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Performance of a No-Till Vegetable Transplanter for Transplanting Thai Round Eggplant (*Solanum melongena* L.) in Conservation Agriculture

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Abstract: Vegetables are vital for human health and are consumed five days a week in Cambodia. However, the production cannot meet domestic demands due to labor-intensive farming and production costs related to soil tillage. Mechanization is needed along with soil quality and sustainability improvements by the adoption of CA (Conservation Agriculture). The research aimed to compare the performance of the no-till vegetable transplanter with punch-planter in CA and hand transplanting in CT (Conventional Tillage). The study was conducted at the Royal University of Agriculture, Cambodia, starting from January to September 2020, by firstly growing sunn hemp as a cover crop and then transplanting Thai round eggplant. A randomized complete block design was used with three treatments, replicated three times. Each plot was 2 m by 15 m, with 0.2-m row spacing. The results showed that the transplanter speed was 0.54 $km \cdot h^{-1}$, almost two times the speed of punch planter and 9 times the speed of hand transplanting. The highest working capacity was also achieved with the transplanter. However, different transplanting did not affect plant spacing, or plant density. Plant spacing was 1 m, and plant density varied from 10,300 to 11,500 $plants \cdot ha^{-1}$. Plant growth and yield were also not influenced by the transplanter in CA, or hand transplanting in CT. Average fruit diameter, fruit weight, fruit number, and yield were 38 mm, 31.4 $g \cdot fruit^{-1}$, 15.7 $fruits \cdot plant^{-1}$ and 3.9 $t \cdot ha^{-1}$, respectively. The maximum working area of the transplanter and its break-even area were 25.2 $ha \cdot y^{-1}$ and 18.3 $ha \cdot y^{-1}$, respectively. Using the no-till transplanter may save both time and labor, but its use in combination with CA was unlikely to affect plant growth and yield in the short term.

Key words: Break-even area, CA (Conservation Agriculture), economic analysis, plant growth, roller/crimper, working capacity.

1. Introduction

Vegetables are important part of a healthy diet, promoting human body growth and preventing illnesses related to heart, cancer, or digestion [1]. With such benefits, they are served at least once per day for the European population aged 15 years old and beyond [2]. Similarly, in Cambodia, vegetables are eaten five days a week, but not all of them are supplied locally. To meet its domestic demand, Cambodia imports 70% of daily fruit and vegetables from Thailand and Vietnam [3]. In fact, vegetable farming in Cambodia remains conventional and labor-intensive, and at the time of labor shortage, the situation is even worse [4]. With low profitability, the

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farming population has declined sharply to 37%, while the majority prefers to leave hometowns for work in the city, or abroad [5].

Over the last few decades, vegetables have still been planted by hand and on small scale; as a result, farmland expansion remains slow. This poses a serious threat to the stability of local vegetable production. According to a 2015 report by the World Bank, vegetable production in Cambodia grew only 10%, while maize, cassava, and sugarcane grew 20%, 51%, and 22%, respectively [6]. A lack of farm mechanization is the main reason behind this slow progress in vegetable production. In a 2014 national statistics, agricultural machinery imports increased dramatically from 2004 to 2013, but were mostly directed for land preparation, pumping, or harvesting, not for planting. For example, power tillers increased 648% within that period [7]. Without planting machines, the work remains slow.

