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Article

Performance of Cambodia's made vegetable transplanter for two-wheel tractors under tillage conditions

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Abstract: In Cambodia, vegetable crops are planted by hand, making it hard to meet local market demands. However, this production can be boosted by using a mechanical transplanter with two-wheel tractors to cut input costs, when introduced to farmers, while production and productivity can be accelerated. Thus, this research aimed to (1) evaluate the working performance of a locally made vegetable transplanter against manual planting and (2) compare plant survival rates. The study included fabrication, testing, modification, and experiments with farmers, starting from January 2023 to July 2024. The transplanter was fabricated, tested, and improved by the Royal University of Agriculture. Then, two experiments were carried out with a vegetable farming community in Tram Kak District, Takeo Province, Cambodia. Tomato was selected for the testing, choosing seedlings aged four weeks. The randomized complete block design (RCBD) was applied for both experiments with two treatments, manual planting and transplanter use, replicated four times. The results show that the working performance of the transplanter was six times faster than manual planting. Its speed, total field capacity, and planting rate were 1.03 km/h, 0.052 ha/h, and 27 plants/min, respectively, but missed planting was about 4%. Within-row spacing was similar (0.58 m), while using the transplanter made the plants incline at a steeper angle (63°), but could save 81.9% of time, when compared to manual planting. Both treatments had 100% plant survival rates evaluated one week after the transplanting. In short, using the transplanter can save both time and labor, but further assessment should be made with more kinds of fruit vegetable based on different seedling ages, so that the specifications can be confirmed, which is good for actual adoption for farmers.

Keywords: cutting disk; plant survival rate; total field capacity; plant angle; working speed

1. Introduction

Mechanization has long been emphasized for promoting agricultural productivity in Cambodia in the face of labor shortages, as the farm employment rate declined steadily from 48.7% in 2013 to 36.6% in 2022 [1,2]. Many kinds of machinery are imported, or locally developed, to support farm work such as land preparation, planting, or harvesting, mainly focused on a few commodity crops such as rice [3]. However, except for the land preparation [4], vegetable seedlings remain transplanted by hand, which requires repeatable bending, kneeling or stooping, contributing to physical exertion and lower back pain [5]. In general, vegetables are served at least once per day for European families [6], while they are eaten at least five days a week in Cambodia [7]. For healthy balanced diet, daily consumption is recommended [8]. Despite the importance, about 50% of domestic demands still have to be met by imports from Thailand and Vietnam [9]. This issue can be dealt with by any innovations that engage farmers in intensive vegetable farming [10]. Within the whole vegetable production system, mechanical transplanting is considered the most important part besides seedling preparation because it can ensure the right plant depth and spacing [11], which can improve pest management, nutrient and water uptake, and ultimately yield [12].

Many research studies have shown that using vegetable transplanters is superior to manual planting in terms of working performance, resulting in 70%–85% time saving [13,14]. Transplanters are commonly developed as an odd-on system to capitalize on two-wheel, or four-wheel tractors to cut costs. Planting one or two rows at a time is usually targeted, while vegetables such as tomato and eggplant are predominantly selected for the testing. Usual working speed ranges from 1.0 to 3.0 km/h, depending on the type of machine [15–17]. Theoretical field capacity (TFC) is achieved in the range of 0.05–0.15 ha/h, depending on mechanical or automatic operation, while manual planting is 3.4–9 times lower [17,18]. Planting rates are also much higher (16–71 plants/min), when compared to manual planting [7,14,19]. Plant inclination is common, but this does not affect plant growth after transplanting. Using transplanters can cause missed planting during the transplanting process and affect plant survival rates several weeks afterwards, but these problems are reported to be minimal, which is less than 5% [14,20].

To make farmers interested in utilizing a vegetable transplanter, the design should be integrated into already existing power sources. In Cambodia, two-wheel tractors in fact, are main available power for farm machinery, with a 320% increase from 0.15 million to 0.48 million units between 2013 and 2023 [4,21]. With an estimated 2.2 million people engaged in agriculture [22], this means that one in five persons has a two-wheel tractor in their disposal. Because of availability for this power source, it is a huge opportunity to introduce mechanical transplanting to the Cambodian and conceivably for the Southeast Asian markets. Therefore, this study aimed to (1) evaluate the working performance of a locally made vegetable transplanter in comparison with manual planting and (2) compare the plant survival rates one week after the transplanting.

