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PRELIMINARY FIELD AND COST EVALUATIONS OF A PROTOTYPE OIL PALM SEEDLING TRANSPLANTER

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ABSTRACT

Mechanized field transplanting of oil palm seedling with the trailed type transplanter resulted with a planting capacity of 99 seedlings/man-day or 0.62 ha man-day^{-1} as compared to 0.28 ha man-day^{-1} or 45 seedling man-day^{-1} with the manual transplanting planting system; an improvement of 2.2 times. The quality of planting with the mechanized transplanting system indicated insignificant variations in leaning angles, spacing, row alignment, pulling forces and height increment among planted seedlings. Almost 99.45% of the total seedlings planted by the transplanter were categorized under upright palms. The average spacing between adjacent planted seedlings was 8.56 m and exceeded only by 0.06$\pm$0.02 m from the proposed distance, whereas row alignment of planted seedlings variations was 1.78$\pm$0.33 cm along planting lines in each row. The soil around the planted seedling was almost uniformly compacted with an averaged pulling force of 347.39$\pm$20.27 N per planted seedling. The entire seedlings were successfully planted in the field by the transplanter with averaged palms height increment of 18.6$\pm$2.45 cm after the first month of planting and 22.5$\pm$3.34 cm after the second month of planting. The estimated planting cost is RM 2.11 per seedling with mechanized transplanting as compared to RM 2.26 with manual transplanting; a reduction of 6.64%.

Keywords: mechanization, machinery, transplanter, tree seedling, oil palm cultivation.

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INTRODUCTION

Various types of transplanting machines are now available in the market. However, until today there is no machine that has been designed, developed or adopted for oil palm seedling. Most of transplanting machines reported in the literature were for cereal crops, vegetable crops, and only a few of the machines were for tree crops and shrubs.

The current capacity for planting of oil palms in Malaysia according to Hartley (1977) is 16.5 man-day ha^{-1}. The task imposed extensive stress and fatigue to the field workers and thus become an unattractive job for others to pursuit. The employed planting practices are inefficient and unproductive since the planting holes are prepared a few days before actual planting commence. The capacity for hole digging and planting as stated by Rankine and Fairhurst (1999) on mineral soil under optimum work rate is 45 palms man-day^{-1}. When digging operation is excluded, the capacity for planting alone on the same conditions is 90 palms man-day^{-1}. The workers under optimum work rate on peat soil could dig and plant only a total of 40 palms man-day^{-1} but without hole digging, they are capable of planting 80 palms man-day^{-1}.

The Department of Biological and Agricultural Engineering, Universiti Putra Malaysia (UPM) Malaysia has successfully developed a prototype machine system for mechanized field transplanting of oil palm seedling. This integrated machine system is capable of preparing the planting hole, placing of

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seedling in the prepared hole, covering of the seedling in the prepared hole, and compacting of the soil around the planted seedling in plantation field. The machine requires a 4-wheel tractor with at least 63.4 kW PTO engine size and 66.2 litres min^{-1}@172.36 bar hydraulic auxiliary outlet for operation. The transplanting operation involves two operators: a driver for driving the tractor in the field and an operator for operating the hydraulic control system on the transplanter.

This paper describes the preliminary field and cost evaluations of the fully developed integrated prototype machine system for transplanting of oil palm seedlings in the field.

METHOD AND MATERIALS

Preliminary Field Evaluation

An area size of 200 m length and 56 m width at the university farm was chosen to be the test plot for the preliminary field evaluations of the prototype transplanter. DxP seedlings of 16 months old in 36 x 28 cm polybags that have been earlier pruned to 1400 mm height were used in this field test. Determination on the time and motion for the field planting of three rows of seedlings with 20 seedlings per row was made for six days durations. However on the sixth day, the test include the task of removing plastic polybag from the seedling before planting. Removing of plastic polybag from the seedlings was not done on the first day to the fifth day since the seedlings were needed to be reused in the field test.

Measurements for fuel consumption of the tractor-transplanter tractor engine speed of 1500 rpm was only made for four days duration and measurement were made on the third day to the sixth day of the test. Measurement for spacing between planted seedlings and row alignment of planted seedlings was made for the six days duration while measurements for the pulling forces of the planted seedlings were conducted on the last day of the field test. Height of planted seedlings was measured for 20 planted seedlings after the first month and second month planting operation.

All functional systems of the transplanter were initially with its seedling planting assembly at *top* and *forward* positions, auger bit at *tilt* position, and clamper jaws at *closed* position. Once the plantation field is ready for planting, the tractor operator drives the tractor-transplanter to follow the marked planting line in the field plot. The tractor driver stops the tractor for the transplanting operation at the marked planting position. *Figure 1* summarizes the operational sequence of the prototype transplanter. Time made by the transplanter operator for each operational sequence that was involved in the field planting operations was measured. The operations include loading seedlings to the transplanter, moving from seedling supplying point to the first planting point, preparing the planting holes, applying CIRP fertilizer, conveying the seedlings, removing the plastic polybags from seedlings, placing seedlings inside the prepared holes, covering the planted seedlings, compacting the soil around planted seedling, lifting the empty seedling planting assembly, moving between planting points, and turning at headland.

