Technical Performance and Economic Feasibility Assessment of A Mechanical Yam Harvester

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Abstract: *The objective of this study was to evaluate the performance of a mechanical yam harvester. The harvester was operated at average soil depth of 0.30 - 0.33 m and tuber spread values of 0.18 - 0.22 cm. The tuber length varied from 0.33 to 0.38 cm and tuber depth of penetration also varied from 0.29 to 0.37 cm irrespective of yam variety. The tractor harvesting speed and field capacity values were 1.04 to 1.31 m/s and 0.30 to 0.38 ha/h respectively. Fuel consumption and wheel slippage ranged from 9.07 to 9.75 l/ha and 2.93 to 3.79 % for mound and ridged landforms respectively. Tuber damage values were 1.96% and 3.45% for ridge and mound harvesting respectively. Mechanical harvesting reduced harvesting cost by 50%. The cost of US$ 1500.00 for the yam harvester gave a breakeven point of about 180 h of use (~ 64 ha of harvested land area) when used for custom services at a cost of US$ 5.00 per h.*

Keywords: *Mechanical harvester, yam, field performance, economic feasibility.*

INTRODUCTION

Yam (*Dioscorea spp.*) is a staple crop cultivated in parts of West Africa, Asia, India and Brazil. Globally, yams are cultivated on about five million hectares in about 47 countries in tropical and subtropical regions of the world (FAOSTAT, 2013). The majority of yams consumed worldwide are produced in West Africa with over 90% of the world's total production (Nweke, 2005). Over the past two decades, Ghana has performed creditably well by increasing yields from 68,828 kg/ha in 1986 to 115,101 kg/ha in 2010, probably due to the improved agronomic interventions (FAOSTAT, 2013). However, to realise the full potential of the crop and ensure sustainable production of yams in the coming years, it is critical that agronomic interventions become commensurate to mechanised interventions, especially in the area of harvesting. However, there has been no significant improvement or support in the development and adoption of mechanised methods of production (Sowley and Tiesaa, 2007).

Yam harvesting is manually done and Otoo *et al*. (2013) reported that out of the total manually harvested tubers, between 10-40% are damaged from cuts during harvesting, piercing from roots of trees and poor handling of tubers. Any damage to the tuber significantly reduces its value, hence farmers have developed some level of apathy towards the use of mechanised harvesters and would prefer using manual labour, as is traditionally being practised. Itodo and Daudu (2013) reported 19% tuber damage at harvest for a tractor-mounted yam harvester fitted with a collection unit. This perhaps has contributed to the failure of previous attempts of mechanising yam harvesting. Currently, there is no commercially available mechanical yam harvester in Ghana and the West African sub-region, notwithstanding previous research attempts (Opara, 2003; Itodo & Daudu, 2007).

With the increasing demand for yams globally and the desire to increase production, farmers hope for an opportunity to increase their output while reducing harvesting drudgery (Akinbamowo *et al*., 2011). Otoo *et al*. (2013) proposed the need for mechanised yam harvesting to improve farmer productivity and reduce postharvest losses. Therefore, the development of a mechanical yam harvester will enhance yam tuber harvesting in a timely and safe manner, and reduce the level of tuber damage and losses. The objective of this study was to evaluate the performance of a newly-developed mechanical yam harvester.

MATERIALS AND METHODS

Study Area

The study was undertaken at the research field of the Ejura College of Agriculture located at Ejura in the Ashanti Region of Ghana. Ejura is located in a major yam growing area, and the relatively flat nature of the land lends itself to mechanisation, thus it accounts for a large numbers of tractors that are employed by most farmers in the area(Aikins & Haruna, 2012).