Despite the availability of machinery used for land preparation, CT (Conventional Tillage) potentially damages soil structure and soil quality, causing soil moisture deficiency, run-off water with washed out valuable soil particles and nutrients, soil erosion, soil compaction, and reducing soil microbial activities [8]. In addition, this factor also increases production costs related to land preparation, watering, fertilizer and pest. These issues can be tackled by the adoption of CA (Conservation Agriculture) [9]. CA has three main aspects: minimal soil disturbance, permanent soil surface cover utilizing cover crops, and crop diversification. With long-term practices, it can be effective in reversing problems caused by tillage [10]. Due to its benefits, CA was first introduced in Cambodia in 2004, and is active in some provinces such as Battambang and Siem Reap. CA systems for upland crops and rice are practiced on large scale, but CA machinery use is still limited. CA-based vegetable production is done on small scale and by hand, or by simple tools. However, current CA practices increase vegetable yield and profitability in Cambodia [11]. Thus, promotion of small-scale mechanization may contribute toward a bigger impact on local vegetable production and increasing productivity inside the country [12]. In this regard, a vegetable transplanter designed and prototyped by NSDL (National Soil Dynamics Laboratory), the USDA (United States Department of Agriculture), the United States, was brought into Cambodia for testing. It is made specifically for CA purposes and can be easily attached to the Oggun tractor, a 4-wheel small-size tractor, or other light-weight 4-wheel tractors [13]. Its effectiveness should be tested and compared with local vegetable farming practices to provide ease and profit for local economies. The research aimed to compare the performance of the no-till transplanter with punch-planter in CA and hand transplanting in CT, to compare the plant growth and yield, and to perform the economic assessment of the transplanter.

2. Methods and Materials

The research was carried out at the experimental area (11°30′42.3″ N 104°54′02.3″ E), Royal University of Agriculture, Phnom Penh 12401, Cambodia, from January to September 2020. The soil type was sandy loam (58% sand, 32% silt and 10% clay), with pH 5.5, total N 500 $mg \cdot kg^{-1}$, available P 18.8 $mg \cdot kg^{-1}$, and exchangeable K 0.92 meq/100 g. From January to April 2020, there was no rain. Average monthly rainfall increased from 23 mm in May to 149 mm in August 2020. Average daytime temperature ranged from 30 to 33 °C; daily humidity was 66%-81%; and average daytime solar radiation varied from 457 to 563 $W \cdot m^{-2}$ [14].

2.1 Land Preparation and Crop Use

The whole experimental plot was conducted on a sandy loam soil by first preparing and planting the experimental area with sunn hemp (*Crolataria juncea* L.) as the cover crop to establish CA production systems. This cover crop was rolled and crimped by the USDA crimper 60 days after sowing at a blossom growth stage to develop soil mulching (Fig. 3). Two weeks after crimping, termination rate was achieved at 90%; then the whole plot was divided into three sections of each following treatment assigned: (i) vegetable transplanter, (ii) punch-planter, and (iii) hand transplanting. The transplanter and punch-planter were tested in CA systems; meanwhile, hand transplanting was accomplished on the tilled soil by plowing and incorporating the cover crop residue into the soil. In this experiment, Thai round eggplant (*Solanum melongena* L.) was used (Fig. 4). This plant was commonly grown on raised beds with plant spacing of 0.6 m and pH range of 5.5 to 6.5 [15]. In the process, Thai round eggplant seeds were first germinated, and cared for in nursery trays for one month before being used for the experiment. NPK 15:15:15 fertilizer was equally applied two times at rates of 200 kg·ha^{-1} to the field during land preparation and three weeks after transplanting [16].

2.2 USDA Crimper

The roller-crimper used for sunn hemp termination was a patented two-stage roller-crimper developed at NSDL, USDA, located in Auburn, AL 36832, the United States (Fig. 1). It was 1.5 m wide and had two drums. The first drum was in the front, smooth and functioned to flatten cover crops; the second drum functioned to crush them with its six straight crimping bars. Two compression springs (one of each side for the roller's crimping drum) were used to adjust the crimping force to effectively crimp sunn hemp [17].

Fig. 1 Side view of USDA crimper.

2.3 Vegetable Transplanter

The vegetable transplanter used in this experiment was a new prototype developed by NSDL (Fig. 2) [13]. It was a one-row transplanter with six seedling ports that rotate aside on a straight metal bar by means of a 12-V motor; the design was made for CA and attachable to the Oggun tractor. Its dimension was 1.5 m long and 1 m high, with one operator's seat on it. Spacing between dropping ports was 20 cm. In the operation, one more person was required beside the driver for feeding seedlings into the ports.

Fig. 2 Side view of vegetable transplanter.

