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PRELIMINARY FIELD AND COSTS EVALUATION OF A NEW MECHANISED SYSTEM FOR HOLING SOIL IN LARGE POLYBAG IN OIL PALM NURSERY

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ABSTRACT

A preliminary field and costs evaluation was conducted to evaluate the performance of a newly developed prototype machine system for holing soil in large polybags in oil palm nursery. The parameters measured during the preliminary field and costs evaluation included production capacity, mean increase in heart rate, human energy expenditure, total operating costs and return on investment (ROI). The results showed about 257 bags hr^{-1} per man of production capacity were obtained with the new machine system or 209.64% increase as compared to 83 bags hr^{-1} per man with the current practice. Mean increase in heart rate of worker when operating the machine systems was 24.2 beats min^{-1} or a decrease of 52.54% when compared to 51 beats min^{-1} with the current practice. On the basis of human energy expenditure, the new machine system consumed 3.16 kcal min^{-1} per man or 54.34% less exhausting when compared to 6.92 kcal min^{-1} per man with the current practice. Total operating costs of the new machine system was RM 0.05 bag^{-1} or 28.57% cheaper as compared to RM 0.07 bag^{-1} with the current practice. ROI of the new machine system was 233.07%, which assures the investment on this new machine system is worthwhile.

Keywords: transplanting, mechanisation, farm machinery, oil palm nursery.

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INTRODUCTION

Mechanisation has become an important issue arising in oil palm plantation industry especially in Malaysia. This is because mechanisation has been recognised as a mean of solving the increasingly acute shortage of labour in the plantation sector in the country. It is believed that application of mechanisation well-supported by productive and cost-effective agricultural machines is capable of increasing the productivity of land and labour by meeting timelines of the farm operation and increase the work output per unit time.

Although nursery operations are also rigorous works and need to be mechanised, nonetheless the progress of mechanisation in the oil palm nursery is moving at very slow pace compared to the mechanisation in the in-field operations. In fact, mechanisation in the oil palm nursery has been rarely studied. Most of the previous studies have only focused on the use of machines for transplanting vegetable crops and nursery potting machine (Gaikward and Sirohi, 2008; C-Max, 2010).

Oil palm nursery needs proper attention with specialised mechanisation in order to produce high quality seedlings. This is because nursery stage

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is the initial phase for oil palm seedlings to grow. At this stage, they are also extremely sensitive to environmental changes, including mechanical handling. According to Muhammad *et al*. (2010), nursery stage is very crucial due to the seedlings requiring constant and close attention during the first 10 to 12 months of their growth. Thus, a suitable technology is necessary to cater to the operations in the oil palm nursery.

In light of the above-mentioned reasons, Johari and Pebrian (2015) developed a new mechanised system prototype for holing soil in large polybags as shown in *Figure 1*. The machine ran on 8.2 kW with four cycle-cylinders, water cooled diesel engine. The main frame of the machine was made from the main frame of a pedestrian tractor with major modifications. The machine had a specific feature that enabled it to simultaneously dig the soils in two large polybags on both of its sides at every drilling task. The holing operation with this new machine system required only one operator.

As a new technology that would be introduced for oil palm nursery, a preliminary field and costs evaluation was necessary to identify the performance of the newly developed machine system. Thus, this article presents a preliminary field and costs evaluation of the developed prototype machine. The performance parameters measured for the new machine system included its production capacity, mean increase in heart rate and human energy expenditure of the operator. Other than that, total operating costs and return on investment (ROI) of the machine was also computed and analysed.

MATERIALS AND METHODS

Preliminary Field Evaluation

A field evaluation was carried out to evaluate the field performance of the prototype machine system at the Lembah Kesang Oil Palm Nursery, Melaka, Malaysia. The nursery was established by the Perbadanan Pembangunan Negeri Melaka, Malaysia, which is responsible to supply oil palm seedlings to the farmers and smallholders. This organisation was established under the management of Federal Land Consolidation and Rehabilation Authority (Felcra) Sdn Bhd. The data collection was carried out in October 2014. A total of 56 polybags filled with soil and arranged in eight rows with seven polybags at each row were used in this study. These polybags were placed at 90 cm triangular spacing and the distance between rows was 80 cm. *Figure 2* shows schematic of polybags arrangement and pathway for the machine system during field test. The new machine system started the holing operation in the polybags that were arranged in the first (R1) and third (R3) rows, and then continued at the second (R2) and fourth (R4) rows. The same manner was repeated for the rest of the rows until the operation for the whole polybags in the nursery was completed. Turning at the end of the rows was made after completing the holing operation in the rows.