Land Preparation and Yam Varieties

One hectare of field was initially prepared using a disc plough as a primary tillage implement followed by a harrow as a secondary tillage implement. The field was divided into two equal parts mounds were constructed on one part and ridges on the other (Figure 1). The spacing was 1.2 m × 1.0 m with an average height of 0.4m. *Lili* and *Puna* varieties of yam were planted in rows on both ridged and mound landforms. The yam was coppiced and the fields were cleared of weeds prior to harvesting.
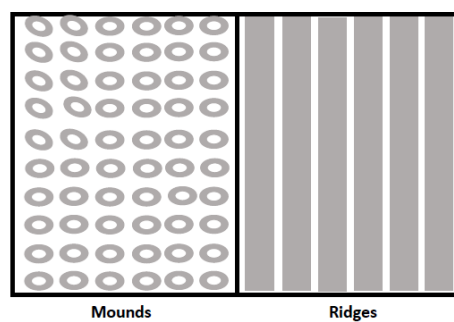

Figure 1. *Field layout for the study*

Description of the Mechanical Yam Harvester

Figure 2 shows the mechanical yam harvester. It has top and lower links for attachment to the three-point linkage of the tractor. A trapezoidal digging blade, bolted to the two vertical supports, dig and lifts the yam tubers from the soil during harvesting. The shaker rods are located at the back of the blade for separation of soil from the yam tubers as the tractor moves ahead. The overall height of the harvester is 1.16 m and it has a gross weight of 105 kg.
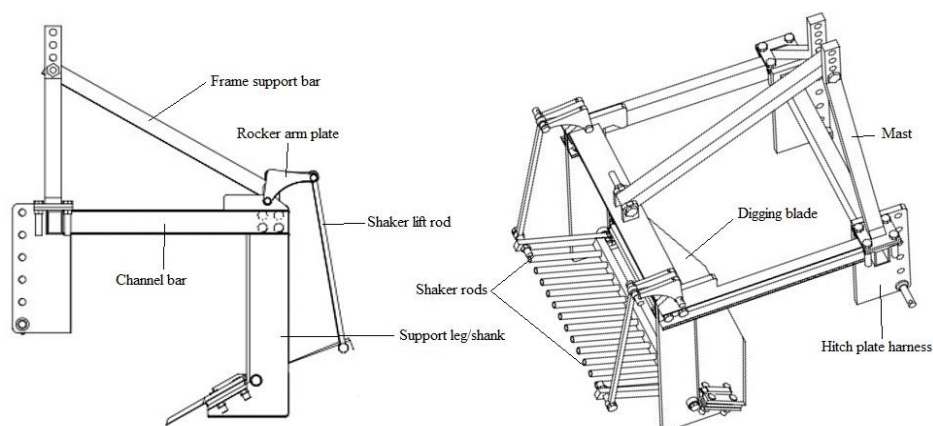

Figure 2. *Schematic diagram of the mechanical yam harvester.*

Data Collection

Soil Sampling

Five replicates of soil samples were randomly collected with a soil auger with 5 cm diameter soil core sampler and a malletat depths of 0-10, 10-20, 20-30 and 30-40 cm while bulk density were determined at depths of 0-20 and 20-40 cm before and after harvesting using a. Samples of the soil were oven dried at a temperature of 105°C for 24 h for soil moisture determination as recommended

by Black (1965).Penetrometer tests were carried witha penetrologger (Eijkelkamp Soil and Water, model 0615SA Giesbeek, The Netherlands) with a 60° circular steel cone and a base area of 100 mm^2 at depths of 0-10, 10-20, 20-30, and 30-40 cm before and after harvest.

Yam Agronomic Measurement

Agronomic data including depth of tuber penetration, tuber length and tuber spread (head to tip) under both mound and ridged land preparation methods were collected on 25 yam hills for each variety. This involved digging around the mound or ridge to expose the yam tuber. Yam tuber length, depth of penetration and tuber spread were determined using a carpenter's tape measure, and tuber roundness was determined using a digital Vernier calliper. Figure 3 shows the measurement of tuber depth of penetration, tuber length and spread.
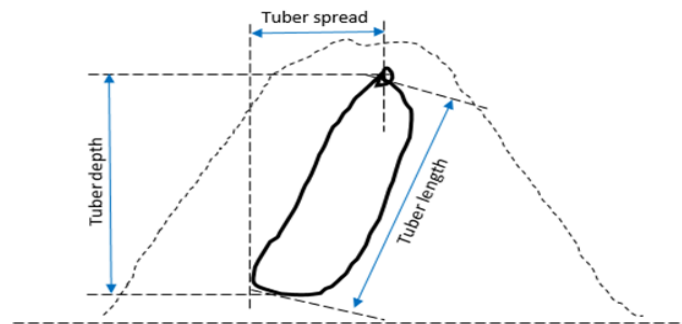