Time for loading the seedlings into the transplanter refers to the total time taken by the worker to manually lift and place the 20 seedlings individually into the transplanter seedling bin from the seedling supplying point. Measurement for the time duration immediately started when the worker started to hold the first seedling at the supplying point that is about 1.5 m distance from the transplanter location and terminated once the 20th seedling has been securely placed into the seedling bin of the transplanter.

Time for moving from seedling supplying point to the first planting point refers to the total time taken by the tractor-transplanter system to move from seedling supplying point to the first point of planting. Measurement for the time duration immediately started when the tractor-transplanter system started to move from the seedling supplying point and terminated once it stopped at the first planting point location.

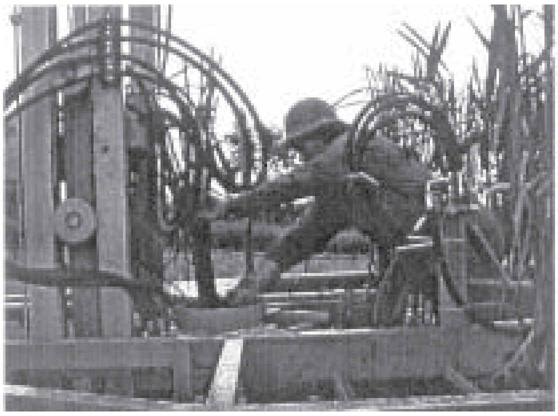
Time for preparing the planting hole refers to the total time taken to erect the auger, rotate and at same time move the auger to penetrate the soil surface, lift up the auger, and tilt the auger to its rest position. Measurement for the time duration immediately started when the operator shifted the hydraulic control lever to erect the auger and terminated when the auger was at its rest position and the clamping-covering mechanism at the convenient height position to the operator.

Time for applying CIRP fertilizer refers to the total time taken for the operator to bend and pick up the cup to scoop the CIRP fertilizer in the small plastic bucket, throw the available fertilizer in the cup into the planting hole, and drop back the cup into the small plastic bucket. Measurement for the time duration immediately started when the operator bend down to pick the cup in the small plastic bucket and terminated when he dropped back the cup into the small plastic bucket after finished applying CIRP fertilizer into the planting hole.

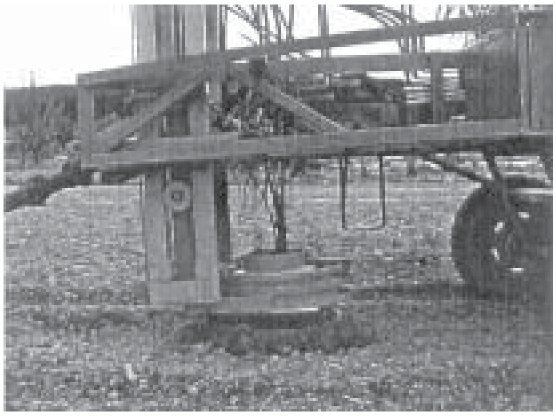
Time for conveying the seedling refers to the total time taken to operate the conveyor to deliver the remaining seedlings in the bin to the position closed to the operator. Measurement for the time duration immediately started when the operator shifted the hydraulic control lever to deliver the seedlings

a. Preparing the holes

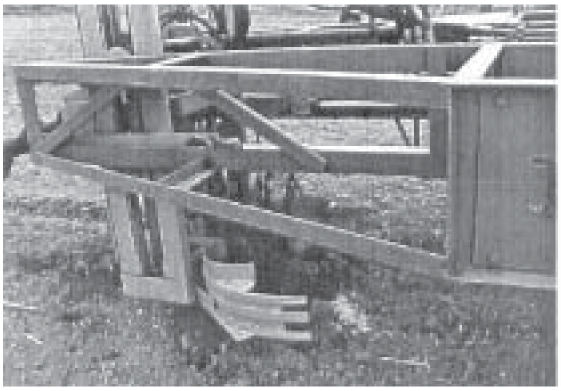
b. Spreading the fertilizer



c. Placing the seedling into clamper



d. Placing the seedling into the prepared hole



e. Covering the seedling

f. Compacting the soil around planted seedling

Figure 1. Operational sequences of the prototype transplanter.

rearward and terminated when the delivered seedlings reached the position closed to the operator.

Time for placing the seedling inside the planting hole refers to the total time taken for the operator begins to pick the seedling in the bin and place it on top the jaws of clamping-covering mechanism, cut and remove the plastic polybag from the seedling, move the seedling planting assembly with the seedling rearward, and release the seedling into the planting hole. Measurement for the time duration immediately started when the operator started to hold seedling in the bin and terminated when the dropped seedling sat at the bottom part of the hole.

Time for covering the seedling refers to the total time taken to open wide the jaws of clamping-covering mechanism and closing back the jaws to push the deposited soil around the planting hole for cover the planted seedling. Measurement for the time duration immediately started when the operator shifted the hydraulic control lever to wide-open the jaws of the clamping-covering mechanism and terminated when the planted hole was satisfactorily being filled with the soil.

Time for compacting the soil around planted seedling refers to the total time taken to close the jaws of clamping-covering mechanism, move up the clamping-covering mechanism to 200 mm height, move it down to compact the soil around the planted seedling, and repeat these sequential operations until the compaction degree of the soil around the planted seedling was satisfied. Measurement for the time duration immediately started when the operator shifted the hydraulic control lever to close the jaws of clamping-covering mechanism and terminated when the soil around the planted seedling was satisfactorily being compacted by the clamping-covering mechanism.

