Research article

Efficiency of No-till Transplanter Use in Conservation Agriculture Tomato (*Solanum lycopersicum* L.) Production Systems in Battambang Province, Cambodia

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Abstract Cambodian farmers have gradually started growing no-tilled vegetables, but production is low due to manual practices. No-till transplanter use in Conservation agriculture (CA) can boost small-holder vegetable production and decrease production costs. Thus, this paper aimed (1) to compare the working capacity of a no-till vegetable transplanter with punch planter work in CA and hand planting in CT (Conventional tillage) and (2) to assess the economic performance of the equipment. The experiment was conducted in Battambang province, Cambodia, from January to August 2022. The experiment was arranged in RCBD with three treatments, plating using a no-till vegetable transplanter, punch planter, and manual or hand plating, each replicated four times. Tomato seedlings were used for this experiment. As a result, the no-till vegetable transplanter's working capacity was shown to be 16 h/ha, or nearly three times faster than punch plater and hand plating and could transplant 10 seedlings per minute. Plant spacing and density were similar for all the treatments at 0.8 m, and the plant density of the hand planter and punch planter was 11,660 plants/ha compared to the no-till transplanter at 9,921 plants/ha. Economic recovery is attainable at the break-even point of 18.20 ha/y for the transplanter.

Keywords conservation agriculture, cover crop, economic recovery, transplanter, hand planting

INTRODUCTION

Farmland areas in Cambodia increased from 27% in 2000 to 32.8% in 2020 (176,520 km^2) (World Bank, 2022); however, the main local vegetable market is dependent on import, which represent more than 65% of the domestic demand (Chea, 2022). Some challenges that have been identified include labor force outflows from the agricultural sector to the construction and industrial sectors, and the lack of mechanization to support farm work, with annual labor demand in vegetable production reaching 169.85 days/ha (World Bank, 2015). Conventional tillage (CT) practices in vegetable production may cause soil disturbance, soil nutrient loss, and unsustainable farming. To minimize these issues, conservation agriculture (CA) is practiced in line with three principles: minimum tillage, permanent soil organic cover, and crop diversification. These components work well with the support of farm machinery and tools, which can address labor shortages, improve productivity, and save time and cost. Sustainable mechanization considers economic, social, environmental and cultural aspects, when contributing to the sustainable agriculture production (FAO, 2022). In Cambodia, CA was established in 2004 and launched as a key development target in Battambang province (CASIC, 2020), and later adopted in vegetable production (Manuel, 2015). A priority target of mechanization is the propagation of no-till vegetable transplanter (NVT) by the National Soil Dynamic Laboratory (NSDL). An NVT funded by USAID was imported to Cambodia for adaptation with small-holder farmers (Jones et al., 2019). The performance of the NVT has demonstrated high field effectiveness, eases planting labor in CA, and is economically affordable for small and medium-sized farmers.

OBJECTIVE

The objectives of this study were (1) to compare the working capacity of a no-till vegetable transplanter with a punch planter work in CA and hand planting in CT and (2) to assess the economic performance of the no-till vegetable transplanter.

METHODOLOGY

The experiment was conducted in the upland area in Ratanak Mondul district, Battambang province, Cambodia (12.93062, 102.85632) from January to August 2022, where average temperature and rainfall were from 25.80°C to 29.60°C and 14 mm to 200 mm, respectively (Climate Data, 2021). The soil type is clay loam, with a pH range from 7.00 – 7.15.

Experimental Design

The whole experimental plot was 175 m^2 and planted with a mixture of two cover crops: sunn hemp (*Crotalaria juncea* L.) and millet (*Cenchrus americanus* L.) at the rate of 25 and 15 kg/ha, respectively. The experimental design was a randomized complete block design (RCBD) that consisted of three treatments, namely NSDL NVT, no-till punch planter, and CT hand planting, each of which had four replicates. Thus, at the age of 60 days, the cover crop was crimped for no-till plots and plowed for CT plots. The size of each replicate was 5 m x 25 m, with a row space of 2 m for easy tractor turning. One month after crimping/disking, tomato seedlings (*Solanum lycopersicum* L.) were prepared for planting at the age of 6 weeks for all the treatments.

No-Till Vegetable Transplanter and Oggun Tractor

The NVT is a single-row transplanter mounted with a tractor and was designed for the no-till vegetable transplanting. In operation, it needs two people, one driving the tractor and one operating the no-till vegetable transplanter. In the process, the no-till planter is working dependent mechanisms, as the main power source of the transplanter is a DC electric motor with a speed control box. The motor transmits force by a roller chain link to a rack and pinion gear, which transfer the rotational motion to the linear motion of a stainless-steel bar comprising six vertical rack holders. The seedling bar continues to travel from left to right when the toggle switch of the control box shifts, and the direction also changes automatically. In addition, the ports that are attached to the rack hold the seedling until the bottom spring-loaded door is opened to allow the seedlings to fall by gravity into the kicker chamber. The spring-loaded kicker positions the plant in the furrow previously opened by the no-till disc coulter and double disk openers. The two closing wheels press the sides of the furrow to the plant to provide sufficient root-to-soil contact for optimum growth of the seedling (Kornecki and Kichler, 2018).