During field evaluation, the new machine was operated by one operator. All the replications in the field evaluation of the new machine was made by

Source: Johari and Pebrian (2015).

Figure 1. The developed prototype new mechanised system for holing soil in large polybags.

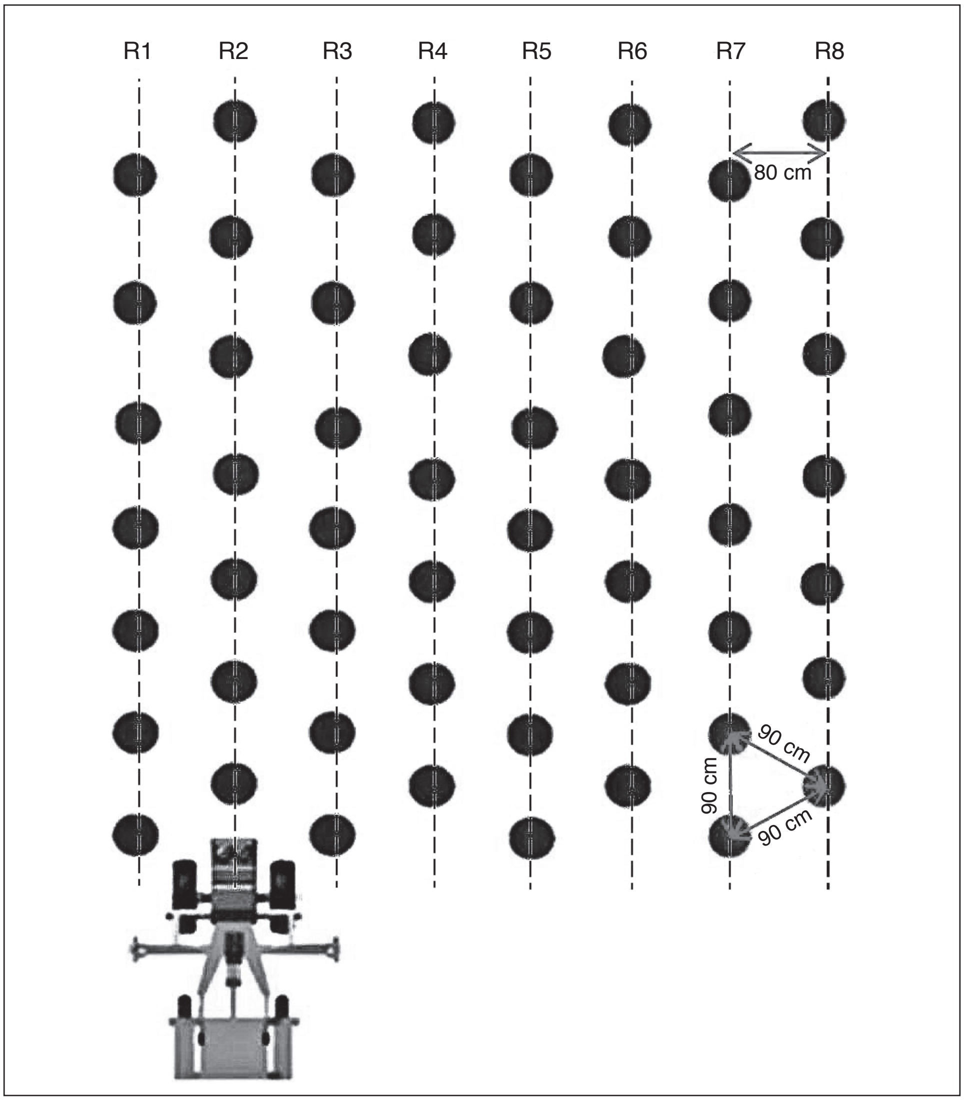

Figure 2. Schematic of polybags arrangement and pathway for the machine system during field evaluation.

