does not include the cost of extra land preparation which is sometimes required for transplanter use. The variation in transplanter cost was partly due to hiring cost which varied from \$50/ha in Nongping to \$12.5/ha at Pak-etue and to \$0 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

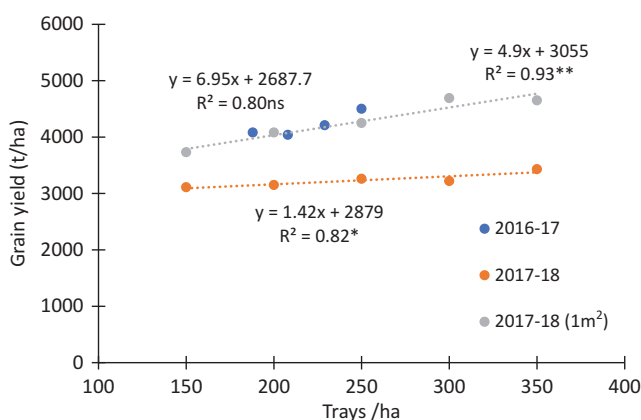
**Figure 1.** Relationship between grain yield and the number of trays used for transplanter planted rice crops at Rice Research Centre, Vientiane in two dry seasons. In the second year, yield was estimated for the whole plot basis and 1 m² sampled area basis.

Table 6. Cost (USD/ha) of transplanting by machine transplanter or manually at different villages in Central Laos (a) and breakdown of the cost (b).

(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

for the cost when transplanter contractor business is considered as this fee would include at least part of depreciation and maintenance costs.

The cost breakdown (Table 6(b)) shows that seed cost was slightly lower for transplanter planted crops because of the lower seeding rate. Transplanter hire cost of \$16/ha was the mean of four villages mentioned above. Tray preparation cost was slightly higher than seedbed preparation cost for manual transplanting. The cost of labour hire for operating transplanter was \$28/ha which was much lower than the sum of the costs for pulling seedlings and manual transplanting of \$166/ha. The number of people required to operate transplanter was 3–4 (Table 7). Large variation in the cost of manual transplanting was mainly due to the variation in labour cost which ranged from \$8.7/day in Pakpung to \$5/day in others and the number of people required to manually transplant (17–24 people to complete a hectare in one day in these villages). Slightly higher number of 20–30 workers than the 17–24 mentioned here is often mentioned in other villages and is shown in Table 7.

The seed drill service fees varied with a high charge of about \$50 in Savannakhet in Central Laos in 2015 when the drill-contracting business started, but it may have become cheaper since that time. Drills required slightly more labour and higher service fee payment than broadcasting (Table 7). However, it required much less labour and cost compared to transplanting methods. While adopting transplanter contracting service would be less costly than manual transplanting, it would be much more expensive than direct seeding methods.

3.4. Seed drill demonstrations in Southern Cambodia

Despite smaller number of plants/m² from drill-planted crops, their yield was generally higher than those

Table 7. Labour requirement (the number of people required for planting 1 ha in 1 day) and the cost of hiring machinery and labour for different methods of rice crop establishment.

Methods	Manual transplanting	Broadcasting	Seed drill	Transplanter
Labour requirement	20–30	1–2	2	3–4
Crop establishment cost	\$190–300	\$10–15	\$30–50	\$120–170

established from broadcasting (Table 8). Economic analysis from the six sites in Cambodia in 2015 WS indicated that the CARDI technology package including the use of seed drill obtained a gross margin of about \$570/ha, which was about \$140/ha higher than the farmers' practice with broadcasting. Similarly, the 2017 results show a gross margin of \$476/ha from the drill-based cropping which was \$70/ha higher than the farmer practice. This comparison is the result of several differences in practices, not just the use of the seed drill. Input cost was also higher in the drill-based technology, with around USD20 higher planting cost. The details of input cost are shown in Table 9(a,b). Costs for irrigation and weeding were higher in the drier season in 2015 than in 2017, and also in the drill-based CARDI technology than in the farmer's practice.

When drill was introduced to Trapeang Chak village, Takeo in southern Cambodia in WS 2014, the season was very dry and without irrigation water. Among 16 farmers who used the drill, two farmers failed to produce any yield, but remaining 14 farmers produced over 10 t of paddy with a mean yield of 3500 kg/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.

4. Discussion

The potential of transplanter and seed drill in Central Laos and Southern Cambodia is discussed in relation to yield and economic benefit to farmers (a) and other aspects (b). The former is directly related to the work presented here while the latter includes some other key aspects that are noted for the last 5 years of trialling transplanter and drill in these countries.

4.1. Transplanter

4.1.1. Yield and economic benefit to farmers

The transplanter-produced grain yield that was on average 16% (614 kg/ha), was lower than manual

Table 8. Comparison of seed drill-based technology and broadcasting-based farmer's practice for gross margin (GM) and its various components for early wet season (a) 2015 and (b) 2017.

	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

Table 9. Comparison of input costs for seed drill-based technology and broadcasting based farmer's practice for (a) 2015 and (b) 2017.

