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Design and Development of a Sweet Potato Digging Device

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ABSTRACT

This paper describes a study on the design, fabrication and testing of a prototype digging device for sweet potato tubers in bris soil. The soil texture was sandy soil (fine sand 94.53%), with mean moisture content of 9.16% and mean bulk density of 1.44 g-cm^{-3}. The soil was prepared in a soil bin. Three types of soil digging tools were designed and fabricated to determine the optimum draft force. These were Flat or plane, V-shaped and Hoe type blades. Plane and V-shaped blades were 30 cm long, and 13 cm wide, while the Hoe type had three rods, 25 mm in diameter, 30 cm long and 6.5 cm wide with sharp cutting edge. The digging tools were tested in a soil bin filled with bris soil to determine the optimum draft force and area of soil disturbance. The results were analysed using statistical analysis of variance (ANOVA). Comparison between all blade types and blade depths to measured draft force and the area of soil disturbed showed that the highest draft of 0.54 kN-m^{-2} was caused by a flat or plane blade at the optimum depth of 20 cm when the area of soil disturbed was 0.180 m^2. The V-shaped blade had the mean draft of 0.51 kN-m^{-2}, with area of soil disturbance of 0.185 m^2. The best choice was V-shaped blade with a rake angle of 30^o at 20 cm. depth. The selected blade was fixed onto the sweet potato harvester and tested on bris soil planted with sweet potato of Telong and VitAto varieties. The harvesting efficiency of the machine in bris soil was 93.64% and 90.49% for Telong (Plot A) and VitAto (Plot B) varieties, respectively. The average ground speed and turning time during operation for plots A and B was 0.56 km-hr^{-1} and 102.7 s and 0.99 km-hr^{-1} and 81.22 s, respectively. The harvesting efficiencies for both plots showed no significant difference. The total productive time (harvesting time) and unproductive time (turning time) in plot A, at a tractor speed of 0.56 km.hr^{-1}, was 14.8 hours for harvesting a hectare of sweet potato (0.068 ha.hr^{-1}). In plot B, the total time for harvesting a hectare of sweet potato was 8.35 hours (0.12 ha.hr^{-1}) at a tractor speed of 0.99 km.hr^{-1}. The average harvesting time for both plots was 11.47 hr.ha^{-1}. The average field work rate was 0.087 ha.hr^{-1} or 34 man-hr.ha^{-1} compared to manual harvesting of 150 man-hrs.ha^{-1}.

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INTRODUCTION

Sweet potato is a minor crop mainly grown for local consumption. Currently, there are about 2,000 ha of the crop grown in Peninsular Malaysia (Tan *et al*., 2006). Even though it is a small industry, sweet potato is being promoted to be grown on an extensive scale to replace the tobacco crop on the coastal sand ridges (bris) of Kelantan and Terengganu on the east coast of Peninsular Malaysia. Its promotion is part of the strategy to counter the increasing competitive pressure on the tobacco crop arising from global trade liberation. At the same time, there are large areas of sand tailings on the ex-mining area which is still not re-utilised and thus, suitable for cultivating sweet potato. Sweet potato has been proven to be cultivable on this type of soil (Tan, 1998; Tan *et al*., 2000).

Cultivation in a large area will involve labour intensive work especially during the harvesting operation. Currently, sweet potato is mostly harvested manually. The manual labour cost for a harvesting operation constitutes about 30 - 40% of the total operational cost (Md. Akhir & Desa., 2005). In manual harvesting of sweet potato tubers, the farmers have to cut and pull out the vines and lay them along the furrow. The tubers will then be dug by using a hand tool such as a hoe and fork, followed by manual collection. The tubers are transported in a basket or gunny sack. The most strenuous and back-breaking task is digging the tubers. The harvesting operation of sweet potato requires about 150 man-hours per hectare (Md. Akhir & Tan, 2002; Md. Akhir *et al*., 2005).

Lately, attempts at harvesting sweet potato mechanically have been made by a few farmers. Tractor mounted tillage tools such as the chisel plough digger, mould-board plough digger and double disk harrow have been used. These diggers are simple and cheap but tend to damage the tubers and usually cause field losses. Such operations also do not leave the tubers well exposed on the ground. In contrast, the digger elevator lifts the dug-out tubers exposed on the ground surface to facilitate easier gathering of tubers. In addition, the sieving action of its elevator conveyor minimises the extent of root losses.