him. The purpose of choosing the same operator in this field evaluation was for maintaining the consistency of the operator's performance when operating the new machine system. The consistent performance of the operator is important for the field evaluation since it directly relates to the parameters measured, *e.g.* time and motion study, energy expenditure and heart beat rate. The operator was a 23 years old male and had one year experience with farm machinery operation. While the anthropometric profiles of the operator were 186 cm height and 80 kg weight. Prior to operating the new machine system, the operator was intensively trained for one month in order to acquaint with the new machine system.

Time taken by the prototype machine system and its motion during the operation in the nursery site was studied for computing the production capacity of the new machine system. Each operational step involved in the soil-holing operation in the nursery was identified. These included the time for lowering the drilling unit, drilling the soil, lifting-up the drilling unit, moving from one polybag to another and turning to the next row. Determination on the time and motion for the nursery transplanting was conducted for three days. The time taken for all tasks started with lowering of the drilling unit, drilling the soil, lifting up the drilling unit, moving to the next polybags and turning to the next row. The time was measured by using a digital stopwatch. The percentage of time spent for each task was established. These tasks were repeated until the last polybag and the machine exited the nursery plot to the main gate.

The total time for lowering the drilling unit was calculated from its initial top position to the time the auger bit of the drilling unit touched the top surface of the soil inside the polybag. Time for drilling the soil refers to the total time taken for the auger bit to penetrate soil surface inside the polybag until completion of the holing process in the polybag. The total time for lifting-up drilling unit started when the holing process finished and the auger bit lifted upwards at its initial top position. Time for moving to the next polybag refers to total time taken for the machine to move from the already drilled polybag to the next polybag within the rows. The total time for turning was measured once the holing operation at the last polybag in the current rows was completed and at the same time the machine turns to enter the next rows for the new holing operation. *Figure 3* shows the operational sequences of the prototype machine system.

The energy expenditure and heart beat rate of the operator were also measured during the field evaluation. The Polar RS800CX Heart Rate Monitor (Polar, 2013) with transmitter and heart rate receiver was used to measure the above parameters. The initial heart rate was recorded before the beginning of every task. The operator was also given 10 min rest time before operating the machine system. The resting heart rate of the operator before operating the machine system was important to be recorded as his initial heart rate. The mean increase in heart rate of the operator during operating the machine was computed by subtracting his mean maximum heart rate with his mean initial heart rate. All measurements were taken from morning until afternoon in order to achieve greater uniformity.

The production capacity and human energy expenditure were computed from the performance of the machine system. The production capacity in bags per hour was computed by dividing the total drilled polybags with the duration of operation. Meanwhile, the mean increase in heart rate in beat per minute was measured by average heart rate for each operation minus with initial heart rate. The human energy expenditure was computed by each operation in kcal per hour with one-man operation.

Analysis of variance (ANOVA) in the Statistical Package for the Sciences (SPSS) (IBM Corp. Released 2013. IBM SPSS Statistics for Windows Version 21.0) was performed to determine statistical differences in average heart rate of subjects and the human energy expenditure among the tasks in the holing operation. Tukey's Multiple Range Test (TMRT) was performed to compare the mean differences of the tested value for increased mean heart rate, production capacity and energy expenditure during the study. Furthermore, comparison of field performance of the new machine system and the current practice was accomplished in the study. The

(a) Operating the machine system and setting positions of drilling unit above the polybags.

(b) Lowering the drilling unit to centre of polybag and drilling soils.

(c) Lifting-up the drilling unit.

(d) Moving to the next polybag.

Figure 3. Operational sequences of the prototype machine system.

current practice adopts a manual method, which is done by using hand-held tools to perform the operation.