2.4 Oggun Tractor

Oggun tractor used in this experiment was a second version of the open-system tractor manufactured by Cleber LLC Company in the United States (Fig. 3c). It was 3.2 m long and 2 m wide, weighing 0.8 t. The tractor has a special zero-turn design and its lowest base is 1 m above the ground, with clear views from the operator's seat to the ground during the operation. Its main power is driven by a gasoline engine that generates 22 hp.

2.5 Punch-Planter

The punch-planter used in this experiment was a 1.5-kg hand tool that had a polyvinyl chloride tube, with a steel conical distributor cup (Fig. 4b). The tube

(a) Land clearance for planting sunn hemp

(b) Sunn hemp growth (30 days after sowing)

(d) Dried sunn hemp at 7 days after crimping

(c) Sunn hemp crimped by USDA roller/crimper

Fig. 3 The process for growing and crimping sunn hemp cover crop by USDA crimper before planting Thai round eggplant.

(a) Hand transplanting

(b) Transplanting by punch-planter

(c) Operation of the no-till transplanter

(d) Thai eggplant seedlings

(e) Thai eggplant at vegetative stage

(f) Fruitlets appeared on the plant

Fig. 4 Thai round eggplant transplanting activities by three different methods and growth process.

was cylindrical, 90 cm in length, and 7.5 cm in diameter. The distributor cup was 14 cm in length and was used to punch holes in the soil, so that seedlings can be placed directly into them with the human force.

2.6 Experimental Design and Data Analysis

A RCBD (Randomized Complete Block Design) was arranged for the experiment with three treatments, replicated three times. Each plot was 15 m × 2 m, with row spacing of 0.2 m. Since the tractor width was 2 m, so the plots for the transplanter were to be finished first before transplanting by other methods.

Transplanting speed was determined by dividing the length of the plot by the time the operator spent for planting within that length. Overall time required for finishing each plot was also recorded and then divided by the plot area to calculate the working capacity by converting it to $ha{\cdot}h^{-1}$.

The number of planted seedlings per minute was also counted and compared among the treatments. The process was to count all the plants in each plot and divide them by the time required for finishing those plots. Plant spacing was randomly measured 6 times in each plot, then averaged and compared among the treatments. Plant density was measured by counting all the plants in 10 m^2 in each plot, and then converted to report the number of $plants{\cdot}ha^{-1}$.

For the no-till transplanter, fuel use was measured in each plot, averaged, and the converted to $L{\cdot}ha^{-1}$ for economic analysis. Angles of the titled plants were measured by randomly choosing 6 plants per plot, then averaged and compared among the treatments.

Plant height and plant diameter were measured 7 days after transplanting, by randomly selecting 6 plants per plot, and such measurement process was repeated once a week for 7 weeks. The number of main branches was counted from the stem on 6 random plants per plot. The sampling process started 7 days after transplanting and was repeated once a week for 7 weeks.

Harvesting was done two months after transplanting, and fruit can be picked so many times in case of frequent pruning, continuous fertilizer use, and proper watering [15]. But in this study, the whole harvesting period lasted only three weeks. In this process, the number of fruits per plant was counted on 10 plants per plot after the plants started to produce good-size fruit until the last harvest. Fruit diameter and fruit weight were also measured on 10 plants per plot in every harvest.

To calculate total yield, fruit collected in each harvest was weighed and added until the last harvest. Then the total yield was compared among the treatments. Thai round eggplant can be grown at least twice or replaced with other crops within a year, but the study only compared the yield in one cycle.

Analysis of variance (ANOVA) was performed using R-program 6.3.1 available online. If differences were significant, adjusted LSD (Least Significant Difference) test was adopted at error of 5% to determine differences between the treatments.

2.7 Economic Analysis

2.7.1 Maximum Working Area

Maximum working area was calculated to identify the annual operation limit of machinery. It was assumed that average transplanting time is 4 $h{\cdot}d^{-1}$, with actual working rate of 70%. A fixed planting period is around 8 months and ratio of days available for work per year is 75% [18]. Therefore, the maximum working area is equal to the multiplication of daily working area and the number of days available for work per year.