Time for moving between planting points refers to the total time taken for the tractor-transplanter to move from one planted seedling to adjacent the planting point within the planting row. Measurement for the time duration immediately started when the tractor-transplanter started to move after finishing planting the seedling and terminated when the tractor-transplanter stop at the next planting hole.

Time for turning at the headland refers to the total time taken for the tractor-transplanter to turn at the headland after completing the planting of seedling in the first planting row. Measurement for the time duration immediately started when the tractor-transplanter started to make a turn from the first planting row at the headland and terminated when the tractor-transplanter stopped at the seedling supplying point for the loading of the seedlings.

The average tractor fuel consumption (litres per hour) was computed by dividing the average recorded volume of fuel consumed for each planting row with the average recorded time for the operation.

Planting quality of the transplanter in performing the planting operation was quantified based on the percentage of planted seedlings, leaning angles of planted seedlings, spacing between planted seedlings, row alignment of planted seedlings, pulling forces of the planted seedlings, and height of planted seedlings growth.

Percentage of planted seedlings indicates the proportion in percentage on the number seedlings that had been successfully planted by the transplanter over the total number of planting points.

Leaning angle of each planted seedling was measured using an abney level immediately after the planting operation. The measurement was taken at the base of seedling with the equipment base placed against the seedling main axis. The percentage of leaned seedlings indicates the proportion in percentage on the number leaned seedlings over the total number of successfully planted seedlings by the transplanter.

Spacing between any two adjacent planted seedlings of a planting row were measured using a measuring tape immediately after the planting operation (*Figure 2*). The computed average spacing performed by the transplanter was then compared with the theoretical proposed spacing of a given planting density as provided by Rankine and Fairhurst (1999).

Row alignment of the planted seedlings was measured using a measuring tape immediately after the planting operation. A string was stretched straight between the first and last planted seedlings of the planting row with its both ends being tied to the respective pegs. The measured perpendicular distance between the centre of seedling stem to the laid string was taken as a measurement of row alignment for the respective planted seedling (*Figure 2*).

Pulling forces of the planted seedlings were measured using an Aikoh Engineering load cell unit immediately after the planting operation. The planted seedlings in the planting row were randomly taken for this measurement. A small wire was banded around the main stem of the selected planted seedling with the other end of the load sense unit. The recorded maximum registered pulling force by Aikoh load sense unit to pull the planted seedling off the ground was recorded.

Height of the planting seedlings was measured using a measuring tape after the first and second month of planting. The planted seedlings in the planting row were randomly taken for this measurement. The height of the planted seedling was measured from ground level to the tip of the youngest seedling sprout.

Economic Cost

An economic cost analysis was made to compare mechanized and manual oil palm transplanting operations. The involved total operation cost is categorized into fixed costs and operating costs. The planting cost comparisons between mechanized and manual transplanting of oil palm seedling were made based on the following assumptions:

i. Initial purchase price of 63.4 kW John Deere 6405 tractor is RM 110 000 and the fabrication cost of transplanter is RM 29 030 for the mechanized system.

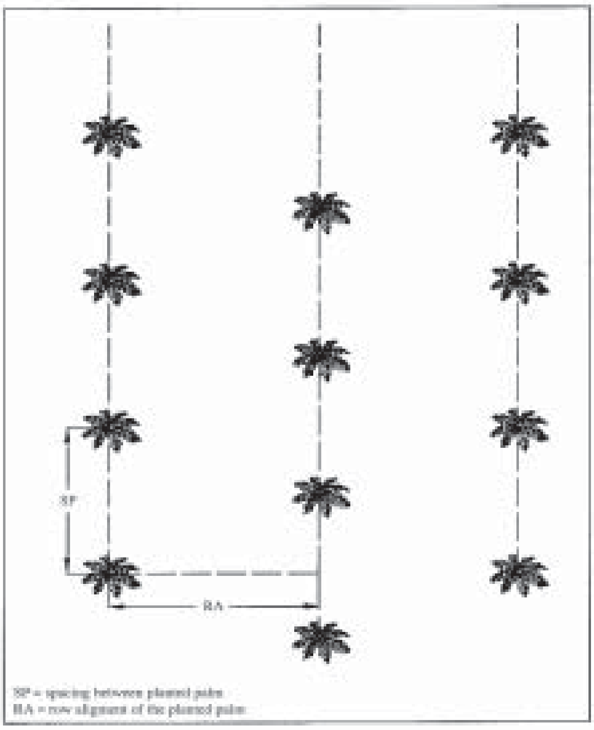


Figure 2. Spacing and row alignment of the planted seedling.

ii. Initial purchase price of 26 kW Massey Ferguson 174S tractor is RM 50 000 and the 18" Howard posthole digger is RM 7500 for manual system.

iii. Salvage value of tractor and posthole digger is 10% of its initial purchase after 10-year economic life.

iv. Salvage value of transplanter is 10% of its initial purchase after 15-year economic life (Kepner *et al.*, 1978).