The Oggun II tractor is an open-source design with special consideration for small-scale farming applications. The tractor is operated by a hydraulic system for rear-wheel drive, weighing around 725 kg, and uses as its power source a 16.5-kW Honda GX690 gasoline engine (Think Oggun, 2020). The dimensions of the tractor are 3.71 m long x 2 m wide, with 0.73 m ground clearance and mid-mount implement clearance of 1.15 m for a clear view of the front working implement during operation (Kornecki et al., 2012).

Punch Planter

The punch planter used in the experiment was the Weasel Bulb Planter, designed to work easily with a comfortable T-bar grip. The process starts with pushing the handle and placing a foot on the footplate to press the sharp blade cylinder and pointed tip into the ground, allowing it to slide into the ground effortlessly and the cores to pop out with ease. The Weasel Bulb Planter weighs less than 1.24 kg and is about 0.90 m long (Garden Weasel, 2022).

Data Collection

During the operation of NVT, transplanting speed, field capacity, number of plants per minute, plant density, plant angle, plant spacing, missing plant, and fuel consumption of tractor were collected for calculating variable cost. The speed was measured by recording three forward times in each plot, which were converted to operation speed. The field capacity depends on the total time of full operation and working width for converting to a hectare (FAO, 1994). Fuel consumption on each plot was measured by every vegetable transplanter after finishing each plot; firstly, the gasoline tank was filled fully after finishing the operation, and the tank was refilled by the measuring glass (Hancock et al., 1991).

$$\textit{Field capacity (ha } h^{-1}) = \frac{Total\ cultivation\ land\ (ha)}{Total\ cultyvation\ time\ (hr)} \quad (1)$$

The number of plants per minute was selected from four rows in 25 m to count the plants in each row and divided by time spent in each row. Plant density was measured by counting the number of plants in each plot and report in a hectare. Plant angle was measured in ten samples by using an angle ruler. Plant spacing was measured in 10 samples, and if the plant spacing was bigger than 1.5 meters, it was counted as one missing plant. The missing plants refers to the percentage of seedlings damaged or wrongly planted in each row.

Break-Even Point

Break-even point analysis (BEP) is the relationship between fixed costs, variable costs, and returns. The BEP is defined as an investment that generates a positive return and can be determined graphically or with simple mathematics. BEP computes according to the following formula:

$$BEP\ (ha\ y^{-1}) = \frac{Total\ fixed\ costs\ (USD\ y^{-1})}{(Service\ Fee\ (USD\ ha^{-1}) - variable\ cost\ (USD\ ha^{-1})} \quad (2)$$

Fixed costs include equipment depreciation, interest costs, TIH (Taxes, insurance, and housing), and general overhead expenses. Depreciation cost depends on a salvage value of 10%, a lifespan of 10 years, and a new condition value, and to simplify calculation TIH: 1% is determined lumped together. The variable cost includes the cost of goods sold or production expenses such as labor and power costs, feed, fuel, and other capital asset investments (Edwards, 2015; Gutierrez and Dalsted, 2012).

Data Analysis and Interpretation

The collected data was analyzed by using analysis of variance (ANOVA) in R (version 4.2.2) and RStudio 4.1.0, which are free software and available online. If the test was significantly different, the least significant difference (LSD) was performed to separate the means in each treatment with an error level of 5% (confidence level of 95%).

RESULT AND DISCUSSION

Transplanting Speed and Field Capacity

According to Table 1, transplanting speed was significantly different ($p<0.001$). The average speed of hand-planting, punch-planter, and NVT was 0.140 km/h, 0.150 km/h, and 0.625 km/h, respectively. The result indicated that using the NVT was 3 times faster than other methods, while the speed of punch-planter and hand-planting was similar. However, the operational speed of the NVT used in this study was lower when compared to an automatic tomato transplanter studied by Zamani et al. (2016), whose operation was in the range of 1-2 km/h.

The field capacity of NVT was significantly ($p<0.001$) higher than the hand and punch planter at 0.07 ha/h, 0.01 ha/h, and 0.02 ha/h respectively (Table 1). The labor requirement for planting tomatoes a hectare per day using the NVT corresponded to 16 h/ha. Meanwhile, hand planting and punch planter required 68 h/ha (Table 1). In line with our study, other study also mentioned the benefits of a transplanter; for instance, the field capacity of a single-row walking transplanter was found to be 22 h/ha, which is equivalent to an 88% labor reduction over hand planting (Park et al., 2005). Likewise, another study revealed that the field capacity was approximately 0.0343 ha/h (Dhupal and Sahu, 2020).

Number of Plants per Minute and Plant Density

Planting rate was shown that the transplanter provided the highest number of seedlings, mostly 10 plants /min, significantly ($p<0.001$) from hand, and punch planter was planted approximately 2.80 plants /min (Table 1). Based on observations, transplanting mechanization improved the time seeding rate compared to man work (manual work).