(a)								
Input costs (\$USD/ha)								
Seed drill			Broadcast and farmer practice					
Seed price	60		57					
Land preparation	89		85					
Fertiliser	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 and farmer practice (average 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
3	Fertiliser urea	kg	75		36	65		31
4	KCI	kg	50	0.6	30	95	0.6	57
5	DAP	kg	50	0.6	30	50	0.6	15
6	Irrigation	l (3 times)	45	0.9	39	19	0.9	13
7	Planting		1	31	31	1	12.5	13
8	Weed control (herbicide)				50			44
9	Harvesting		1	88	88	1	88	88
Total					476			433

transplanting across all fields in three seasons in Laos. However, the relative yield of crops established with transplanter to that of manual establishment methods in the same farm and season varied greatly, and the yield was as good as that of manual transplanting in Tung village. This may be related to the fact that the owner of the transplanter in this village was very familiar with the operation of the transplanter as he has used it every season since 2012.

Crops established from transplanter generally had a lower hill density than manual transplanting, and this appears to be particularly disadvantageous in DS, when farmers generally use higher hill density with manual transplanting. Typical spacing for hand planting would be 20 × 20 cm (25 hills/m²) for DS and 25 × 25 cm (16

hills/m²) for WS. The low hill density from transplanter crops was not only due to wide row spacing of 30 cm but also due to wide spacing of around 20 cm or greater between hills in some cases. The mean number of hills/m² (24–27 hills/m²) determined in the farmers' fields shown in Table 4 indicated that some 250 trays/ha were used, but not all fields were planted with such high tray number. The row spacing (30 cm) of seedlings established with transplanter appears too wide for the tropical Lao and Cambodia environment, particularly for DS. Basnayake et al. (2006) showed the importance of increased plant density for achieving high yield in hand transplanted crops. According to their estimation, the plant density may not be sufficiently high to achieve maximum yield, assuming 24–27 hills/m² would be

equivalent of about 75–125 plants/m² with 3–5 plants/hill. It is likely that higher plant density would be required for a wide row of 30 cm. The regressions shown in [Figure 1](#) indicate that doubling tray number from 150 to 300/ha would increase the yield of transplanter-planted crops by 7–19%.

The major advantage of the transplanter is time and labour saving compared with manual transplanting ([Tables 6 and 7](#)). However, the analysis also suggests that the transplanter contracting service was rather expensive and the benefit of adoption of mechanised transplanting over manual transplanting may be limited ([Table 7](#)). This was partly related to the fact that the transplanter requires several people to operate on the day of transplanting. Transplanter was a costly purchase (USD 4–5000) and also a complex machine that requires frequent maintenance and repair, hence resulting in rather high depreciation cost that would have reflected in the hiring fees that the owner would charge. In addition, a large number of seed trays are required and they add to increased cost of adoption of mechanised transplanting. If 240 trays/ha are used and 1 ha planted/day, and transplanter is used for 15 days, 3600 trays are required and they would cost about \$6000 (USD1.6 per tray). In the analysis shown in [Table 6](#), the cost for hiring tray was small as the groups had already owned most trays required, but extra cost would need to be factored in further for the estimation of the economic benefit of adopting mechanised transplanting. Because of the rather high total cost, transplanter would be more suitable for production of high value crops such as seed rice, the advantages and disadvantages are summarised in [Fukai et al. \(2019\)](#).

4.1.2. Other aspects

A limitation of the transplanter is the use of young seedlings, and this could cause susceptibility to submergence ([Ros, Bell, & White, 2003](#); [Ros, White, & Bell, 2015](#)). For example, of the eight transplanter demonstration fields in Cambodia in 2016 WS, four were damaged by flood, two resulting in complete crop failure. Two crops destroyed were submerged 12–14 days after transplanting for 12 and 6 days. However, neighbouring manually transplanted crops established using older seedlings (45–60 days or perhaps even older) of local varieties survived the flood. With the incorporation of the submergence tolerance locus (SUB1) QTL, rice varieties are now available in many genetic backgrounds that can survive transient submergence after establishment ([Ismail et al., 2013](#)). The use of transplanter should be avoided in low lying areas where flood is likely to be a problem. Paddy fields with good drainage facilities are advisable for avoiding submergence

problem. Good drainage also helps the problem caused by golden apple snail particularly in WS.

The transplanter is considered to have a potential role in the following cases: when there is not sufficient labour available for manual transplanting, where the crop is for seed production or high value rice, where there is a need to control weeds after years of continuous broadcasting and where herbicides are not utilised and where there is a need to reduce crop duration in the main season to allow for more intensive cropping systems. It requires levelled land and preferably clay soils. Even for manual transplanting, the land is ploughed just before transplanting, but for the transplanter, the land has to be also harrowed further.