The potato digger-elevator for a single-row crop has also been tested for sweet potato harvesting in mineral and bris soils (Md. Akhir *et al*., 2008). However, its performance was found to be not very effective under local conditions. In view of the current need for a mechanized sweet potato harvesting system to facilitate large scale production, a sweet potato harvester needs to be developed. The major part involved in the design of tuber crop harvester is the digger blade device.

Dash *et al*. (1998) reported on the performance of four different types of bullock-drawn groundnut diggers, namely, two-row ridging type, ridging type with semi-circular blade v-type and ridger type. The results showed that the average draft for two-row ridging type, semi-circular blade, v-type blade and ridger type were 85.5, 72.3, 66.8 and 57.0 kgf, respectively. Meanwhile, the maximum digging efficiencies were 74.3, 65.5, 81.9 and 92.0%, respectively.

This paper highlights the study on the three types of digger blades in bris soil under controlled conditions. The blades were Flat blade, V-Shaped and Hoe type. The most suitable blade among the three was selected to be fixed onto the designed and fabricated sweet potato harvester. The completed prototype was then tested in the sweet potato field to study its performance.

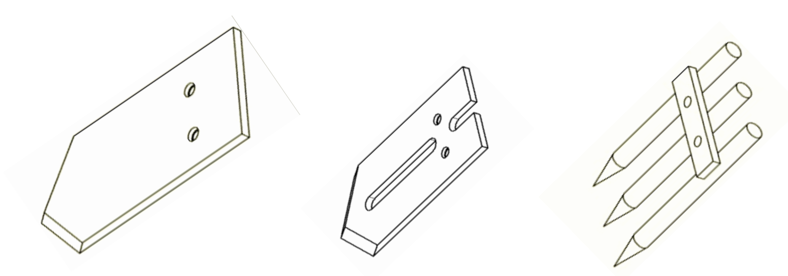
MATERIALS AND METHODS

Bris Soil Properties

Five random samples of bris soil were taken from the sweet potato fields for analysis of the properties. Bris soil texture was determined by float pipette method, while soil moisture and bulk density were determined by using the gravity method.

Blade Design and Fabrication

Three types of digger blades were designed and developed to study their draft force and soil disturbance in a soil bin. The blades were Flat blade (B_1) 13 cm wide, 30 cm long; V- shaped (B_2) with 13 cm width, 30 cm long; and Hoe type (B_3) with three iron rods, 25 mm in diameter, 30cm long and sharp at the end (Fig.1a). All the blades were tested in a soil bin filled with bris soil with average moisture content and bulk density similar to field conditions before harvesting. The draft force was determined using different blade types (B_1, B_2 and B_3) at different rake angles with the horizontal ($A_1 = 30^o$, $A_2 = 45^o$ and $A_3 = 60^o$) and depths of cutting (D_1=10 cm, D_2=15 cm and D_3= 20 cm). The best blade with the optimum angle and depth was selected to be fixed onto the digger frame (Fig.1b.) and attached to a prototype sweet potato harvester (Fig.2). The harvester with the selected blade was tested to harvest the sweet potato in bris soil. The data on the performance of the device and prototype sweet potato harvester were analysed using one way analysis of variance (ANOVA).



Flat blade (B_1) V-Shaped blade (B_2) Hoe type (B_3)