Figure 3. *Yam tuber depth, spread and length measurements.*

Mechanical Yam Harvesting

The mechanical yam harvester was hitched to the three point linkages of two models of agricultural tractors-a Cabrio 50 hp Category I 4WD tractoranda 75 hp New Holland Category II general purpose 2WD tractor (Figure 4). The necessary adjustments were made before the commencement of the harvesting operations.

Figure 4. *Harvester hitched to (a) Category I tractor (b) Category II tractor.*

Depth of Harvester Blade Penetration

Depth of blade penetration after harvesting was determined using a depth measuring probe together with a measuring tape as adopted by Amponsah *et al*. (2014a).

Yam Tuber Damage

Yam tuber mass and damaged (broken) tubers after harvest were determined using an electronic balance. Broken or severely bruised yam tubers were separated, weighed and tuber damage calculated as a percentage of the total tuber mass for each variety.

Fuel Consumption

Measurement of fuel consumption was carried out according to the method used by Smith (1994) and Amponsah *et al*. (2014).

Harvesting Speed and Slip Measurement

Wheel slip was measured according to the method used by Smith (1994) and Amponsah *et al*. (2014). Tractor wheel slippage was then determined using Equation 1.

$$\text{Slippage (\%)} = \left(1 - \frac{\text{Speed under loading condition (m/s)}}{\text{Speed under no loading condition (m/s)}}\right) \times 100 \quad (1)$$

Harvesting field Capacity

The field capacity was determined by recording the total time expended to harvest a given area of the field. From the effective working width of the harvester and the average speed of harvest, the field capacity was determined using Equation 2:

$$\text{Field capacity (ha/h)} = \frac{\text{Working width (m)} \times \text{Speed (m/s)} \times 3600}{10000} \tag{2}$$

Economics of Mechanical Yam Harvesting

The total cost of mechanical yam harvesting was determined by taking into consideration the fixed and variable cost parameters based on the recommendations and assumptions by Hunt (1983) and Hanna (2001) (Table 1).

Table 1. *Assumptions and recommendations for cost calculations.*

Cost Parameter	Assumption
Taxes	0% of purchase price
Shelter	0.5% of purchase price
Insurance	0.5% of purchase price
Repairs and maintenance	5% of purchase price
Lubricant cost	15% of fuel cost

The expected revenue, profit and break-even cost were determined using the calculated total harvesting cost aassumed per hour based on custiom hiring service.Lindeburg (1993) and Fairhurst (2012) calculated the breakeven cost using Equation 3.

$$\text{Breakeven cost} = \frac{\text{Total fixed cost}}{\text{Hiring cost - total variable cost}} \tag{3}$$

Statistical Analysis

Descriptive statistics of means using three replicates were determined and reported for all results obtained. The statistical analysis was performed using completely randomized design with single factor analysis of variance (ANOVA) for all data and analysed with Genstat Analysis software (VSN International, 2011). Least significant differences (LSD) was carried out at 5% level to pinpoint any differences in treatment means and also determine interactions between factors.