2.7.2 Break-Even Area

For profitability, a specific size of annual planting area should be clearly determined for any purchased machinery [19]. The main formula components are total FC (Fixed Costs) per year, service fees per hectare (S), and variable costs per hectare (VC). Total fixed costs include depreciation cost, repair, or O&M cost, TIH (Taxes, Interest Rate and Housing). Meanwhile, variable costs include fuel, lubricant, and labor [20]. It is assumed that lubricant is equal to 15%

of fuel consumption. Depreciation costs are based on PV (Present Value); SV (Salvage Value), equal to 10% of PV; and a machine lifespan [21]. The lifespans for the Oggun tractor and the vegetable transplanter are 10 years and 6 years, respectively.

$$D = \frac{PV - SV}{L} \tag{1}$$

where D represents depreciation cost (USD·y^{-1}), PV is present value (USD); SV is salvage value (USD); and L is a machine lifespan (y).

O&M costs are assumed to be 2% of the present value, and TIH is assumed by 1.5% of the present value [22]. Service fees used in this calculation are based on actual labor fees paid for manual vegetable transplanting in Cambodia at rates of 10 USD·$person^{-1}$·d^{-1}. Normally, a hectare of land requires 20 persons for manual vegetable transplanting; therefore, service fees for the machine were assumed to be equal to labor fees, which were 200 USD·ha^{-1}. In this regard, Break-even area is shown as Eq. (2):

$$BE = \frac{\mathrm{FC}}{\mathrm{S-VC}} \tag{2}$$

where BE represents break-even area (ha·y^{-1}); FC is total fixed cost per year (USD·y^{-1}); S is service fee or additional return per hectare (USD·ha^{-1}); and VC is variable cost per hectare (USD·ha^{-1}).

3. Results and Discussion

3.1 Transplanting Speed

There were significant differences in transplanting speed among the treatments ($p < 0.001$; Table 1). Average speed for the transplanter, punch-planter, and hand transplanting was 0.54 km·h^{-1}, 0.30 km·h^{-1} and 0.06 km·h^{-1}, respectively. It was observed that the transplanter was the fastest due to mechanization aid, whereas hand transplanting was the slowest. The transplanter speed in this study was similar to research by Hassen and Almubarak [23], as both cases had a delay time for feeding seedlings. However, the speed was lower, when compared to Tsuga and Kumar & Raheman, whose tranpslanters were operated at 0.7-1.3 km·h^{-1} [18, 24]. The reason was that the studied transplanter needed a synchronous movement between the transplanting operator and the seedling ports driven by a motor that moved slowly. Faster motor movement might misplace the seedlings. In contrast, the other two transplanters used an automatic system that could better guarantee a plant feeding mechanism.

3.2 Planting Rate

Significant differences were observed among the treatment ($p < 0.001$), and the transplanter had the highest planting rate, followed by the punch-planter (Table 1). Planting rates for the transplanter, punch planter, and hand transplanting were 8.5, 5.3 and 1 plant·min^{-1}, respectively. This means that mechanized transplanting reduced working time on the field. Still, the result remained low, when compared to a two-row transplanter developed by Dihingia, et al. for tomato, chilli, and eggplant, with planting rates of 31 plants·min^{-1} [25]. Their performance was better because of more planting rows, but the main reason was that they used a power tiller that needed only one operator to walk behind easily, while feeding the seedlings. With automatic systems, a two-row vegetable transplanter could even reach 60 plants·min^{-1} [18]. In addition, higher planting rates with a single-row transplanter can also be achieved, when the operation becomes more and more automatic. The rates can vary from 60 to 120, or up to 300 seedlings·min^{-1} [26, 27].

3.3 Working Capacity

The working capacity was evaluated for the three transplanting methods (Table 1). It was observed that differences were significant among the treatments ($p = 0.024$). The highest working capacity was achieved with the transplanter, being 0.050 ha·h^{-1}, while the use of punch-planter and hand transplanting was only 0.025 ha·h^{-1} and 0.006 ha·h^{-1}, respectively. The time required for planting by the transplanter was half the time required for the punch-planter. When using the punch-planter, the operator had to walk and carry, resulting in faster exhaustion, fatigue, and lower working capacity. In this study, the working capacity of the no-till transplanter was relatively high, when compared with Dihingia, et al. [25] whose finding was 0.045 ha·h^{-1}, but it was lower than the recommended vegetable transplanting within the range of 0.082 to 0.090 ha·h^{-1} [23]. The punch-planter had a better working capacity, when compared to a similar study by Lokhande, et al. [28]. The difference was because of the speed at which the operator fed the seedlings.