2. Materials and methods

The study consisted of three phases starting from fabrication, testing, modification, and actual experiments on farmer's land. The transplanter was fabricated by the Faculty of Agricultural Biosystems Engineering Department, Royal University of Agriculture in Cambodia (11°30′42.3″ N 104°54′02.3″ E). Testing and modification were repeated from January 2023 to June 2024 to ensure its optimum functionality. Then, two experiments were carried out in collaboration with a vegetable farming community located in Tram Kak District, Takeo Province, about 90 km south of the capital city, between April and July during the late dry and early rainy seasons, respectively. The soils there were sandy loam (55%–60% sand), and to ensure the experimental uniformity, the same soil preparation was made in both experiments. In this study, the seasonal effect was not considered, while the main focus was on the transplanter performance against manual planting only.

2.1. Material

The transplanter could plant one row at a time, and it was developed by modifying a prototype [23] provided by the National Soil Dynamics Laboratory (NSDL) of the United States Department of Agriculture (USDA) in the United States of America (USA). This fabrication was made possible under an open systems agricultural machinery manufacturing (OSAMM). The original prototype was designed to be attachable to a two-wheel tractor, but the operator had to walk behind. Then, improvements included adding a rear seat for the operator, a hydraulic control pedal, and two rear-seat wheels; adjusting the height and width of the transplanter; and installing a hydraulic pump to a two-wheel tractor to regulate the transplanter's height and planting depth (**Figure 1**; **Table 1**). Other parts were made the same, and they included a 24-V DC motor, used to roll a four-pod metal bar back and forth to allow the operator to feed seedlings; a transplanting tube used to convey the seedlings to the ground; a front cutting disk used for cutting residue; two furrow-opening disks; and two depth-adjusting wheels.

Figure 1. Side view of the transplanter photographed during the experiment.

Table 1. Specifications of two-wheel tractor and vegetable transplanter.

Letters	Two-wheel tractor parts	Letters	Transplanter parts
A	Hydraulic oil tank	G	24-V DC battery
B	Hydraulic transmission belt	H	Seedling feeding tube
C	15.5 hp diesel engine	I	Control box
D	Attachment hitch	J	Cutting disk
E	Handle	K	Furrow-opening disk
F	Hydraulic controller	L	Transplanting Tube
		M	Depth adjustment wheel
		N	Hydraulic control pedal
		O	Seat and planting depth adjusting wheel
		P	Operator's seat

2.2. Study design

In the two experiments, the plots were designed employing the randomized complete block design (RCBD) with two treatments, manual planting (T1) and the transplanter use (T2), each replicated four times. Each replicated plot was 1 m × 15 m for the first experiment and 1 m × 20 m for the second experiment, with 5 m preserved on both ends of the plots for easily maneuvering the two-wheel tractor.

Tomato (*Solanum lycopersicum* L.) was selected for the testing, and its seeds were an F1 hybrid purchased from East-West Seed (Cambodia) Company Limited. Seedlings were prepared four weeks in advance, and their average height was 114.0 ± 5.0 mm at the time of the testing. The soil was plowed and levelled, with the seedling beds raised for both treatments. The transplanter required only one operator, but another person periodically assisted in bringing trays of seedlings for the operator to continue the work (**Table 2**, **Figure 2**). Manual planting was also done by one person, so that comparison could be made in terms of working speed, planting rates, missed planting, and time saving. TFC was also calculated and compared. Within-row spacing, plant inclination angles, and plant survival rate one week after transplanting were also measured and compared between the two treatments.

Table 2. Comparison of working performance between manual planting and the transplanter use.

Treatment	Speed (km/h)	TFC (ha/h)	Planting rate (plant/min)	Missed planting (%)	Tim saving (%)
Manual planting (T1)	0.17 ± 0.01	0.009 ± 0.001	4.8 ± 0.39	0	-
Transplanter (T2)	1.03 ± 0.03	0.052 ± 0.001	27.2 ± 1.05	3.9 ± 0.23	81.9 ± 1.52
Ratio*	6	5.8	5.6	-	-
Pr (> F)	< 0.001	< 0.001	< 0.001	< 0.001	-

Note: "*" means the division of the values in T2 by the values in T1.