Fig.1a: A schematic diagram of digger blade devices

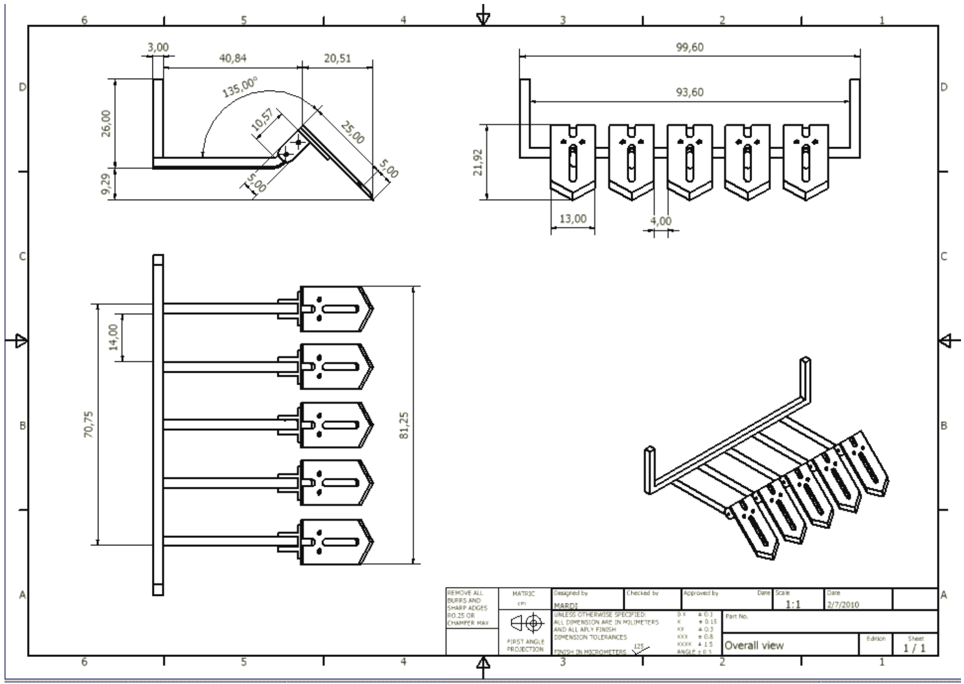


Fig.1b: A detailed design of selected digger blade (V-shape) attached to the digger frame

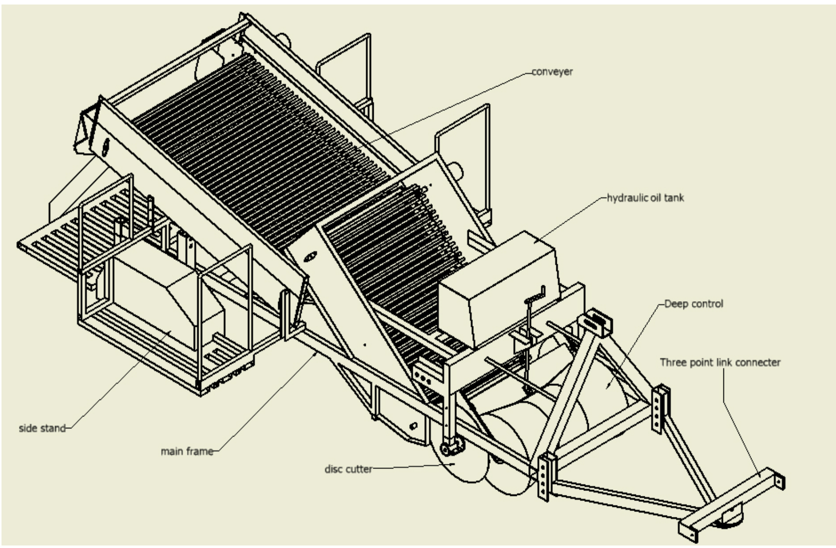


Fig.2: A schematic diagram of prototype sweet potato harvester

RESULTS AND DISCUSSION

Soil Condition

The physical properties of bris soil in this study are shown in Table 1.

TABLE 1
The Physical Properties of Bris Soil

Soil depth (cm)	Mechanical analysis (%)			Other material (%)	Moisture content (%)	Bulk density (t/m^3)
	Clay	Silt	Sand	compost		
0- 15	0.11	0.13	94.63	5.13	9.3	1.49
15-30					9.51	1.56
30-45					10.2	1.57
Average					9.67	1.54

Table 1 shows that silt, clay, sand, and other material contents were 0.13%, 0.11%, 94.63% and 5.13%, respectively. The average moisture content and bulk density of the soil during harvesting operation were 9.67% and 1.54 t/m^3, respectively. In order to simulate the actual field condition, bris soil in soil bin was compacted and watered to achieve a bulk density and moisture content similar to that measured in the field.

Blade Performance in Soil Bin

Results from statistical analysis of draft force and soil disturbance areas for different blade types, rake angles and depths in soil bin are shown in Fig.3 to Fig.8. In these figures, the means between treatments followed by similar letters do not differ significantly at p>0.05.