RESULTS AND DISCUSSIONS

Soil Condition

Figure 5 shows the soil moisture content before and after mechanical harvesting with the yam harvester for both mound and ridged land preparation methods. Soil moisture values ranged from 11.91 % d.b to 14.48 %d.b. before harvesting while it varied from 11.47 % d.b to 14.27 % d.b after harvesting as soil depth increased from 10cm to 40 cm.
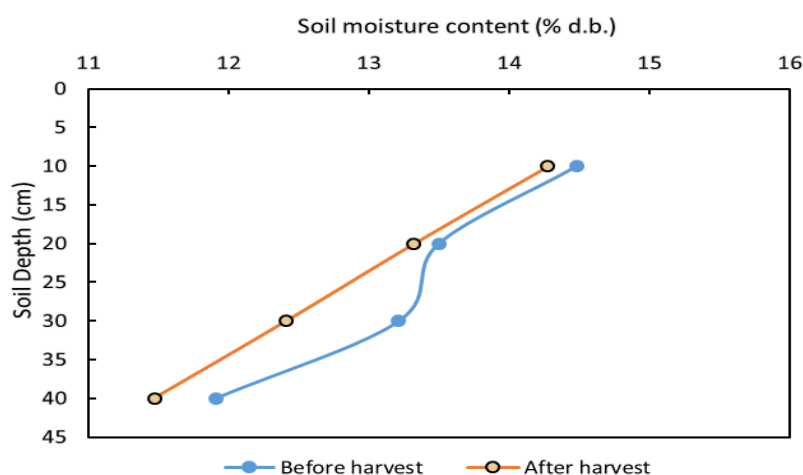

Figure 5. *Soil moisture content before and after mechanical yam harvesting.*

The results show a general decreasing trend in soil moisture content with increasing soil depth from 0-40 cm before and after harvesting. This suggests that there was less moisture as the soil profile increase. Though soil moisture after harvesting was relatively lower than before harvesting, no significant difference ($p>0.05$) was observed. The relatively lower moisture content after harvesting could be attributed to water evaporation due to the exposure of pulverised soil after mounds or ridges have been destroyed during harvesting.

Figure 6 shows the soil bulk density before and after mechanical yam harvesting for both mounds and ridged land preparation methods. Bulk density ranged from 1.50 g/cm^3 to 1.62 g/cm^3 before harvesting while ranging from 1.55 g/cm^3 to 1.63 g/cm^3 after harvesting as soil depth increased from 10 to 40 cm.
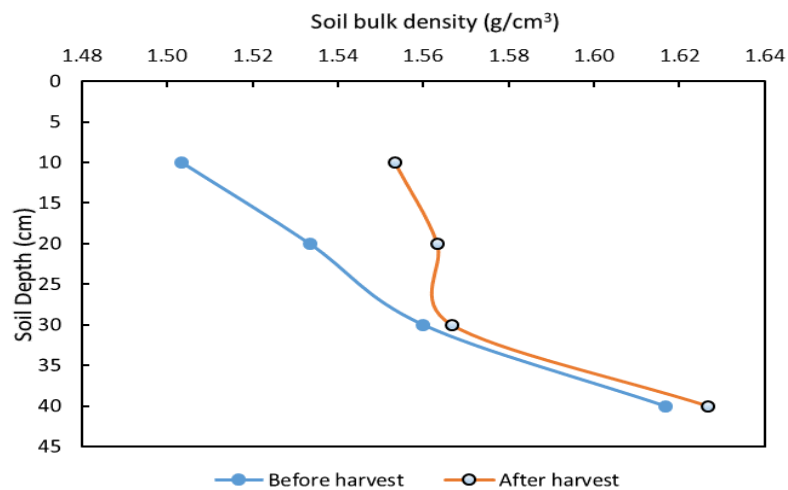

Figure 6. *Soil bulk density before and after mechanical yam harvesting.*

The results show a relatively greater soil bulk density after harvesting than before harvesting. This suggests that the tractor with implement might have caused some degree of compaction to the soil; though no significant difference ($p>0.05$) was observed between bulk density before and after mechanical harvesting. Results also show a generally increasing soil bulk density for both before and after harvesting with increasing soil depth (0-40), regardless of the land preparation method (mound or ridge).