3.4 Planting Angle

Table 1 presents the angle at which plants tilted during the transplanting. Significant differences were detected among the treatments ($p < 0.001$). Seedlings measured in the punch-planter and hand transplanting treatments stood more vertically from 73.9° to 82.5°. Meanwhile, plant angle was 42.4° when the vegetable transplanter was used. The reason is that the seedlings were dropped through the transplanter ports from the height of 1 m above the ground. In contrast, seedlings planted by punch planter dropped into the ground through the tube that had a close contact to the soil. Additionally, seedlings planted by hand were right on the ground and earth was piled up around their bases, so they were more vertical and secure.

3.5 Plant Spacing

Plant spacing was not significantly different among the treatments ($p = 0.360$; Table 1). In such a case, it was observed that all the treatments had similar plant-to-plant spacing of about 1 m. Plant spacing in this experiment tends to be high, when compared to the recommended spacing for Thai round eggplant farming. The optimal spacing is about 0.6 m apart from plant to plant [15]. An automatic vegetable transplanter could limit plant spacing to 0.3 m [26]. However, such spacing was not possible for the transplanter in this study because it had a 1.5-m, six-port bar that was moved aside back and forth by the motor. To have smaller spacing, faster forward movement is required, but this may not enable the planting operator to timely feed the seedlings into the ports. Furthermore, as yield is affected by the number of plants per plot, spacing for the punch planter and hand transplanting was set equal to that of the transplanter, so that final yield could be compared.

Table 1 Performance of different transplanting methods (mean ± SE).

Treatment	Speed (km·h^{-1})	Number of plants·min^{-1}	Working capacity (ha·h^{-1})	Plant angle (°)	Spacing (m)	Plant density (plant·ha^{-1})
Vegetable transplanter	0.54^{a} ± 0.03	8.5^{a} ± 1.01	0.050^{a} ± 0.004	42.4^{b} ± 5.56	0.9^{a} ± 0.07	$10{,}300^{a}$ ± 630
Punch-planter	0.30^{b} ± 0.01	5.3^{b} ± 0.25	0.025^{b} ± 0.001	73.9^{a} ± 2.13	1.0^{a} ± 0.1	$11{,}500^{a}$ ± 290
Hand transplanting	0.06^{c} ± 0.01	1.0^{c} ± 0.05	0.006^{a} ± 0.001	82.5^{a} ± 1.84	1.0^{a} ± 0.1	$10{,}800^{a}$ ± 250
CV (%)	14.27	25	10.5	22.81	14.98	8.28
p-value	$< 0.001^{***}$	$< 0.001^{***}$	0.024	$< 0.001^{***}$	0.360	0.221

Different lower-case letters at each column indicate significant differences between the treatment means. The sign '***' represents significance level at 0.001.

3.6 Plant Density

Transplanting methods had no effect on plant density ($p = 0.221$), as seen in Table 1. Plant density varied from 10,300 plants·ha^{-1} in the vegetable transplanter to 11,500 plants·ha^{-1} in the punch-planter. When compared with similar varieties, long eggplant, the plant density in this study was acceptable because it fell within the recommended range 7,000 to 13,000 plants·ha^{-1} [29].

3.7 Plant Height

Plant height in the transplanter treatment was the greatest from weeks 3 to 6, followed by the hand transplanting (Fig. 5a). In contrast, slower growth rates were observed in the punch-planter. All treatments had similar plant height in week 7. Plants grew slowly in the first two weeks after transplanting because plants needed time for recovery to adapt to new soils. In week 3, plant height was significantly different among the treatments ($p = 0.020$). Plant height in the transplanter, punch-planter, and hand transplanting was 17 cm, 12 cm, 13 cm, respectively. From weeks 4 to 6, plants grew quickly. Still, the greatest height was in the transplanter. In week 6, plant height for the transplanter, punch planter, and hand transplanting was 62.5, 60.4 and 60.9 cm, respectively. In week 7, plant height was around 72 cm in all treatments. The plant had a relatively greater height, when compared to commercial seed, which is a round 50 cm [30].