The difference in plant density was significant ($p<0.001$); the transplanter planted fewer seedlings than hand planting and the punch planter at 9,921 plants/ha, 11,666 plants/ha, and 11,666 plants/ha, respectively (Table 1). However, the plant population still followed the recommended tomato planting density of between 8,000 and 14,000 plants/ha (Jones, 1999).

Plant Angle and Plant Spacing

The plant angle was significantly different ($p<0.001$) between the tested methods. The hand planting and punch planter had a bigger angle than the NVT (Table 1) with angles of 76.40^{o}, 79.70^{o}, and 58.80^{o}, respectively. The reason the NVT made smaller angles was that the angle was affected by the seedling root being soft with gravitational drop off about 1 meter high into the furrow, making the seedling unstable. Another reason is that the soil clods on the surface were not broken into small pieces properly or smoothly; when the closing wheel turned the soil to fill the roof in action, the plant moved the geometry.

The difference in plant spacing was not significant among the planting treatments, and spacing was around 0.80 m for each treatment (Table 1). It was bigger than the FAO standard for tomato plant spacing in the field, which ranges from 0.30 m to 0.60 m. The serial performance of a two-wheel tractor mounted with a row no-till plant transplanter evaluated between 2017 and 2019 delivered tomato spacing of between 0.59-0.70 m (Kornecki and Reyes, 2020).

Missing Plant Ratio and Fuel Consumption

Missing plant ratio (plant damage) was measured in NVT plot where the space between larger than 1.5 m was found to be 15.83% per hectare. Dhupal and Sahu (2020) recorded a missing plant ratio of less than 5.33% at three different speeds 0.29 km/h, 0.28 km/h, and 0.27 km/h. Fuel consumption of the Oggun implement with NVT for operation was at 4.20 L/hr at 90% power.

Table 1 Performance and plant physics for different planting methods

Residue retention	Speed (km/h)	No. of plants (per min)	Plant no. (plants/ha)	Field capacity (ha/h)	Plant angle (˚)	Plant spacing (m)
Hand planter	$0.14^{b} \pm 0.00$	$2.73^{b} \pm 0.18$	$11{,}666^{a} \pm 5$	$0.01^{b} \pm 0.00$	$76.35^{a} \pm 7.73$	0.80 ± 7.73
Punch planter	$0.15^{b} \pm 0.00$	$2.82^{b} \pm 0.13$	$11{,}666^{a} \pm 8$	$0.02^{b} \pm 0.00$	$79.70^{a} \pm 7.17$	0.80 ± 7.17
NSDL NVT	$0.61^{a} \pm 0.03$	$9.84^{a} \pm 2.34$	$9{,}921^{b} \pm$	$0.07^{a} \pm 0.00$	$58.85^{b} \pm 17.6$	0.80 ± 17.6
p-value	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	0.95
CV (%)	7.43	25.76	11.41	11.41	16.47	N/S
Overall mean						0.79

** Means significant at p<0.05, ** significant at p<0.01, *** significant at p<0.001,*
Different alphabetic letters are used to denote significant differences between the treatments

Break-even Point (BEP)

The initial investment cost of the Oggun tractor was 12,500 USD (Table 2). Its annual working hours were determined at 150 h/year for 15 years of economic life with a salvage cost of 10% per year, accounting for a depreciation cost of 1,125 USD/y. The service fee sum of the total operation and ownership cost was 213.75 USD/ha, in terms of 10 USD/day of labor cost (Carter et al., 1997). The investment cost of the NSDL NVT was 3,000 USD for a unit in new condition with a 6-year life span, 50 annual hours, and a depreciation cost of 450 USD/ha. The break-even area of the Oggun tractor-mounted NVT was 18.20 ha/y. Hin et al. (2020) found a similar result with a break-even area was 18.30 ha/y.

Table 2 Calculation of annual break-even area for the Oggun mounted transplanter

BE	Unit	Oggun	NVT	Total
Investment cost	USD	12,500.00	3,000.00	15,500.00
Salvage value	USD	1,250.00	300.00	1,550.00
Economic life	y	10.00	6.00	-
Annual hour	h/y	150.00	50.00	-
Total FC	USD/y	1,443.75	526.50	1,970.25
Total VC	USD/ha	105.52	-	-
Service fees	USD/ha	213.75	-	-
BE area	ha/y	18.20	-	-

CONCLUSION

An important trend in promoting sustainable labor and vegetable production in Cambodia is the widespread implementation of CA by small-scale farmers, who are employing small and mid-size agricultural machinery. The NVT arrangement on an Oggun tractor showed that it could reduce hard labor and time by a factor of three as compared to manual labor. The planting experiment's findings showed that, in comparison to punch and hand planters, the NVT method's shortcomings included a higher percentage of missing plants and smaller plant angles. However, from an economic standpoint, the result was still acceptable. The break-even point – a measure of the method's economic performance – is the most crucial component in determining the viability of conservation agricultural gear. According to the study, the tested NVT setup's break-even point was 18.20 ha/y with a service price of 213 USD/y. This suggests the NVT owner should have more planting space than is necessary or the option to provide NVT services to other farmers.

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