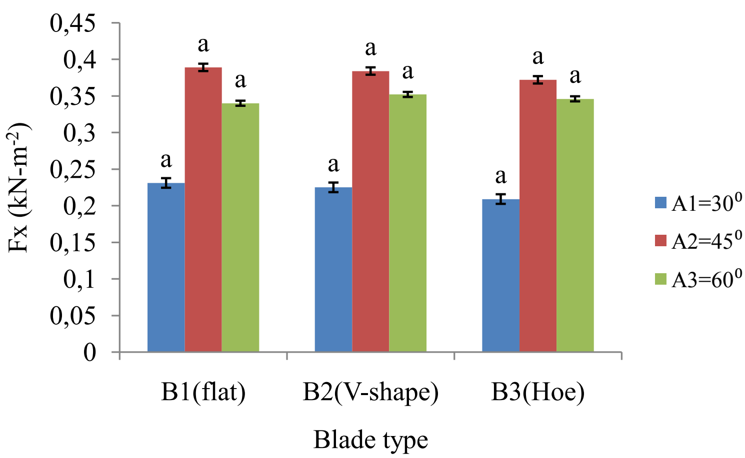


Fig.3: Draft force (*Fx*) in combination with blade type (B) and rake angle (A)

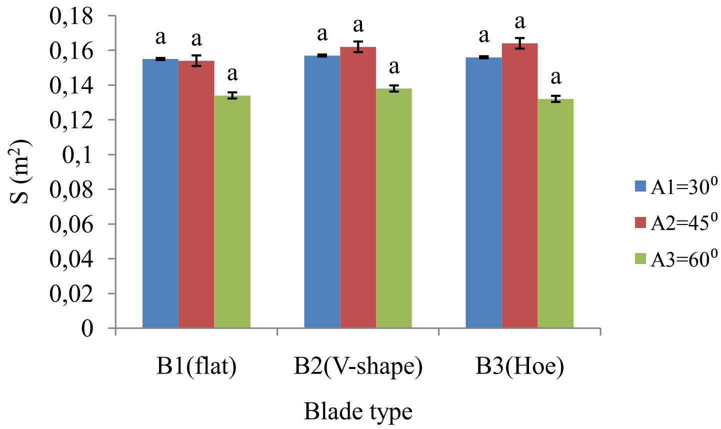


Fig.4: Soil disturbance area (*S*) in combination with blade type (B) and rake angle

Fig.3 shows that there are no significant effects of draft force (Fx) combination with the blade type and rake angle. The hoe type blade rake angle of 30^{o} gives the lowest draft force of 0.209 kN-m^{-2}. The highest draft force of 0.389 kN-m^{-2} was obtained by Flat blade (B1) at a rake angle of 45^{o} (A2).

The effects on soil disturbance area(S) during the experiment in combination with blade type (B) and rake angle (A) are shown in Fig.4. It shows that there was no significant effect on soil disturbance area in combination with blade types and rake angle. The highest soil disturbance area of 0.164 m^{2} was for Hoe type blade at a rake angle of 45^{o} and no significant effect was found between blade types. There were no significant effects at level $p>0.05$ on soil disturbance area at the rake angle of 60^{o}.

The effect on draft force (Fx) in combination with blade type (B) and depth (D) is shown in Fig.5. The figure shows that there was no significant effect on the draft force by the blade types, but there were significant effects on the draft force at $p> 0.01$ in combination with blade type and depth. The figure also shows that an increase of blade depth will increase the draft force, except for hoe type (B3) at the depth of 15cm(D2) and 20 cm (D3). This happened because the soil moved between the rods. The lowest draft force caused by the Flat blade at 10cm depth was 0.148 kN-m^{-2}. The highest draft force of 0.535 kNm^{-2} was caused by the Flat blade, followed by V-Shaped blade with 0.51 kN- m^{-2} and Hoe type of 0.492 kNm^{-2} at a depth of 20 cm, respectively.

The effects on soil disturbance area (S), in combination with blade type (B) and depth (D), are shown in Fig.6. There was no significant effect on soil disturbance area between blade types but there were highly significant effect at $p> 0.01$ for both the depth and combination blade type and depth. The high effect of soil disturbance area of 0.183 m^{2} was at a depth of 20 cm. The highest effect in combination with blade type and depth was caused by the V-shaped blade. The lowest effect was hoe type blade at a depth of 10 cm with soil disturbance area of 0.112 m^{2}.