Costs Evaluations

Costs analysis was performed to compare the total operating costs of the prototype machine system over the current practice. The total costs involved in the prototype machine system were categorised into fixed costs and operating costs. The fixed costs included depreciation, taxes, insurance and interest. Meanwhile, the operating costs included repair and maintenance costs, fuel consumption cost, lubrication cost and labour cost per hour. The total operating costs evaluation of the machine system were made based on the following assumptions:

i. Estimated initial cost to purchase and modify a 8.2 kW diesel engine walking tractor for the year 2013 was RM 20 000.
ii. Estimated economic life of six years based on 12 000 hr of use for two-wheel drive (ASABE, 2015b).
iii. Salvage value of 10% of its initial purchase after six years' economic life.
iv. Tax, shelter, insurance and interest at 2% of the initial costs of the machine system (ASABE, 2015a).
v. Repair and maintenance factors of RF^1 = 0.007 and RF^2 = 2.0 were estimated for machine system based on the 2WD tractors (ASABE, 2015b).
vi. The lubricant cost was estimated for 15% of the fuel cost (Bowers, 1981).
vii. Malaysia's diesel market price for the year 2014 was RM 2.30 litre^{-1}.
viii. Average measured fuel consumption for the machine system was 0.25 litre hr^{-1}.
ix. Operating hours was 1152 hr based on the holing operation duration in oil palm nursery.
x. Labour cost was RM 35 based on the labour wages rate for manual holing within 6 hr working commitment in a day.

RESULTS AND DISCUSSION

Preliminary Field Evaluation

Table 1 shows production capacity of the machine system. The average production capacity for holing machine for large polybags was 257 bags hr^{-1} per man and therefore, average production capacity for 6 hr per day operation was 1542 bags per day per man based on three days of field evaluations. Results show the production capacity increased by each day of the operation since the operator has been increasingly familiar with the operation of the machine system. Even though the operator has been trained before operating the machine, on the first day he still felt uncomfortable to manoeuvre the machine along the narrow path and took much time for setting up the position. The operator also took a longer time on the first day to do turning by moving the machine system to the next row of polybags and less time during end of the third day.

The average fuel consumption of the new machine system was 0.25 litre hr^{-1} as shown in *Table 2.* The fuel consumption decreased each day of operation with the differences of 0.07 litre hr^{-1} from Day 1 to Day 2 and 0.04 litre hr^{-1} from Day 2 to Day 3. The operator had much experience to operate the machine system on the final day of the study. The fuel consumption on the first day was 0.31 litre hr^{-1} higher than the other days of operation since the operator had less experience in handling the machine system. The operator failed to operate the new machine at full throttle to maximise the drilling soil operation. Besides, much time was spent at the pathway from the entrance to the first row of the plot in order to get the best position before proceeding to the holing task. The high level of soil moisture content in the polybags also contributed to the high power consumption of the machine system. Pebrian and Yahya (2003) stated that the fuel consumption of the machine was influenced by the different types of soil surface where the fuel usage of a machine operating on sloping terrain was 1.83 times higher than that of the gently undulating terrain.

Table 3 shows the comparisons of the percentage distribution of tasks duration, mean increase in heart rate and energy expenditure of oil palm main nursery for the machine system. Turning to the next row task with 46.82% of the time spent is the highest on nursery holing activity. Meanwhile, lowering and lifting-up the drilling unit were considered as the least time consuming tasks with both recording 6.82% only.

TABLE 1. PRODUCTION CAPACITY OF THE MACHINE SYSTEM

Day	Production capacity (bag hr^{-1} per man)	Production capacity (bag day^{-1} per man)
1	241	1 446
2	263	1 578
3	267	1 602
Average	257	1 542