The cone penetration resistance before and after mechanical yam harvesting increased with increasing soil depth is presented in Figure 7.
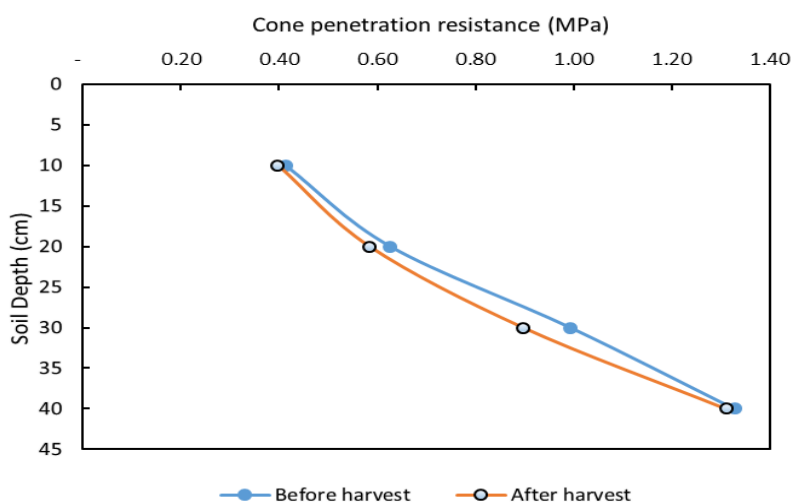

Figure 7. *Cone penetration resistance before and after mechanical yam harvesting.*

Cone penetration resistance ranged from 0.41 to 1.33 MPa before harvesting but ranged between 0.40 MPa and 1.31 MPa after harvesting with increasing soil depth (0-40 cm) irrespective of the method of land preparation (mound or ridge). The results show a generally increasing soil strength (cone penetration resistance) with increasing soil depth from 10 cm to 40 cm. Soil strength before

harvesting was relatively greater than after harvesting. This could be attributed to the pulverisation of soil during harvesting operation by the harvester, thereby causing a reduction in soil strength after harvesting. However, no significant difference (p>0.05) was observed between soil strength before and after harvesting, irrespective of the method of land preparation.

Yam Agronomic Properties

Yam tuber yield, length and spread of *Lili* and *Pona* at harvest are presented in Table 2. The mass per tuber ranged from 2.05 to 3.13 kg for *Lili* and *Pona* varieties respectively. Tuber length and spread ranged from 0.33 to 0.38 cm and 0.18 to 0.22 cm for *Pona* and *Lili* respectively, irrespective of the land preparation method.

Table 2. *Tuber yield, length and spread for Lili and Pona yam varieties.*

		Lili	*Pona*	LSD
Tuber yield (kg)		2.05	3.13	0.54
Tuber length (cm)		0.38	0.33	0.029
Tuber spread (cm)		0.22	0.18	0.036

The mass per tuber value of *Pona* was significantly greater than that of *Lili*. Conversely, tuber length and spread for *Pona* were significantly lower than *Lili*. Characteristically, *Pona* tubers are heavier but short in length whiles *Lili* tubers are slender and longer but weigh less. The results also indicate that the tuber spread for both yam varieties are within the cutting width of the mechanical harvester (0.8 m). Therefore, there is the less likelihood of tuber damages resulting from the harvester side supports (legs) during harvesting for *Pona* and *Lili*.

Figure 8 shows the depth of soil penetration by yam tubers and harvester blade on the mound and ridge land preparation methods.
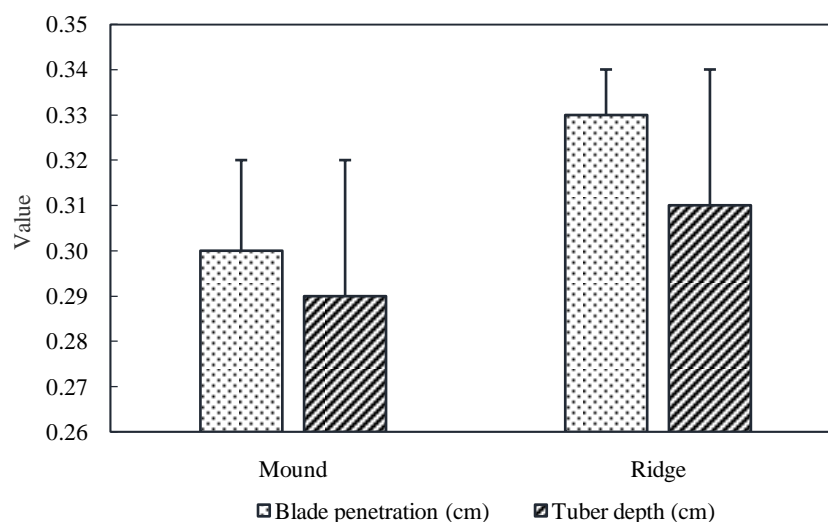