3.8 Plant Diameter

No significant differences were observed between the treatments from weeks 1 to 7 (Fig. 5b). This means that using different transplanting methods did not affect the growth of plant diameter. In the trend, plant diameter grew constantly from weeks 1 to 7, from 0.3 cm in week 1 to 1.5 cm in week 7. However, the findings had a smaller stem diameter, when compared to the standard size, around 3.8 cm [31].

3.9 Number of Branches

There were no significant differences in the number of main branches from weeks 1 to 7 (Fig. 5c). It was observed that in the first two weeks, there was no new branch that emerged. This was because plants needed time to overcome stress. Then, the number of branches increased constantly from weeks 3 to 6, from 3 to 11 branches. After that, it leveled off in week 7 at 11 branches.

3.10 Fruit Diameter

There were no significant differences among them, and fruit diameter measured varied from 36.3 to 39.7 mm (Table 2). Fruit diameter seems to be indifferent among the treatments, because the harvested fruit size was based on the collector's random observation and by following the desired market size. Bigger fruit was not preferred, except for a case of processing. It was expected that if the harvesting period was extended, fruit to be harvested might grow bigger and bigger.

3.11 Fruit Weight

It was observed that there were no significant differences in fruit weight among the treatments (Table 2). This may be a result of the similarity in average fruit size among the treatments. Average fruit weight ranged from 30 to 33 $g \cdot fruit^{-1}$.

3.12 Number of Fruits per Plant

There were no significant differences in fruit number per plant, and it was observed that the average fruit number per plant was around 15-16 fruits (Table 2). If the harvesting period was extended longer than three weeks, fruit number might be greater than this.

3.13 Fruit Yield

Significant differences were not observed among the treatments, although the yield was low in hand transplanting in CT. Therefore, the findings show that average yield was not different, and ranged from 3.6 to 4.1 $t \cdot ha^{-1}$. This was because of no difference in branch number and fruit number on the plant.

3.14 Maximum Working Area

Table 3 presents the maximum working area estimated for the performance of the transplanter. With the hourly working capacity of 0.05 $ha \cdot h^{-1}$, daily working hours of 4 h, and actual working rate of 70%, the daily working capacity was expected to be 0.14 $ha \cdot d^{-1}$. Transplanting could be done for 8 months a year, and available time for work was 75%, so the number of days available for annual work was estimated to be 180 d. Thus, the maximum working area the no-till transplanter might achieve was estimated to be 25.2 $ha \cdot y^{-1}$. It does not necessarily mean that when using the machine, individual farmers had to own the same size of the calculated area. With smaller areas, it is