v. Taxes, shelter and insurance is 2% of the total initial purchase price of the machine according to ASAE Standard EP Standard 496.2 JAN01 (ASAE, 2001).

vi. Interest rate of 10% on the higher extreme value was assumed under the present economic scenario in Malaysia.

vii. Factors of 0.010% and 0.075% were used in Kepner *et al.* (1978) equation for the tractor and transplanter for the calculations of their respective accumulated repair and maintenance cost.

viii. Factors of 0.010% and 0.040% were used in Kepner *et al.* (1978) equation for the tractor and posthole digger for the calculations of their respective accumulated repair and maintenance cost.

ix. Standard monthly wage for tractor operator in oil palm plantation in Malaysia is RM 900 which is equivalent to an average rate of RM 40.90 day^{-1} for 22 working days in a month.

x. Daily standard wage for an average field worker in an oil palm plantation is RM 17 day^{-1}.

xi. Current local market price of diesel is RM 1 litre^{-1}. A load factor of 0.126 was used in ASAE Standard EP496.2 (ASAE Standard, 2001) equation for the calculations of the tractor average annual fuel consumption.

RESULTS AND DISCUSSION

Table 1 shows that the average total time for mechanized transplanting of 20 seedlings was calculated to be 2740.87 s or 45.68 min for the first five days of operation. As observed, preparing planting holes was the most time consuming operation, followed by placing seedlings inside the prepared holes, lifting the empty seedling covering and compacting mechanism, moving in between planting points, loading seedlings into the transplanter, compacting the soil around planted seedlings, covering the seedlings, applying CIRP fertilizer, turning at headland, moving from seedling supplying point to the first planting point, and conveying the seedling.

Duncan multiple test (SAS, 1996) in *Table 1* indicates that there were no significant differences among time spent in moving from seedling supplying point to the first planting point, conveying the seedlings and turning at headland. There were also no significant differences between time spent

TABLE 1. BREAKDOWN OF AVERAGE TIME IN MECHANIZED FIELD TRANSPLANTING ON THE FIFTH DAY OF FIELD EVALUATION

Operations	Time (s)	Percentage from total time
Loading seedlings into the transplanter	218.07[d]	7.95
Moving from seedling supplying point to the first planting point	18.00[g]	0.65
Preparing planting holes	823.60[a]	30.05
Applying CIRP fertilizer	61.20[f]	2.23
Conveying the seedlings	7.33[g]	0.28
Placing seedlings inside the prepared holes	566.40[b]	20.66
Covering the seedlings	168.80[e]	6.16
Compacting the soil around planted seedlings	174.47[e]	6.37
Lifting the empty covering and compacting mechanism	430.00[c]	15.69
Moving between planting points	248.93[d]	9.08
Turning at headland	24.07[gf]	0.88
Total time	2740.87	100

Note: [a,b,c,d,e,f,g] means with the different superscript letter are significant at Pr = 0.05.

in moving between planting points and time spent in loading seedlings into the transplanter and between time spent in applying CIRP fertilizer and the time in turning at headland.

Duncan multiple range test in *Table 2* indicates that there was a general trend that average planting rate increased with the consecutive days of operations with the exception on the third day. Such trend was expected as the transplanter operator and tractor driver had gathered enough skills and experiences on the later days of testing. However, the planting capacity rate for the third day was slightly less than the second day. The rain on the third day had slowed down the performance of the transplanter operator. Furthermore, mobility of the tractor-transplanter for the transplanting operation was observed to be slightly difficult on that day due to soggy field conditions.

Duncan multiple range test in *Table 3* shows similar results to that of *Table 1*. The percentage of the total time spent in removing the plastic polybags from the seedlings was computed to be 6.60%. Thus, based on the earlier average total time of 2740.87 s or 45.68 min, the actual average total time for mechanized transplanting of 20 seedlings with the inclusion of removing the plastic polybags from seedlings would be 2921.76 s or 48.70 min and for a seedling would be 146.09 s or 2.44 min. For a plantation employing a planting density of 160 palms ha^{-1} (Hartley, 1977) and two workers for the operation with working commitment of 8 hr day^{-1}, the expected capacity for mechanized transplanting

TABLE 2. PLANTING RATE WITH MECHANIZED FIELD TRANSPLATING OF SEEDLING

Day No.	Average planting rate, seedling/hr
1	23[a]
2	26[b]
3	25[c]
4	28[d]
5	30[e]

Note: [a,b,c,d,e] means with the different superscript are significant at Pr = 0.05.

TABLE 3. BREAKDOWN OF AVERAGE TIME IN MECHANIZED FIELD TRANSPLANTING ON THE SIXTH DAY OF FIELD EVALUATION

Operations	Time (s)	Percentage from total time
Loading seedlings into the transplanter	196.33^{e}	7.50
Moving from seedling supplying point to the first planting point	15.33^{g}	0.58
Preparing planting holes	686.33^{a}	26.23
Applying CIRP fertilizer	63.22^{f}	2.42
Conveying the seedlings	8.67^{g}	0.33
Removing the plastic polybags from the seedlings	172.67^{e}	6.60
Placing seedlings inside the prepared holes	455.67^{b}	17.41
Covering the seedlings	182.67^{e}	6.98
Compacting the soil around planted seedlings	189.33^{e}	7.23
Lifting the empty covering and compacting mechanism	400.00^{c}	15.29
Moving between planting points	220.33^{d}	8.42
Turning at headland	26.33^{g}	1.00
Total time	2616.88	100

Note: ^{a,b,c,d,e,f,g} means with the different superscript letter are significant at Pr = 0.05.

on seedling basis would be 99 seedlings man-day^{-1}. In other words, with a planting density of 160 palms ha^{-1} and a planting capacity of 99 seedlings man-day^{-1}, the expected capacity for manual transplanting on hectare basis would be 0.62 ha man-day^{-1}.