Fig.7 shows that there was no significant effect of draft force between the rake angles, but highly significant effect at $p>0.01$ for both the depth and combination with the rake angle and the depth. The lowest draft force (Fx) of 0.156 kN-m^{-2} was at a depth of 10 cm (D1). At the rake angle of 30° (A1), the draft force of 0.105 kN-m^{-2} was at a depth of 10 cm. The high draft force of 0.742 kN-m^{-2} was for 45° rake angle at a depth of 20cm (D3).

Fig.8 shows that there were significant effects at p>0.01 of soil disturbance area for the depth and combination with the blade rake angle and depth. The highest soil disturbance area of 0.193 m^2 was at a depth of 20 cm (D3) and at a rake angle of 45°. For the high rake angle of 60°, and at a depth of 20 cm (D3), the soil disturbance area was 0.173 m^2.

Based on Fig.3 to Fig.8, the best combination was blade type (B) and rake angle (A) at the depth of 20 cm (D3) for getting the high soil disturbance area via the optimum draft force for the selected blade that was fitted to the sweet potato harvester. The V-shaped blade had the optimum draft of 0.51 kN-m^{-2} at a rake angle of 30° with soil disturbance area of 0.185 m^2 at the depth of 20 cm. The Hoe-type tool with the lowest draft of 0.34 kN-m^{-2} and soil disturbance area of 0.184 m^2 was not selected because soil can pass through the rods easily and can cause excessive damage to tubers.

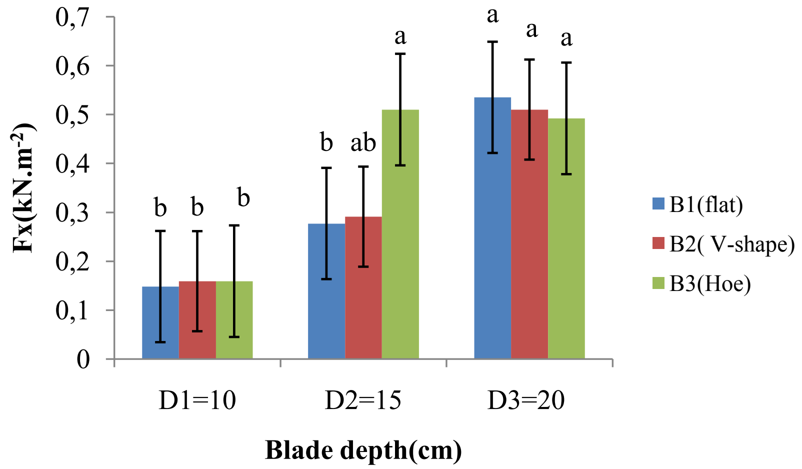


Fig.5: Draft force (Fx) in combination with blade type (B) and depth (D)

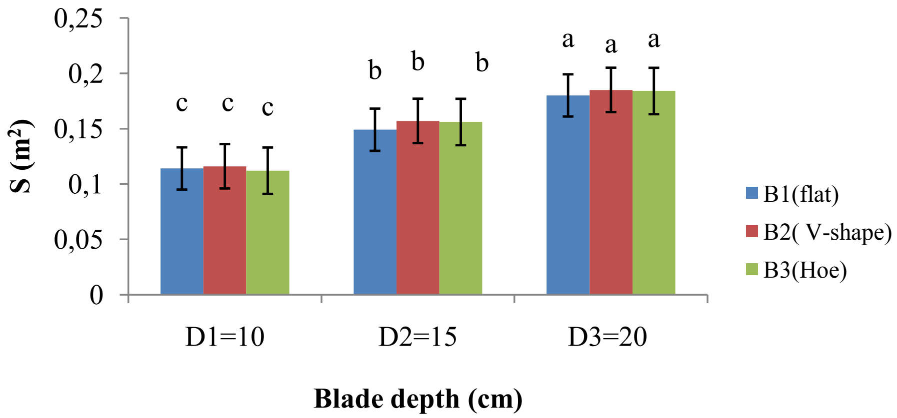


Fig.6: Soil disturbance area (S) in combination with blade type (B) and depth (D)