TABLE 2. AVERAGE FUEL CONSUMPTION OF THE MACHINE SYSTEM

Day	Fuel consumption (litre hr^{-1})
1	0.31
2	0.24
3	0.20
Average	0.25

TABLE 3. TASK DURATION, INCREASE IN HEART RATE AND ENERGY EXPENDITURE FOR MACHINE SYSTEM

Task	Mean task duration (%)	Mean increase in heart rate (beat min^{-1})	Mean task duration (s bag^{-1})	Energy expenditure (kcal min^{-1} per man)
Lowering the drilling unit	6.82	33^{a} ±1.528	0.930^{c} ± 0.050	5.375^{b}
Drilling the soil	29.46	33a ±2.082	4.093^{b} ± 0.261	5.371^{b}
Lifting-up the drilling unit	6.82	32^{a} ±2.082	0.887^{c} ± 0.006	5.583^{a}
Moving to the next polybag	10.08	3^{c} ±0.577	1.397^{c} ± 0.091	1.766^{d}
Turning to the next row	46.82	20^{b} ±2.082	6.700^{a} ± 1.083	3.038^{c}

Note: Means in a given columns having a suffixes with a same letter are treated not significantly different at 0.05 probability level.

TMRT was performed and it indicated that there was no significant difference among mean increase in heart rate during lowering the drilling unit, drilling the soil and lifting-up the drilling unit. The respective heart rates of the machine operator performing the tasks were 33, 33 and 32 beats min^{-1}. Meanwhile, there was a significant difference of operator's heart rate of 3 beats min^{-1} when moving to the next polybag and 20 beats min^{-1} for turning to the next row. Both tasks are easier than other tasks and required less movement to finish the tasks.

Based on the tasks duration, there was significant difference between time for turning to the next row (6.7 s) and drilling soil (4.093 s). Nonetheless, no significant differences were found between the time for lowering the drilling unit, lifting-up the drilling unit and moving to the next polybags. Meanwhile, turning to the next row at 6.7 s was the highest rate among the tasks. The time taken by turning to the next row was influenced by the long distance to travel and the large turning radius of the machine system.

The energy expenditure for lifting-up the drilling unit showed the highest value followed by drilling the soil, lowering the drilling unit, turning to the next row and moving to the next polybag. Lifting-up the drilling unit consumed about 5.583 kcal min^{-1} per man which ranked the highest energy expenditure, while moving to the next polybag task with the lowest energy expenditure of 1.766 kcal^{-1} min^{-1} per man. Lowering the drilling unit, drilling soil and turning to the next row tasks consumed 5.375, 5.371 and 3.038 kcal^{-1} min^{-1} per man respectively. There was significant difference between human energy expenditure during lifting-up the drilling unit and other tasks. Lifting-up the drilling task also ranked as the highest energy expenditure. From the analysis, lowering drilling unit and drilling the soil showed no significant difference. This infers that both tasks are also quite laborious after lifting-up the drilling unit task.

Table 4 shows the comparisons of the production capacity, human energy expenditure and increase in mean heart rate for both the current practice and the machine system. Based on the calculations, the increment obtained by the machine system was 209.64% with 257 bags hr^{-1} per man compared the current practice at 83 bags hr^{-1} per man. The production capacity was much influenced by the performance of the machine system where it could accommodate two holes in one drilling task. Increase in the output by mechanised system was already stated by Pebrian and Yahya (2013) where mechanisation on the oil palm cultivation increased the worker's productivity by 3.74 times when compared to manual method.

From the aspect of human energy expenditure, the current practice was 54.34% more exhausting with 6.92 kcal min^{-1} per man energy spent compared to the machine system with 3.16 kcal min^{-1} per man. The current practice spent most energy during the holing task compared to mechanised method by the holing machine system. The rate of energy expenditure on the machine system operation can be categorised as moderate work between 2.18 to 4.34 kcal min^{-1} of energy spent as compared to the current practice, which was categorised as an extreme heavy

TABLE 4. PRODUCTION CAPACITY, HUMAN ENERGY EXPENDITURE AND MEAN INCREASE IN HEART RATE FOR CURRENT PRACTICE AND MACHINE SYSTEM

Parameter	Machine	Manual	Different	(%)
Production capacity (bag hr^{-1} per man)	257	83	+174	209.64
Human energy expenditure (kcal min^{-1} per man)	3.16	6.92	-3.76	54.34
Mean increase in heart rate (beat min^{-1})	24.2	51	-26.8	52.54

work with heart rate of 6.51 kcal min^{-1} and above (Nag and Dutt, 1980). The worker spent most of his energy to produce the transplanting hole in the current practice instead of the mechanised method, which had a pair of special auger bits to reduce the energy consumption.