PLANTING QUALITY

Table 4 shows that all the seedlings were successfully planted in the field by the transplanter during the field evaluation. All transplanting operations were performed smoothly with the exception of covering and compacting operations at the spot on the gullies (formed by the heavy downpour that occurred a few days before the field evaluation). Only one seedling out of the 60 seedlings was not fully covered and compacted by the clamping-covering mechanism of the transplanter due to the gullies in the field.

The 1.15^{o}average variation in leaning angles among planted seedlings with the measured sample size could be considered small. Almost 99.45% of the total seedling planted by the transplanter could be categorized as upright palm based on the three leaning categorizes by Mohd Tayeb *et al*. (1997). There was no seedling that was categorized as topple. The leaning incidence of the planted seedlings was observed to be very much influenced by the quality of the seedling in the polybag. If the seedling in the polybag brought from the nursery was not upright, there was a high tendency for the seedling to be leaning when planted in the field. Selection for upright seedlings in polybag at the nursery was therefore crucial for mechanized field transplanting in order to achieve high planting quality. The problem of planted seedlings occurred on first and second days of the field evaluation when operator had not familiarized the operation of the transplanter as yet. It was no longer a problem at a later stage when the operator had acquired sufficient skill to operate the transplanter. A skilled operator was able to know the optimum position to place the seedling inside the clamper of the transplanter so as to make sure that the seedling was placed upright in the planting hole.

The 0.02 m average variation in spacing among planted seedlings with the measured sample size could be considered small. The measured average spacing was 8.56 m and exceeded 0.06 ± 0.02 m from the proposed value for a planting density of 160 palms ha^{-1} by Rankine and Fairhurst (1999). The difficulty to stop the tractor-transplanter precisely at the marked planting point explained for such a variation. Signalling to stop at the planting point by the transplanter operator to the tractor driver was done manually. However, this problem could be solved by installing a buzzer alert system closed to the tractor driver position to warn him to stop when the tractor-transplanter had reached the planting point. Furthermore, white and red pegs need to be accurately located in the field along the planting row before the transplanting operation commenced.

The 0.35 cm average variation in row alignment among planted seedlings with the measured sample size could be considered small. The design configuration of the tractor or transplanter has no direct effect on the row alignment of the planted seedlings. However, the precision on the row alignment of the planted seedlings under this mechanized transplanting method was very much

TABLE 4. PLANTING QUALITY OF THE TRANSPLANTER

Day No.	Row	Percent. of planted seedlings,	Average leaning angles of planted seedlings, (degree)	Percentage leaning categories of planted seedlings			Average spacing between planted seedlings (m)	Average row alignment, of planted seedlings, (m)
				0°-30°	31°-60°	61°-90°		
I	1	100	74.05	0	5	95	8.55	1.90
	2	100	81.45	0	0	100	8.60	1.73
	3	100*	82.73	0	0	100	8.61	1.89
II	1	100	78.70	0	5	95	8.55	2.05
	2	100	81.75	0	0	100	8.58	1.68
	3	100*	81.68	0	0	100	8.59	1.30
III	1	100	83.50	0	0	100	8.63	2.40
	2	100	81.25	0	0	100	8.59	2.05
	3	100*	82.42	0	0	100	8.60	2.15
IV	1	100	83.35	0	0	100	8.51	1.15
	2	100	83.00	0	0	100	8.53	0.75
	3	100*	80.73	0	0	100	8.50	1.21
V	1	100	83.05	0	0	100	8.62	1.45
	2	100	80.35	0	0	100	8.61	1.80
	3	100*	84.05	0	0	100	8.53	1.63
VI	1	100	81.60	0	0	100	8.63	0.95
	2	100	82.85	0	0	100	8.52	4.05
	3	100*	83.31	0	0	100	8.48	2.05
Total number of samples		360	354	354	354	354	342	354
Average percentage		100	-	0	0.55	99.45	-	-
95% Confidence interval		-	81.65± 1.15	-	-	-	8.56±0.02	1.78±0.35

Note: * The seedling was not fully covered and compacted by the clamping-covering mechanism of the transplanter because of the gullies formed by the heavy downpour that occurs a few days before the field evaluation.

determined by the driver of the tractor that was used to pull the transplanter. Proper lining need to be carried out in the field to accurately indicate the planting row using wire and the location of the planting points along the marked rows using white and red painted pegs. It was very crucial for the tractor driver to move the tractor precisely along the lining wire in the field and stop the transplanter at the location of the planting peg while doing the transplanting operation.