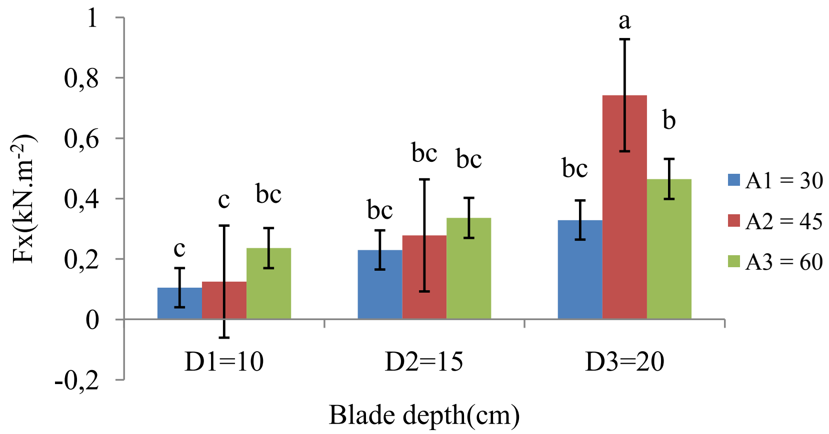


Fig.7: Draft force (Fx) in combination with rake angle (A) and depth (D)

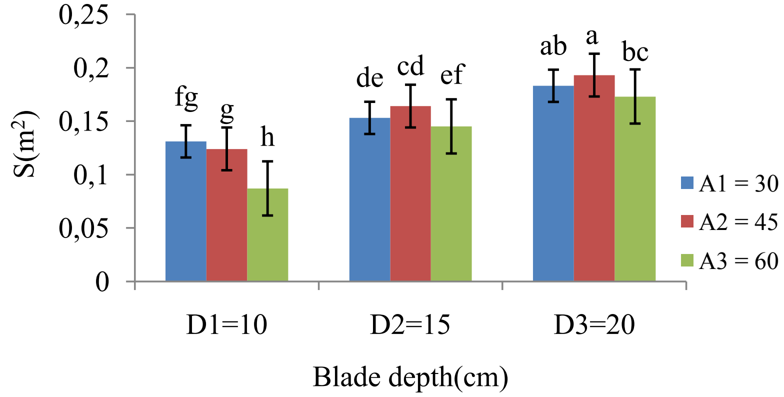


Fig.8: Area of soil disturbance (S) in combination with blade rake angle (A) and depth (D)

Digger Blade Design and Development

The selected V-shaped digger blade was used in this design based on the performance test in a soil bin. The data such as blade rake angle, blade depth and blade width were used to design and develop the sweet potato digging device. Fig.1b shows the detailed design of the selected digger blade (V-shaped) attached to the digger frame. The digger blade and frame (digging device) were than attached to the sweet potato harvester for performance testing (Fig.2).

Performance of Sweet Potato Harvester

The study was conducted on two plots, A and B, where each plot had an area of 0.25 ha. Plot A had 10 beds of 50 m length, 1.5 m from furrow to furrow and 1 m wide at the top. Plot B also had 10 beds, but these were 70 m in length. Both plots were of bris soil located at MARDI Research Station at Telong in Kelantan. Land preparation was carried out in accordance with the standard procedures as recommended by Md. Akhir *et al*. (2002). For a double-row planting, the bed size was 1.5 m wide and 30 cm high. Sweet potato vines were planted along the bed in two rows using a mechanical transplanter. The plant spacing was 30 cm between plants and 45 cm between rows. Plot A was planted with Telong variety while plot B was planted with VitAto variety. The crop agronomies application and maintainence were done according to the standard procedure as proposed by Tan *et al*. (1998), and harvested 120 days after planting.

The field evaluation of the harvester was carried out at the experimental plots when the sweet potato plants were about 120 days old and ready for harvest. Prior to harvesting, the vines and leafs were mechanically removed from the surface to ensure smooth operation of the harvester. During harvesting operation, the time taken to cover the distance as well as the turning time for each operation was measured using a stopwatch. In addition, the functional performance of the machine such as durability, consistency during operation, conveyor operation and machine manoeuvrability were observed and noted. The machine performance data which were collected included tractor speed, digging losses, tuber damage and overall machine efficiency.

The harvesting results were analysed through simple statistical analysis RBD (Randomized block design) to determine the harvesting performance for each plot, A and B. The harvesting performance in bris soil with Telong and Vitato variety of sweet potatoes are shown in Tables 2 and 3, respectively.