Working speed was calculated by dividing the working distance, which was the plot length, by the operational time, recorded in each plot. TFC was calculated by multiplying the working width with the working speed [24,25]. In this study, the working width was the spacing between rows, and was considered to be 0.6 m [26]. Meanwhile, planting rates were calculated by counting all the plants in each plot and dividing them by the operational time [14]. Missed planting was calculated by dividing damaged, or misplaced, plants by the total number of plants in individual plots during the experimental process [27]. Within-row spacing and plant angles were measured within each plot using a systematic random sampling method in which the measurement was chosen for every 4 plants [7]. Plant survival rate was evaluated by dividing remaining plants one week after the testing by the total number of plants counted right after the testing [28]. Time saving was calculated by subtracting the time for manual planting and the time for mechanical transplanting and dividing the difference by the time for manual planting [29]. Below are the formulas employed in this study.

$$Working\ Speed\ (km.h^{-1}) = 3.6 \times \frac{Travel\ distance\ (m)}{Operational\ time\ (s)} \quad (1)$$

$$TFC\ (ha.h^{-1}) = \frac{Working\ speed\ (km.h^{-1}) \times working\ width\ (m)}{10} \quad (2)$$

$$Planting\ rate\ (plant.min^{-1}) = 60 \times \frac{Total\ plant\ number\ per\ row}{Operational\ time\ (s)} \quad (3)$$

$$Missed\ planting\ (\%) = 100 \times \frac{Missed\ plants\ per\ row}{Total\ plant\ number\ per\ row} \quad (4)$$

$$Survival\ rate\ (\%) = 100 \times \frac{Remaining\ plants\ per\ row}{Total\ plant\ number\ per\ row} \quad (5)$$

$$Time\ saving\ (\%) = 100 \times \frac{Time_{mp} - Time_{tr}}{Time_{mp}} \quad (6)$$

where: $Time_{mp}$ means time required to finish manual planting per plot. $Time_{tr}$ means time required to finish mechanical transplanting per plot.

(a) **(b)**

Figure 2. Photos of the transplanting experiment between manual planting **(a)** and the use of transplanter **(b)**.

2.3. Data analysis and interpretation

Data were entered into MS Excel and analyzed by using the R Program (version 4.4.0) and RStudio (version 2024.04.2+764), available for free online at https://posit.co/download/rstudio-desktop/. Packages “rstatix” [30] were used to perform analysis of variance (ANOVA) for a mixed-effect model, considering two different experimental periods as a random effect and two transplanting techniques as a fixed effect, while packages “ggplot2” [31] were used to create boxplots. When significant differences were detected at the error level of 5% (95% confidence level), means were separated using the least significant differences (LSD) test, adopting adjusted LSD Bonferroni’s test.

3. Results

Working speed, TFC, planting rates, and missed plantings were compared between the two treatments, and the working performance of the transplanter was much better, about six times greater than manual planting (**Table 2**). The speed of the transplanter was 1.03 ± 0.03 km/h, while the manual planting speed was only 0.17 ± 0.01 km/h. In terms of TFC, the transplanter could do the work faster (0.052 ha/h), while TFC for manual planting was only 0.009 ha/h. The planting rates were 27.2 ±

1.05 seedlings/min and 4.8 ± 0.39 seedlings/min for the transplanter use and manual planting, respectively. Unlike manual planting, using the transplanting could damage or misplace the seedings; however, the missed planting was quite low. This means that in 100 seedlings, only four could be misplaced or damaged.

Plant spacing, angle and survival rate

Within-row spacing and plant angles were compared between the two treatments (**Figure 3**). There was no significant difference in within-row spacing (P = 0.291), while the average spacing was about 0.58 m. In contrast, the plant inclination angle had significant differences (P = 0.002), and it was about 63° for seedlings planted by the transplanter. Meanwhile, the seedlings planted by hand stood more straight up. The differences in plant inclination angles were because seedlings were dropped down for the transplanter, while seedlings planted by hand were handled more carefully.

One week after transplanting, the number of plants per row and plant survival rates were compared between the treatments (**Table 3**). Both plant number per row (P = 0.553) and plant survival rates were not significantly different between the two treatments. The total number of plants per row was 31.0 ± 0.81 plants in a 20-m-long row, and plant survival rates were 100%, evaluated one week after the transplanting.