4.2. Seed drill

4.2.1. Yield and economic benefit to farmers

The results of the present work show that the yield of crops established from drill is comparable to manual establishment methods when they were compared within the same farm and season. However, across all fields in different villages and seasons, manual transplanting generally produced higher yield than seed drill. Thus, in the farms where only drill was tested in a particular season, their yield was lower than that from manual transplanting conducted in the villages. Thus, the growing condition was not suitable for drill use in these cases, and this would include clay loam soils, as the yield was particularly lower in Hatkhamhieng and Pakpung village. On the other hand, the yield was slightly higher than manually transplanted crops in Tung village where sandy soil prevailed. [Hayashi et al. \(2009\)](#) indicated a problem of uneven establishment for broadcast crop, and [Rickman et al. \(2001\)](#) showed increased yield when the land was more level. Drill planting may have a similar problem if land is not well levelled. While direct seeding is a time-saving technology, crop establishment is not always high and this could limit yield ([Naklang, Fukai, & Nathabut, 1996](#)). If establishment is successful, they found that biomass production was higher, and grain yield was similar or even higher in broadcasting under lowland conditions.

Yield component analysis ([Table 4](#)) has indicated that estimated panicle number tended to be lower in drill-planted crop than in manual transplanting or broadcasting in DS in Laos and EWS in Cambodia, and this could be a limitation for higher yield. On the other hand, the yield of drill-planted crops was similar to that of hand transplanted crop in Tung village, and this could be partly related to their practice of double seeding – one way first, and then at right angle to the original direction so that the density was doubled. It

may be that the drill may be modified to produce a paired row arrangement (Ali et al., 2012) to increase plant density. In direct seeded crops, higher plant density was suggested to be required than the transplanted crops to achieve maximum yield, because of its increased weed problem (Basnayake et al., 2006). For crops established from dibbling seeds, which would be similar to the drill-planted crops, they showed that higher yield can be obtained by reducing plant spacing from 25 to 10 cm and even less (continuous planting) for 25 cm wide row spacing. The row spacing established in the four-row drill used in the current work was about 25 cm. The drill from Thailand used in the present work does not have metering device to control the rate of seed dropping, while the more advanced model has a metering device.

The seed drill appears promising as long as the planting condition is favourable, the advantages and disadvantages are summarised in Fukai et al. (2019). Table 7 shows clearly that adopting a drill contracting service is an attractive option for farmers who are not satisfied with the performance of crops established from broadcasting such as weedy fields or uneven establishment. As the price of drill in Laos has reduced to around \$350 in recent years, it is an attractive option for farmers who have become familiar with the drill to provide drill service to other farmers. In Savannakhet province in Laos, 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 is spreading have sandier soils than most areas in Khammouan and Bolikhamxay where the current work was concentrated in Laos, which could be a factor causing the difference in adoption of drill contracting services.

4.2.2. Other aspects

Drill needs to be used before the soil is saturated with water, and this commonly results in earlier than usual planting for rice in WS. An advantage of drill over broadcasting is that seed can be planted in deeper soils where soil moisture content is generally higher during a dry period, and hence varieties that can emerge from deeper planting position would be advantageous (Ohno et al., 2018). On the other hand, when rice is seeded by drill early in the season in Laos, photoperiod insensitive varieties may not be suitable as they are likely to flower in September in the middle of the rainy period. Thus, photoperiod sensitive varieties are required and they would

flower in mid-October and mature in early November even if the crop was planted in May (Rajatasereekul et al., 1997). One major issue of drill is weed control, as is the case with broadcasting. While row planted crops are more readily weeded than broadcasted crops, this remains a major challenge for drilled crops, and the economic benefit would also be affected.

The seed drill can be used for rice as well as other crops such as peanuts, corn and mungbean, e.g. mungbean in Cambodia, as described by Bunna et al. (2011). This increases the usage of seed drill considerably and provides more options to farmers, for example, peanuts may be considered too labour intensive for hand planting and may not have been tried previously, but the drill could make peanut a viable option.

Availability of a seed-drill manufacturer in Savannakhet and machinery shops selling drills in different provinces should help the rapid spread of the drill in Central Laos.

5. Conclusions

It can be concluded that the seed drill is relatively cheap and easy to operate and saves the time and cost of hiring labour, while yield advantage over manual transplanting is limited except under dry conditions. In areas where manual transplanting is still practised but labour shortage has started to increase the labour cost, the drill is likely to be well adopted by farmers. In the area where broadcasting is already practised, drill may still be adopted due to improved crop establishment and ease of weed control. Weed control is a major issue with the drill, and sound weed control measures are required. The ability to plant early in WS with the seed drill needs to be fully exploited for achieving further production gain. Transplanter also saves labour cost compared to manual transplanting and can be beneficial when weeds are a potential problem, but it is still expensive to operate compared to direct seeding and would be more suitable for high value rice crops such as for production of seed. A transplanter type that would result in narrower row spacing than 30 cm would be required for Laos and Cambodia. Research strategies for promotion of mechanised rice production in the SE Asia region where crop production is in transition from subsistence to commercial agriculture were developed recently, including the technical aspect of improved mechanised planting as well as policy intervention points in the rice value chain, by Fukai et al. (2019).

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