Mean increase in heart rate of operator in operating the new machine system was 24.2 beats min^{-1} or 52.54% lesser than 51 beats min^{-1} with the current practice. The high rate of mean increase in heart rate for the current practice shows that the worker spent much works especially in performing a perfect transplanting hole for each polybag. He might repeat the task twice to three times and this may contribute to a long rest before continuing the activity. It was supported by Kvíz and Kroulík (2017) that the worker's heart rate was lower on automatic guidance steering rather than the conventional manual steering of the tractor-implement set for soil tillage and sowing field operations.

Obviously, the new machine system was able to give a better field performance as compared to the current practice, and reduce the human energy expenditure. Moreover, the worker's fatigue in holing soil in large polybags has been much reduced by using this new machine system.

Total Operating Costs Analysis

Total costs for operating the machine is tabulated in *Table 5*. The total operating cost for holing in large polybags was RM 14.80 hr^{-1} with a total of 257 polybags. Thus, the production capacity for holing activity is RM 0.05 bag^{-1}. The labour cost shows the highest percentage cost breakdown (47.36%) of the total operation costs, followed by the fuel cost (31.08%) and depreciation cost (10.50%). Tax, shelter and insurance costs show the lowest percentage cost breakdown with 2.36% of the total operation costs. The study found diverse results in comparison with past studies by Pebrian and Yahya (2013), who reported that the fuel consumption per hour for machine was the highest percentage as compared with other costs within the total cost of operation. The difference of the estimated cost analysis between the new machine and the fruit bunch collection and spraying machines is because of the different operational activities, the total area covered and labour wages. Even though the tax, shelter and insurance hold as the lowest portion in the cost of operation, they should be taken into account as factors in the machine costs.

TABLE 5. ESTIMATED TOTAL COSTS OF THE MACHINE SYSTEM

Cost component*	Cost	Cost (%)	Rank
Depreciation (RM hr^{-1})	1.56	10.50	3
TSII (RM hr^{-1})	0.35	2.36	6
Fuel cost (RM hr^{-1})	4.60	31.08	2
Lubricant cost (RM hr^{-1})	0.69	4.66	4
Repair and maintenance cost (RM hr^{-1})	0.60	4.12	5
Labour cost (RM hr^{-1})	7.00	47.36	1
Total cost (RM hr^{-1})	14.80	100	

Note: *1 Ringgit Malaysia (RM) = USD 0.243 (exchange rate during the study).
TSII - tax, shelter, insurance and interest.

Table 6 compares performance and cost comparisons between the machine system and current practice. The machine system output covered 257 bags hr^{-1} compared to the manual method with 83 bags hr^{-1} production per worker. The production output was based on 6 hr of operation per man day^{-1}. According to the nursery manager of Lembah Kesang Oil Palm Nursery, the production capacity for holing soil in large polybag was 500 bags with the labour cost at RM 35 per man. By referring to the labour cost spent for holing in polybags activity, the holing operation by the machine system costs about RM 14.80 hr^{-1} or 2.55 times higher as compared to the current practice with RM 5.80 hr^{-1} of operation. However, even though the labour cost for current practice is lower compared to the machine system, the production capacity for the machine system is higher than the current practice. The holing machine system comes with two drilling units that could simultaneously dig two holes in one drilling task. The machine system continuously operates the holing task in the polybags until the assigned area is completed. On the contrary, the current practice is tedious and tiring. In fact, the worker needs longer rest periods during working.