Figure 8. *Yam tuber and harvester blade depth of penetration.*

The mean harvester blade penetration values were 0.30 m and 0.33 m for the mound and ridge land preparations respectively. Similarly, the yam tuber depth ranged 0.29 to 0.31 m respectively for mound and ridged land preparations. The depth of harvester penetration on ridges was significantly greater (p>0.05) than on mounds, irrespective of the yam variety. This could be attributed to the less undulating nature of the ridged landform, thus the harvester had less resistance to movement with consequent increasing depth of penetration. Similarly, the tuber penetration depth on the ridges was greater than on the mound; though no significant difference was observed. From the results, the depth of blade penetration generally was beyond the yam tuber depth. This suggests that no tuber damage would result from the blade cutting the yam tubers.

Performance Evaluation

Figure 9 shows the percentage tuber damage for mound and ridged land preparation methods during harvesting with the mechanical yam harvester. Mean tuber damage ranged from 1.96 to 3.44 % for the ridged and mound land preparation methods respectively.
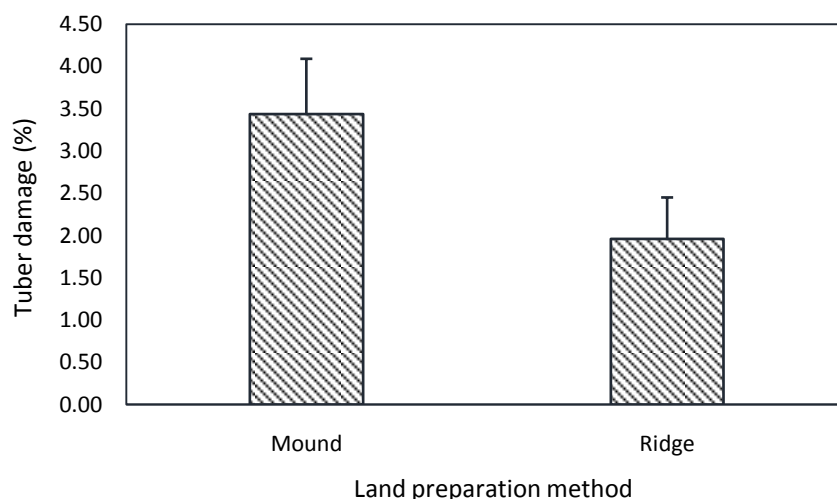
Figure 9. *Percentage tuber damage experienced on mound and ridges at harvest.*

The results indicate that percentage tuber damage on ridges was significantly ($p > 0.05$) lower than on the mound landform. This was because harvesting on the ridges was smoother since there was less lifting and lowering of the harvester.

Table 3 presents the technical performance evaluation results (speed, field capacity, fuel consumption and percentage wheel slip) during mechanical yam harvesting on mound and ridged land preparation methods.

Table 3. *Technical performance evaluation parameters of the mechanical yam harvester during harvesting on mounds and ridges*

Landform	Evaluation Parameter			
	Speed (m/s)	Field capacity (ha/h)	Fuel consumption (l/ha)	Wheel slip (%)
Mound	1.31	0.38	9.07	2.93
Ridge	1.04	0.30	9.75	3.79
LSD	0.128	0.037	0.394	0.579

The results show that harvesting speed and field capacity ranged from 1.04 to 1.31 m/s and 0.30 to 0.38 ha/h respectively for ridged and mound landforms. On the other hand, fuel consumption and tractor wheel slip ranged from 9.07 to 9.75 l/ha and 2.93 to 3.79 % respectively for mound and ridged landforms. Harvesting on the mound offered greater speed of travel, and field capacity which was significantly ($p > 0.05$) greater than harvesting on the ridge. This was due to the draft force encountered in the ridged landform as compared to the mounds which had intra-row space between successive mounds thus offering lower resistance to tractor movement.