The 19.72 N variations in pulling forces among the planted seedlings with the measured sample size in *Table 5* could be considered small. The pulling force was taken as an indicator to denote the compaction degree of the soil around of the planted seedlings. Uniformity in the degree of compaction on the soil around the planted seedling with mechanized transplanting was easily achievable since the compacting operation was mechanical powered. On the other hand, uniformity in the degree of compaction was difficult to be obtained

TABLE 5. PULLING FORCE OF PLANTED PALM SEEDLING WITH MECHANIZED TRANSPLANTING

Seedling No.	Pulling force of planted seedling, N
1	368.7
2	333.6
3	328.2
4	375.5
5	329.8
6	348.8
7	320.1
8	317.5
9	373.2
10	443.2
11	369.5
12	318.9
13	325.8
14	420.5
15	340.5
16	289.3
17	269.5
18	358.7
19	355.9
20	360.7
95 % Confidence interval	346.69±19.72

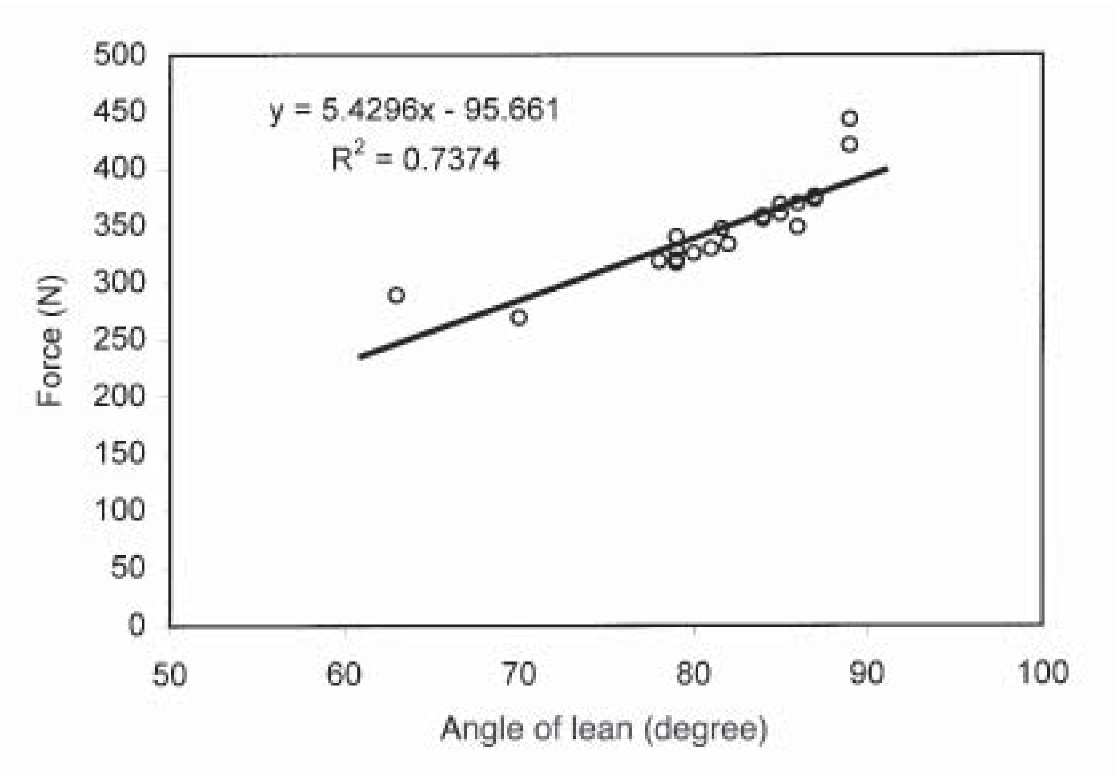


Figure 3. Plot of pulling force versus learning angle of planted seedling.

with manual transplanting since the compacting activity was done manually with the use of the hoe and through feet stamping.

Figure 3 shows that there was a linear relationship with acceptable correlation coefficient between the pulling forces and leaning angles of the planted seedlings. The pulling forces increased with the leaning angles of the planted seedlings. In other word, as the leaning angles of the planted increased or as the planted seedling was more to upright, the degree of compaction the soil around of the planted seedlings increased. Obviously the clamper base of the clamping-covering mechanism of the transplanter was able to function perfectly in conducting the compacting operation when the planted seedling closed to up-right position. With lean seedlings, the operator experienced some difficulties in moving the clamper of the clamping-covering mechanism at a much higher height above ground level to proceed with the compacting operation. Thus, force on the clamper base was not high enough to compact the soil around the planted seedling.

Duncan multiple range test in *Table 6* indicates that there were significant differences on the maximum height of the planted seedlings with the months of observation. Regardless of the agronomic treatments, maintenance post-planting and soil fertility on the field, all planted seedlings showed an average growth of 18.6 cm at the end of the first month and 22.5 cm at the end of the second month after planting in the field. The machine was able to plant the seedlings with harmony without giving any shock that could harm the seedlings' growth.