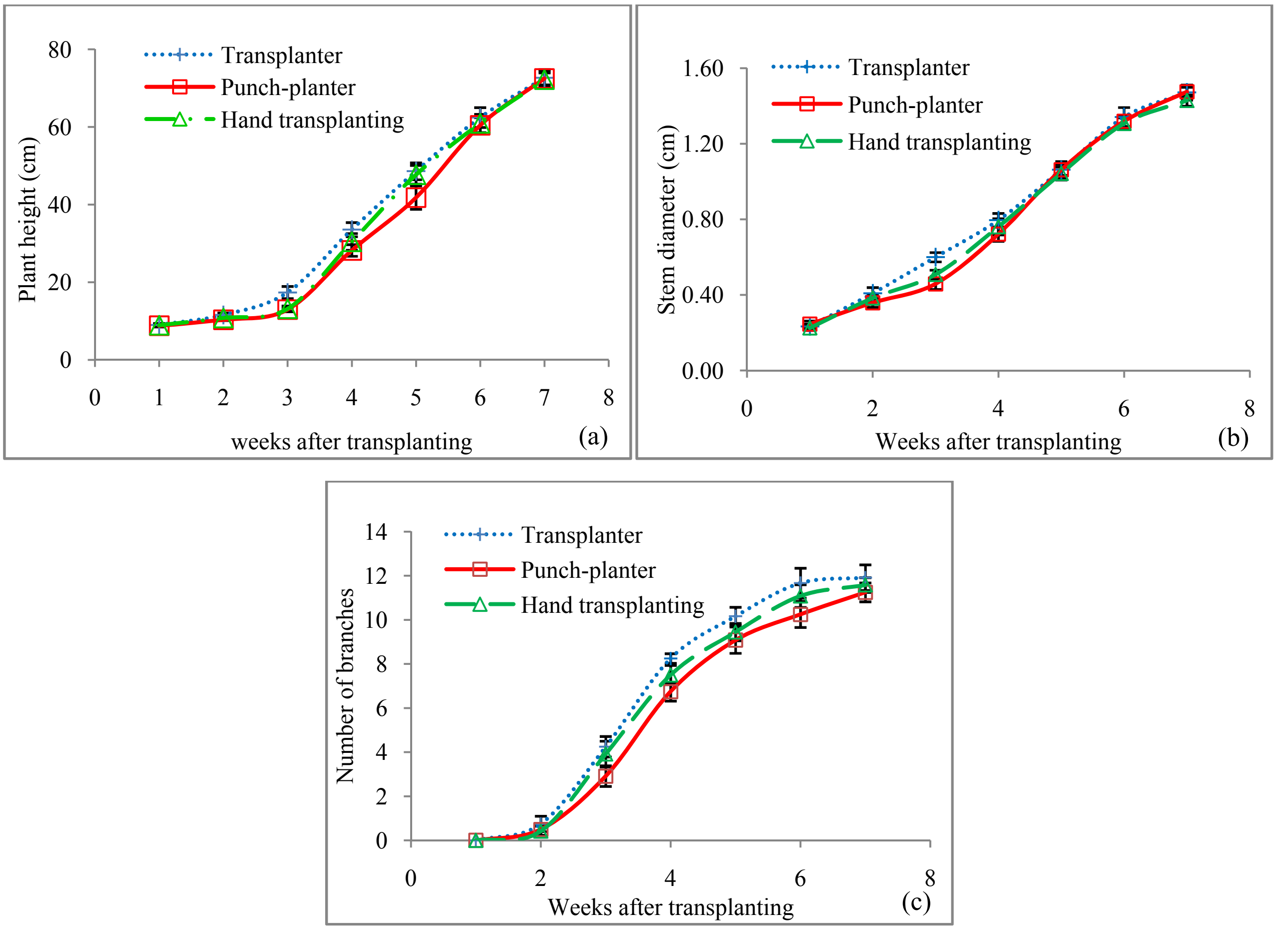

Fig. 5 Comparison of plant height (a), stem diameter (b), and number of branches (c) (mean ± SE) examined among different transplanting methods once a week for 7 weeks.

Table 2 Comparison of fruit diameter, fruit weight, fruit number per plant, and yield per cycle among transplanting methods using (mean ± SE).

Treatment	Fruit diameter (mm)	Fruit weight (g·fruit^{-1})	Number of fruits·plant^{-1}	Yield (t·ha^{-1})
Vegetable transplanter	37.9 ± 0.83	32.7 ± 1.26	15.8 ± 2.94	4.1 ± 2.94
Punch-planter	36.3 ± 1.09	31.1 ± 1.22	15.9 ± 2.30	4.1 ± 2.30
Hand transplanting	39.7 ± 0.79	30.4 ± 1.46	15.5 ± 2.05	3.6 ± 2.05
CV (%)	14.12	25.38	31.84	23.6
p-value	0.320	0.443	0.991	0.244

necessary to double, or multiply the planting seasons, or to provide planting service to achieve bigger areas. The finding was much lower, when compared with the study by Tsuga [18], whose result doubled due to automatic systems. Moreover, the working capacity of that transplanter was also two times that of the tested transplanter. Nevertheless, the maximum working area of the tested no-till transplanter was considered better than a manually operated vegetable transplanter [32].