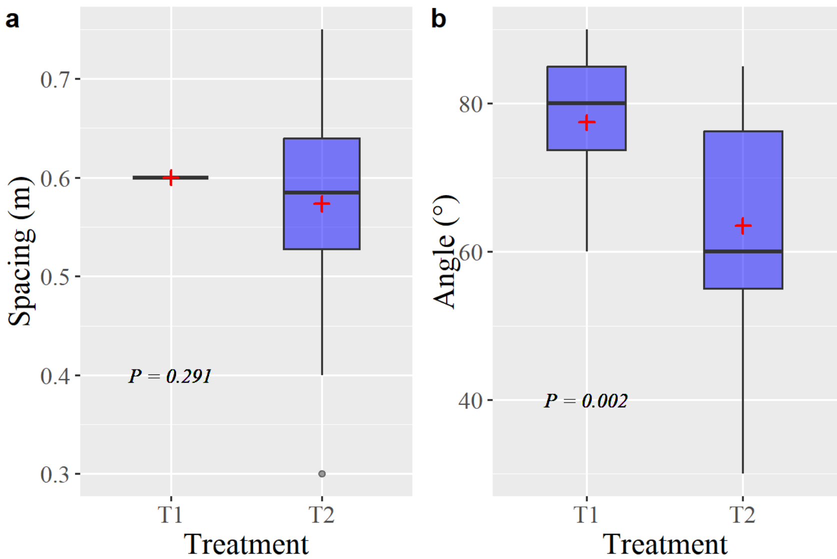

Figure 3. Comparison of plant spacing **(a)** and plant angles **(b)** between manual planting and the transplanter use.

Table 3. Comparison of the total plant number and survival rate within each row.

Treatment	Plants per plot*	Plant survival rate (%)
Manual planting (T1)	31.0 ± 0.52	100
Transplanter (2)	31.1 ± 1.08	100
Ratio	1	1
Pr (> F)	0.553	-

Note: "*" denotes that the number of plants was standardized based on a 20-m-long plot.

4. Discussion

This study was reviewed and compared with several research studies on development and testing of vegetable transplanters, identifying similarities and differences, so that the transplanter being tested can be further improved for better efficiency before being recommended to farmers. Although it was mechanically based, but the comparison was also made with mechanical, semi-automatic, and automatic operations, focused on fruit vegetables only.

Most research studies indicated that the working speed of vegetable transplanters ranged from 1.0 to 3.0 km/h, while slower speed was associated with mechanical operation and higher speed with semi-automatic or automatic operation. Thus, the working speed of the transplanter in this research falls within the common speed range. The transplanter tested in this experiment had TFC of 0.052 ha/h, which was similar to the studies by Durga et al. [17] and Dihingia et al. [14] because they all operated one-row transplanters. In contrast, the TFC was about two times smaller than the studies by Khadatkar et al. [18] and Narang [20]; however, this is because they all operated two-row vegetable transplanters.

Planting rates evaluated in this study was about 27 plants/min, which was 15% lower than the study by Dihingia et al. [14], who also used a two-wheel tractor to operate the vegetable transplanter. Higher planting rates were also found with the studies by Kumar and Raheman [13] (32 plant/min), and the difference was because an automatic two-row transplanting system was integrated into a walk-behind tractor. A more advanced transplanter using a universal chain-type system could achieve a planting rate of 71 plants/min [19]. Missed planting was unavoidable with the use of vegetable transplanters, and it was reported in the range of 2%–5% [13,14,18,20], while the missed planting evaluated in this study was within that range. However, a study by Durga et al. [17] had much higher missed planting rate (about 10%). Time saving achieved by the use of the transplanter in this study was high (81.9%), which was greater than a study by Durga et al. [17] and similar to the studies by Kumar and Raheman [13] and Bhambota et al. [15], whose findings was between 80 and 80%.

Within-row spacing in the study was about 0.6 m, which is similar to the study by Dihingia et al. [14]. However, it was wider than the study by Shama and Khar [32] because they used an automatic planting system to obtain more precise spacing. Meanwhile, the seedlings planted by the transplanter in this study inclined at 60°, leaning more when compared to other studies [15,20]. A week after planting, all plants in the transplanter treatment survived, while many research studies showed that some plant mortality was common. The reason that plant mortality occurred was because those studies did the evaluation 20 days after transplanting [18,20].

5. Conclusion

The transplanter was tested and evaluated against manual planting by conducting two experiments with tomato. It was fabricated locally by just improving the existing prototype from abroad to suit the Cambodian vegetable farming climatic and soil conditions, utilizing a wide availability of two-wheel tractors across the country. In the experiments, the performance of the transplanter was much greater than manual planting although the seedlings may incline more and some missed planting was found, but the plant survival rate was the same, evaluated one week after the transplanting. Much time was saved when using the transplanter due to faster working speed and planting rates. Despite its effectiveness, the transplanter should be further assessed with other kinds of fruit vegetables at different seedling ages, so that more precise specifications can be made and documented, making it ready for actual wide spread adoption by farming community.

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