Duncan multiple range test in *Table 7* indicates that there were no significant differences on the measured fuel consumption between the days of operation. The tractor used in the mechanized field transplanting of seedling consumed on average about 1.78 litres hr^{-1}. However, the estimated average fuel consumption of the same tractor operating at rated engine speed based on the equation given in ASAE Standard EP496.2JAN01 (ASAE Standard, 2001) was 14.11 litres hr^{-1}. The measured average fuel consumption was very much lower than the estimated average value by ASAE because the tractor was not set to operate at its rated engine speed during the mechanized field transplanting operation. A 0.126 load factor was calculated for this mechanized transplanting operation based on the ratio taken between the measured average fuel consumption of the tractor in the mechanized field transplanting operation and the estimated average fuel consumption by ASAE. This load factor value is to be used later in the operating cost calculation for the fuel cost component in manual field transplanting of seedling.

Table 8 shows the cost breakdown comparison between mechanized transplanting and manual transplanting of seedlings. Seedling transplanting hourly cost for mechanized system was calculated to be RM 52.23 hr^{-1} while that for manual system to be RM 25.44 hr^{-1}; a difference of 2.05 times between the two systems. Such a distinct different in hourly cost may be due to the high initial costs of the machinery involved in mechanized system.

With mechanized system, repair and maintenance cost showed the highest percentage cost breakdown with a value of 62.73% of the total cost. Tax, shelter and insurance cost showed the lowest percentage cost breakdown with a value of 2.50% of the total cost for mechanized transplanting operation. The repair and maintenance cost of the tractor and transplanter were estimated based on the initial purchase prices of the machines. Tax, shelter and insurance cost even though normally constitute as minor costs in the total fixed cost of the machinery, should not to be left out in the cost analysis of any machinery (Kepner *et al*., 1978).

With manual system, operator cost shows the highest percentage cost breakdown with a value of 48.88% from total cost. As before, tax, shelter and insurance cost showed the lowest percentage cost breakdown with a value of 1.53% of the total cost for manual transplanting operation. Higher operator cost among the other cost components in manual transplanting operation simply because the field planting of seedlings is carried out manually. Almost about 58.85% of the operator cost estimated here was allocated to pay for the labour in manual field transplanting of seedlings.

Among the listed cost components, the tax, shelter and insurance cost shows the highest percentage different with a value of 78.27% and the operator cost shows the lowest percentage different with a value 41.70% when comparing between mechanized and manual transplanting operations. All the cost component with the exception of the operator cost for mechanized transplanting operation are higher than for manual transplanting operation. The cost components for depreciation, interest on investment, tax, shelter and insurance, and repair and maintenance are greater for mechanized transplanting operation simply because the estimation on their values are directly dependent on the initial purchase prices of the machinery used in the operations. The machinery involved with mechanized system are a 63.4 kW 6406 John Deere tractor and the prototype transplanter while with manual system are 26 kW 174S Massey Ferguson with a locally made 40.64 cm diameter posthole digger.

The machinery initial purchase price with manual system is about 54.54% lower than that of mechanized system. Besides that, the component cost for fuel consumption on mechanized transplanting is much greater than for manual transplanting operation simply because the

TABLE 6. PLANTED SEEDLING GROWTH WITH MECHANIZED TRANSPLANTING

Seedling No.	Maximum height during planting (cm)	Maximum height after 1st month (cm)	Maximum height after 2nd month, (cm)	Amount of growth after 1st month, (cm)	Amount of growth after 2nd month, (cm)
1	49	67	89	18	22
2	67	75	96	8	21
3	52	66	94	14	28
4	42	67	90	25	23
5	45	64	95	19	31
6	46	69	97	23	28
7	74	105	133	31	28
8	53	68	79	15	11
9	97	110	133	13	23
10	65	83	97	18	14
11	71	85	92	14	7
12	80	101	130	21	29
13	33	48	61	15	13
14	49	75	103	26	28
15	64	83	99	19	16
16	66	82	112	16	30
17	56	76	100	20	24
18	66	81	103	15	22
19	72	92	112	20	20
20	69	91	123	22	32
Average values, cm	60.80[a]	79.40[b]	101.90[c]	18.6	22.55
95% Confidence interval	-	-	-	18.6±2.45	22.55±3.34

Note: [a,b,c] means with the different superscript are significant at P = 0.05.

TABLE 7. FUEL CONSUMPTION OF THE TRACTOR WITH MECHANIZED TRANSPLANTING

Day No.	Row	Fuel consumption, (ml hr^{-1})	Average fuel consumption, (ml hr^{-1})
I	1	2 131.32	1 936.6[a]
	2	1 894.08	
	3	1 784.40	
II	1	1 756.77	1 934.9[a]
	2	1 917.80	
	3	2 130.17	
III	1	1 790.38	1 641.7[a]
	2	1 658.29	
	3	1 476.53	
IV	1	1 470.76	1 596.8[a]
	2	1 759.81	
	3	1 559.76	
95% Confidence interval		1 777.50±133.54	

Note: [a]means with the same superscript letter are not significant at Pr=0.05.