3.15 Break-Even Area

In Table 4, total depreciation costs were 1,575 USD·y^{-1}, with 70% for the Oggun tractor. TIH and O&M costs were 233 and 310 USD·y^{-1}, respectively, and Oggun tractor accounted for 80%. Transplanting by the Oggun tractor consumed 12.4 L·h^{-1}, or 11.2 USD·ha^{-1}; then lubricant costs were estimated at 1.7 USD·ha^{-1}.

Table 3 Determination of maximum working area achieved by the use of no-till vegetable transplanter and Oggun tractor.

Description	Unit	Oggun-mounted transplanter
Working capacity per hour	$ha \cdot h^{-1}$	0.05
Working capacity per hectare	$h \cdot ha^{-1}$	20
Working hour per day	$h \cdot d^{-1}$	4
Actual working rate per day	%	70
Time available for work per day	$h \cdot d^{-1}$	2.8
Working area	$ha \cdot d^{-1}$	0.14
Fixed planting period	$month \cdot y^{-1}$	8
Number of working days per year	$d \cdot y^{-1}$	240
Ratio of days available for working	%	75
Number of days available for working	$d \cdot y^{-1}$	180
Maximum working area	$ha \cdot y^{-1}$	25.2

Table 4 Calculation of break-even area the transplanter achieved on annual basis.

Cost	Unit	Oggun tractor	No-till vegetable transplanter	Total
Present value	USD	12,500	3,000	15,500
Salvage value	USD	1,250	300	1,550
Lifespan	y	10	6	
Fixed cost (FC)				
Depreciation cost	$USD \cdot y^{-1}$	1,125	450	1,575
O&M cost	$USD \cdot y^{-1}$	250	60	310
TIH	$USD \cdot y^{-1}$	188	45	233
Total FC	$USD \cdot y^{-1}$	1,563	555	2,118
Variable cost (VC)				
Fuel	$USD \cdot ha^{-1}$	11.2		
Lubricant	$USD \cdot ha^{-1}$	1.7		
Labor	$USD \cdot ha^{-1}$	71.4		
Total VC	$USD \cdot ha^{-1}$	84		
Service fees (S)	$USD \cdot ha^{-1}$	200		
Break-even area (BE)	$ha \cdot y^{-1}$	18.3		

Labor cost was estimated to be 71.4 $USD \cdot ha^{-1}$. Therefore, it is expected that the break-even area for the Oggun-mounted vegetable transplanter was 18.3 $ha \cdot y^{-1}$. When compared with the maximum working area, the difference is not much, only about 6.9 ha difference. To increase profitability, two options can be thought of before deciding to use the transplanter. The first option is to reduce the machine investment costs by purchasing a tractor with a lower price. Lower prices are closely associated with locally made machinery, or second-hand products. Another option is to increasing annual working days. In this study, transplanting work was assumed to be done in 8 months, and if the working period increases, so does the maximum working area. In doing so, it is possible to make more profits when operating the machine.

4. Conclusion

The performance evaluation of the no-till vegetable transplanter mounted on the Oggun Tractor was performed by planting Thai round eggplant in CA production systems that used sunn hemp as a cover crop, in comparison with the punch-planter in CA and hand transplanting in CT.

The results indicate that the use of transplanter tends to affect operational speed, number of plants per minute, working capacity, when compared with other treatments, as its performance was much faster. This tends to save both time and labor. However, the seedlings planted by the no-till transplanter are likely to tilt more.

Plant spacing, plant density, fruit weight, number of fruits per plant, and overall yield were not likely affected by the use of the transplanter. This means that using any methods of transplanting, the growth and yield were not different, either in CA or in CT, in case the plants are cared for and watered properly. However, in the short term, CA might not show any effects since soil improvements need time.

For profitability, the Oggun-mounted transplanter should be used to cover a farm area of 18.3 $ha{\cdot}y^{-1}$, while its maximum working area is only 25.2 $ha{\cdot}y^{-1}$. Therefore, increasing planting seasons or providing planting service should be considered before deciding to purchase the transplanter.

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