TABLE 2
Harvesting performance in bris soil with Telong variety

No. of rows	Distance (m)	Harvesting time (s)	Turning time (s)	Tractor speed (km/h)	Yield collected/row	Damaged + missing	Harvesting efficiency
					(kg)	Kg/row	%
Total	500	3217	924	5.63	922	62.7	93.64
Average	50	321.7	102.7	0.56	92.2	6.27	93.64
Max	50	338	112	0.68	111	8.6	95.72
Min	50	265	95	0.53	84.0	3.8	91.00
Stdev	0.00	23.28	6.26	0.046	8.28	1.31	1.31
Cv		0.07	0.06	0.082	0.09	0.22	0.014

TABLE 3
Harvesting performance in bris soil with VitAto variety

No. of rows	Distance (m)	Harvesting time (s)	Turning time(s)	Tractor speed (km/h)	Yield collected/row	Damaged + missing	Harvesting efficiency
					(kg)	Kg/row	%
Total	70	2540	731	9.99	999.66	105.60	90.49
Average	70	254.0	81.22	0.99	99.97	10.56	90.49
Max	70	297	103	1.14	121.38	16.40	93.22
Min	70	221	62.0	0.85	80.92	6.80	86.83
Stdev	0.00	22.59	28.66	0.09	14.38	3.15	2.13
Cv		0.09	0.35	0.09	0.14	0.30	0.02

Table 2 shows the machine performance on bris soil for the Telong variety. There were ten beds and each bed was 50 m in length. The mean harvest time for each bed was 321.7 s at an average ground speed of 0.56 km/hr. The harvester was capable of collecting 92.2 kg of tubers per row with a corresponding loss (missing or damaged) of 6.27 kg per row. The average time for turning the tractor from row to row was 102.7 s (1.43 minutes). The harvesting efficiency was 93.6% with coefficient of variation of 0.014. Table 3 shows the statistical analysis on the performance of sweet potato harvesting machine on VitAto variety. There were ten beds and each bed was 70 m in length. The mean harvesting time for each bed was 254.0 s, with a mean turning time between beds of 81.2 s. The mean harvesting speed was 0.99 $km\text{-}hr^{-1}$. The mean yield collected was 99.97 kg of tubers per row while missing and damaged tubers were 10.56 kg per row. The total mean harvesting efficiency was 90.5%, with a coefficient of variation of 0.02.

Based on Tables 2 and 3, the total mean harvesting efficiency showed no significant difference. These results also showed that the mean effective work-rate of the machine in bris soil was 93.64% and 90.49% for Telong and VitAto varieties, respectively. The average tractor speed and turning time was 0.56 km/hr and 102.7 s and 0.99 km/hr and 81.2 s for plots A and B, respectively. Differences in results of ground speed and turning time between plots may have been attributed to different operators. Neither operator had experience with the prototype machine. Other factors included plot length as Plot A had a 50 m seedbed length while Plot B was 70 m. A comparison of harvesting efficiency shows that there was not much difference between the plots. The harvesting efficiencies for both plots were above 90%. The effective field capacity or field work rate was obtained after considering time losses for unproductive tasks such as headland turn and travel between beds. The total productive time (harvesting time) and unproductive time (turning time) resulted in a sweet potato harvest capacity of 0.068 ha/hr for plot A and nearly double the capacity or 0.12 ha/hr for plot B. The average field work rate was 0.087 ha/hr or 34 man-hr/ha compared to manual harvesting of 150 man-hr/ha.

CONCLUSION

Based on the results of the soil bin experiments, the best digging device was the V-shaped blade with a rake angle of 30^o to be fixed onto the prototype sweet potato harvester. In the field study, the performance of the prototype sweet potato harvester was evaluated and observed. It was found that the machine efficiency in bris soil were 93.64% and 90.49% for Telong and VitAto varieties, respectively, with a corresponding work rate of 0.28 kg/sec (1.032 ton/hr) and 0.39kg/s (1.42 t/hr). The harvested yields were 92.2 kg/row for Telong and 99.97kg/row for VitAto varieties. Sweet potato losses and damages during harvesting operations were 6.27kg (6.36%) and 10.56kg (9.51%) for each variety respectively. The coefficient of variation (CV) of the machine operation was 0.014 and 0.02 for both varieties, respectively.

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