From the foregoing, fuel consumption and wheel slip at harvest were significantly ($p > 0.05$) lower on the mound than on the ridged landform. This was because at higher travel speed, the tractor had enough force to overcome soil rolling resistances hence the lower wheel slip observed on the mounds. Furthermore, at a higher travel speed, harvesting operation is faster and this results in lower fuel consumption as was observed during harvesting on the mounds.

Economic Evaluation

The total cost (variable and fixed) parameters of the mechanical yam harvester based on relevant assumptions is presented in Table 4.

Table 4. *Total cost of mechanical yam harvesting.*

Cost Parameter	Yam harvester
Purchase price (US$)	1500
Salvage value (US$)	150
Economic life (years)	10
Fixed Cost (US$/y)	
Depreciation	135
Interest	8.25

Insurance	7.5
Tax	0
Shelter	7.5
Total Fixed Cost	158.25
Fuel (Diesel) cost (US$/L)	0.91
Fuel Consumption (L/h)	3.71
Field Capacity (ha/h)	0.38
Working hours/y	1000
Engine oil consumption (L/h)	0.01
Lubricant cost (US$/L)	0.1365
Worker's salary (US$)	70
Number of Workers	2
Variable cost (US$/h)	
Fuel	3.38
Lubricant	0.00
Repairs & Maintenance	0.08
Labour	0.67
Total Variable Cost (US$/h)	4.13
Total Variable Cost (US$/y)	4126
TOTAL COST (US$/y)	**4284**

The result shows that the total annual cost of the harvester is US4, 284.00.

Figure 10 shows the average total cost of yam production on either mounds or ridges for selected yam growing communities in Ghana as at November, 2016.
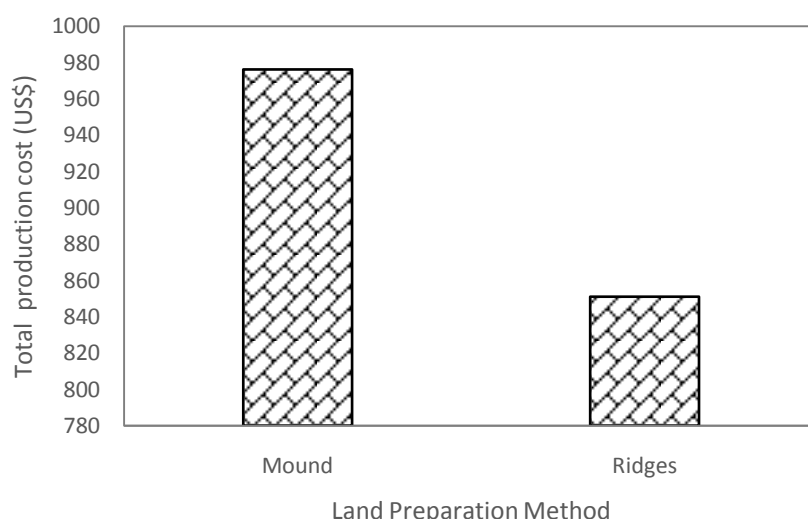

Figure 10. *Total cost of yam production under mounding and ridging land preparation options.*

The total cost of yam production under ridges was US$ 851.00 whereas under the mounding option it was US$976.00. This implies that the total production cost of yams using ridges was generally lower than that of mounds.

Table 5 shows the total cost of manual and mechanised harvesting on mounds and ridged land preparation methods as a percentage of total yam production cost.

Table 5. *Total cost of manual and mechanised harvesting on mounds and ridged landforms as a percentage of total production cost.*

Land preparation method	Harvesting method	
	Manual	**Mechanised**
Ridges	14	7
Mounds	12	6

The results show that the total cost of mechanised yam harvesting was 50% less than that of the manual harvesting method under either the mound or ridged land preparation method.