TABLE 8. COSTS BREAKDOWN FOR MECHANIZED AND MANUAL SYSTEMS

Cost component	Transplanting method				Percent. differ.
	Mechanized transplanting	Percent. from total cost	Manual transplanting	Percent. from total cost	
Depreciation cost, RM hr^{-1}	5.51	10.55	2.45	9.63	55.55
Interest on investment cost, RM hr^{-1}	3.62	6.93	1.49	5.88	52.30
Tax, shelter and insurance cost, RM hr^{-1}	1.31	2.50	0.39	1.53	78.27
Repair and maintenance cost,RM hr^{-1}	32.77	62.73	8.00	31.4	475.58
Fuel consumption cost, RM hr^{-1}	1.78	3.43	0.72	2.82	59.77
Operators cost, RM hr^{-1}	7.24	13.86	12.42	48.88	41.70
Total, RM hr^{-1}	52.23	100	25.44	100	51.29

estimations on their fuel consumption are directly dependent on the tractor engine sizes used in the operation. The tractor engine size with manual system is about 59% lower than that of mechanized system. Finally, the computed planting cost per man-hour for mechanized system that involves two workers for the operation is RM 26.12 man-hr^{-1} while for manual system that involves on average of two workers for the operation is RM 12.74 man-hr^{-1}. Consequently, the planting cost for mechanized system is a 2.05 times greater than that of the manual system.

Table 9 presents planting capacity and cost comparisons between mechanized and manual systems. Based on the earlier calculated planting capacity of 99 seedlings man-day^{-1} and the planting cost of RM 26.12 man-hr^{-1} with mechanized system, the planting cost of a seedling is RM 2.07. Again, based on the earlier calculated and reported planting capacities of 56 seedlings man-day^{-1} and 45 seedlings man-day^{-1} and the planting cost of RM 12.74 man-hr^{-1} with manual system, the planting cost of a seedling is RM 1.82 and RM 2.26, respectively.

An increased in planting capacity per man-day of 2.2 times was obtained with the mechanized system over the manual system based on the reported planting capacity value for optimum work rate on mineral soil by Rankine and Fairhurst (1999). Similarly, an increased in planting capacity per man-day of 1.77 times was obtained with the mechanized system over manual system based on the field observations.

A planting cost reduction per seedling of 6.64% or a cost saving of RM 0.15 per seedling was obtained with the mechanized system over the manual system based on the reported planting capacity value by Rankine and Fairhurst (1999). Greater in terms of the absolute value for the planting capacity ratio than the planting cost ratio of the mechanized system over the manual system based on the reported values by by Rankine and Fairhurst (1999) explained for cost reduction per seedling with mechanized system.

TABLE 9. PLANTING CAPACITY AND COST COMPARISONS BETWEEN MECHANIZED AND MANUAL SYSTEMS

Parameter	Mechanized transplanting	Manual transplanting		Differences	
		Field	Reported observations	I** value*	II***
Planting capacity, seedlings man-day^{-1}	99	56	45	1.77 times	2.20 times
Total cost, RM man-hr^{-1}	26.12	12.72	12.72	2.05 times	2.05 times
Planting cost, RM seedling^{-1}	2.11	1.82	2.26	+13.7%	-6.64%

Notes:
* Planting capacity based from Rankine and Fairhurst (1999).
** Comparison planting capacity between mechanized transplanting and field observation of manual transplanting.
*** Comparison planting capacity between mechanized transplanting and reported value by Rankine and Fairhurst (1999).

However, a planting cost increment per seedling of 13.74% or an addition cost of RM 0.29 per seedling was obtained with mechanized system over the manual system based on the field observations planting capacity that was earlier conducted.

CONCLUSION

The performance of a prototype of a transplanter has been tested and evaluated. The average time for mechanized transplanting of a seedling was 146.09 s or 2.44 min per seedling. Preparing the planting hole was the most time consuming operation, whereas conveying the seedling was the least time consuming operation about 30.05% of the total time for mechanized transplanting of seedlings was spent in preparing the planting hole and about 0.28% of the total time was spent in conveying the seedlings.

The expected output for mechanized transplanting on seedling basis was 99 seedlings man-day^{-1} for a plantation having a standard planting density of 160 palms ha^{-1} and two workers involvement in the operation with working commitment of 8 hr day^{-1}. Consequently, the expected capacity for manual transplanting on hectare basis was 0.62 ha man-day^{-1}.

The mechanized transplanting system showed good planting quality as indicated by the insignificant variations in leaning angles, spacing, row alignment, pulling and growth among planted seedlings. The 99.45% of the total seedlings planted by the transplanter were classified under upright palms. The average spacing between adjacent planted seedlings was 8.56 m and exceeded only by 0.06 ± 0.02 m from the proposed distance, whereas row alignment of planted seedlings variations was 1.78 ± 0.33 cm along planting lines in each row. The soil around planted seedling was almost uniformly compacted with an averaged pulling force of 347.39 ± 20.27 N per planted seedling. The entire seedlings were successfully planted in the field by the transplanter with averaged palms height increment of about 18.6 ± 2.45 cm after the first month of planting and 22.5 ± 3.34 cm after the second month of planting.

The average fuel consumption for the tractor-transplanter system was 1.78 litres hr^{-1} and was much lower than the average normal fuel consumption of other tractor field operations. A cost saving of RM 0.15 per seedling was obtained with the mechanized system over the manual system. The estimated transplanting cost is RM 2.07 per seedling with mechanized transplanting as compared to RM 2.26 per seedling with manual transplanting based on the reported value of planting capacity by Rankine and Fairhurst (1999). However, the estimated transplanting cost per seedling with mechanized transplanting was slightly higher by RM 0.29 than the transplanting cost with manual transplanting based on value that was obtained from field observation.

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