The total costs of operation for holing soil per polybag by the machine system is RM 14.80 hr^{-1}, while the total cost for holing soil per polybag by the current practice is RM 5.80 hr^{-1}. The total cost

TABLE 6. FIELD PERFORMANCES AND COSTS COMPARISONS BETWEEN CURRENT PRACTICE AND MACHINE SYSTEM

Type of system	Production capacity (bag hr^{-1} per man)	Cost of holing soil operation (RM hr^{-1})	Cost of holing soil operation (RM bag^{-1})
Manual	83	5.80	0.07
Machine system	257	14.80	0.05

of operation for the current practice was computed based on 6 hr working commitment in a day with wage of RM 35 per worker from the personal communication with the General Manager of Lembah Kesang Oil Palm Nursery. Even though the total costs for the machine system is higher than that of the current practice, the total costs for holing soil per polybag by the machine system is RM 0.05 bag^{-1} for 257 polybags production capacity. Whereas, the total cost for holing oil per polybag by the current practice is RM 0.07 bag^{-1} for 86 polybags production capacity. A small difference of RM 0.02 bag^{-1}, but gives an impact in the long-run. In addition, this can be considered as an advantage where the machine system is able to produce two polybags holes per drilling task.

Economics Analysis

Economics analysis of the new machine was verified based on the results of financial calculation as shown in *Tables 7* and *8*. The new machine system has proven its feasibility. Most of the parameters showed positive signs. Based on calculation, the Net Present Value (NPV) and Internal Rate of Return (IRR) were RM 25 646.49 and 50.79%, respectively, which shows that the new machine system is viable with positive return. The ROI accounted for 233.07%, which means that every RM 1.00 invested will get a return of RM 2.33. The payback period is calculated for 1.8 years, which accounted that within 1.8 years, the initial investment will be recovered from the net profit.

CONCLUSION

The field performance and costs of a newly developed machine system for holing soil in large polybags in oil palm nursery has been evaluated. The new machine system has successfully enhanced the operation of holing soil in large polybags by holing 257 bags hr^{-1} per man or 209.64% increase in production capacity and reducing human energy expenditure up to 6.9 kcal min^{-1} per man or 54.34% reduction as compared to the current practice. The mean increase in heart rate of the operator was also reduced by 52.54% from 51 beats min^{-1} using the current practice to 24.2 beats min^{-1} with the use of the machine. In terms of total operating cost, the machine system also reduced 28.57% of the total operating costs from RM 0.07 bag^{-1} to RM 0.05 bag^{-1} of the current practice. The most effective production capacity on the basis of the amount of polybags per hour goes to machine system performance when compared to the current practice since two holes could be simultaneously accommodated by the machine at once drilling task. Conclusively, this new technology has shown a huge capability in reducing the workers' workload, improving the production capacity and saving the total costs of the operation of holing soil in large polybags in oil palm nursery. Moreover, this new machine system has proven its feasibility by giving 233.07% of the ROI.

TABLE 7. CASH FLOW AND NET PROFIT FORECAST OF THE MACHINE SYSTEM

Item	Quantity				Cash flow						Total
					Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	
	Bag^{-1}	hr^{-1}	Day^{-1}	$Month^{-1}$	yr^{-1}	yr^{-1}	yr^{-1}	yr^{-1}	yr^{-1}	yr^{-1}	
Bag production	-	257	1 542	46 260	555 120	555 120	555 120	555 120	555 120	555 120	3 330 720
Sales (RM)	0.07	17.99	107.94	3 238.2	38 858.4	38 858.4	38 858.4	38 858.4	38 858.4	38 858.4	233 150.4
Cost (RM)	0.05	12.85	77.1	2 313	27 756	27 756	27 756	27 756	27 756	27 756	166 536
Net profit (RM)	0.02	5.14	30.84	925.2	11 102.4	11 102.4	11 102.4	11 102.4	11 102.4	11 102.4	66 614.4

TABLE 8. FINANCIAL FEASIBILITIES OF THE MACHINE SYSTEM

Item	Value
Profit margin (%)	40
Investment length (yr)	6
Investment gain (RM)	46 614.4
Return on investment [ROI (%)]	233.07
Annualised ROI (%)	22.21
Present value*	33 748.93
Net present value*	25 646.49
Internal rate of return [IRR (%)]	50.79
Payback period (yr)	1.8
Return on sales (%)	28.57

Note: *6 hr day^{-1}, 30 days $month^{-1}$, RM 0.07 bag^{-1} and discount rate of 12%.

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