Figure 11 shows the breakeven analysis chart for the mechanical yam harvester at a total fixed cost of US$ 158.25 per annum, variable cost of US$4.13 per h and machine hiring cost of US$ 5.00 per h.
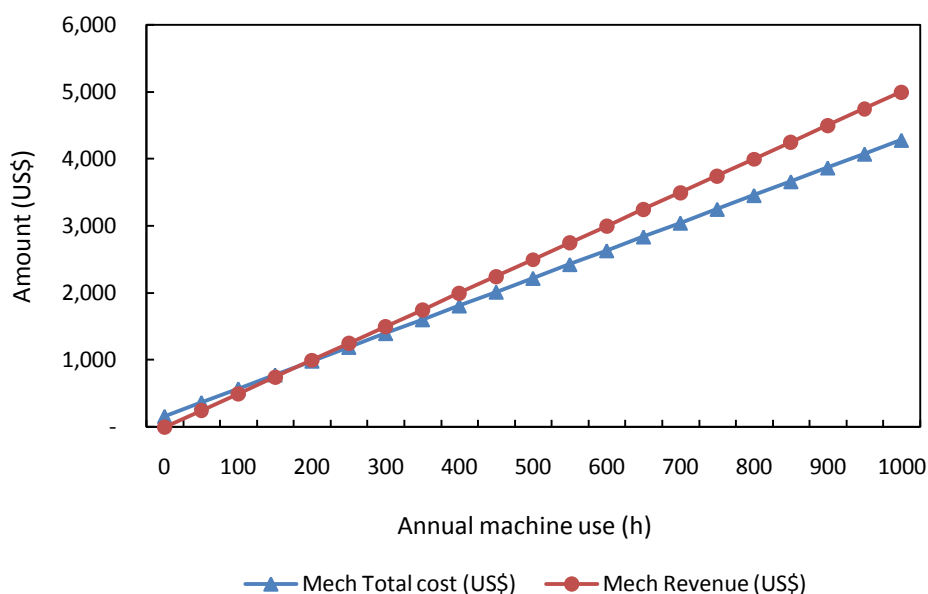
Figure 11. *Breakeven analysis of using the mechanical yam harvester*

The breakeven point for the hours of use of the mechanical yam harvester was 180 h which was equivalent to approximately 64 ha of yam field harvested. This implies that in a season the investment into a mechanical yam harvester for custom services can be recovered with substantial profit.

CONCLUSIONS

From the results of this study, the following conclusions can be made on the mechanical yam harvester:

1. The harvester performed satisfactorily on soils with minimal trash, moisture content ranged from 11.91 % d.b to 14.48 %d.b., bulk density ranged from 1.50 g/cm^3 to 1.62 g/cm^3, and cone penetration resistance of 0.41 to 1.33 MPa.

2. The harvester operated safely at an average soil depth range of 0.30 - 0.33 m and tuber depth of penetration ranging from 0.29 to 0.37 cm. The tuber length from 0.33 to 0.38 cm and tuber damage ranged from 1.96% and 3.45% irrespective of yam variety.

3. Tractor harvesting speed ranged from 1.04 to 1.31 m/s for ridged and mound landforms respectively whilst the field capacity ranged from 0.30 to 0.38 ha/h for ridged and mound landforms respectively. The fuel consumption ranged from 9.07 to 9.75 l/ha for mound and ridged landforms respectively whilst tractor wheel slip ranged from 2.93 to 3.79 % for mound and ridged landforms respectively.

4. Mounding offered lower resistance to tractor movement coupled with reduced engine fuel consumption and lower tractor wheel slip though ridging was better at considerably reducing tuber damage during harvesting with the mechanical harvester, irrespective of yam variety harvested.

5. Ridging method of land preparation was generally better than mounding at reducing the total cost of production.

6. The use of the mechanical yam harvester was much better at reducing the total harvesting cost (approximately 50% reduction) than manual harvesting options, irrespective of land preparation method. An added advantage of using the mechanical harvester was that the field was levelled after the harvesting operation. This offers an additional opportunity for immediate cropping.

7. With an investment of US$ 1500.00, the mechanical yam harvester at a fixed cost of US$ 158.25 per annum and a variable cost of US$4.13 per h, the breakeven point was 180 h of use (equivalent to 64 ha of field harvested) when hired for custom services at a cost of US$ 5.00 per h.

8. The harvester is recommended for use by farmers to reduce drudgery to expedite yam harvesting operations.

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