MECHANICAL CASSAVA HARVESTING AS INFLUENCED BY SEEDBED PREPARATION AND CASSAVA VARIETY


ABSTRACT. Cassava (Manihot esculenta Crantz) is the world’s third most important crop and an essential source of food and income throughout the tropics providing livelihood for over 500 million farmers and countless processors and traders. In Ghana, cassava contributes 22% of Agricultural Gross Domestic Product (AGDP) and is an emerging profitable industry crop. Large-scale cassava harvesting especially during the dry season is the greatest constraint to its industrial demand and commercial production. Manual harvesting is slow and associated with drudgery and high root damage in the dry season. A mechanical harvester is needed to break the labor bottleneck associated with cassava harvesting. Research on mechanization of cassava production however is very low, especially in the area of harvesting and currently there exists no known mechanical cassava harvesters in Ghana. The main objective of this study was to assess the response of five different cassava varieties to mechanical harvesting on ridged and flat landforms. Results from field trials using the tek mechanical cassava harvester showed that best performance was achieved on ridged landforms, which have better tuber yields and root tuber orientation. Among all the cassava varieties, “Nkabom” was generally found to more easily lend itself to mechanical harvesting due to its bunchy nature. The tek mechanical harvester worked best on fields with minimal trash or weeds and relatively dry soils with moisture content from 12%-16% d.b. and requires drafts of up to 10.33 kN with penetration depth from 23 to 29 cm. Best harvesting performance was achieved at a tractor speed of 5 km/h giving a field capacity of 1.9 to 2.5 h/ha. After mechanical harvesting, the field is left plowed with savings on fuel, time and cost. However, it is recommended to field evaluate the harvester in all agro-ecological zones and through a wide range of soil moisture regimes in Ghana to determine suitable areas for mechanical harvesting and to promote nationwide adoption.

Keywords. Cassava, Mechanical harvesters, Landform, Bunchy, Ghana.

Cassava is the world’s third most important crop and an essential source of food and income throughout the tropics (IFAD, AU, and NEPAD, 2008) and provides the livelihood for more than 500 million farmers and countless processors and traders (FAO and IFAD, 2000). It is the basic staple food of millions of people in the tropical and subtropical regions, as well as being a major source of raw material such as flour and starch for numerous industrial applications and animal food with worldwide acreage of more than 16 million ha and annual root yield of more than 170 million tons (Anderson et al., 2004). World cassava production for 2007 was estimated at 228 million tons, with 118 million tons in Africa, 72 million tons in Asia, and 37 million tons in South America (FAOSTAT, 2006). In Ghana, serious attention is being paid to the development and promotion of some traditional starchy staples to bridge the food production gap. In terms of relative importance, cassava is considered as a very important food crop which contributes substantially to the national economy (Apea Bah et al., 2003; CIA, 2010). In recent times, the crop has found new and profitable uses in industry and contributes 22% of Ghana’s Agricultural Gross Domestic Product (AGDP) (FAOSTAT, 2006) and a very useful raw material for the production of starch, bio-ethanol, and cassava flour and chips for export (Graffham et al., 2003; Ranola et al., 2009).

Due to the enormous benefit of cassava to the country’s economy, most farmers are gradually shifting from the small-scale and subsistence cassava cultivation to plantation farming because of the high industrial demand for the crop as part of what is described as the cassava transformation (FAO and IFAD, 2000). This transformation process has caused public research focus to be shifted onto improving cassava yields through more genetic research evidenced by the recent release of 14 high-yielding cassava varieties by the Root and Tuber
Improvement and Marketing Programme (RTIMP) under the Ministry of Food and Agriculture (MoFA) for multiplication in all the agro-ecological zones of Ghana. Some of these varieties take between 6 to 9 months to mature after planting. This without doubt, has gone a long way to dramatically help increase cassava production in terms of yield but on the other hand, created a challenge in terms of harvesting. Since these cassava varieties are relatively bulkier in size and go deeper into the soil, it is manually difficult to harvest them all year round, thus shifting the labor constraint from weeding to harvesting especially in the dry season.

PROBLEM STATEMENT AND JUSTIFICATION

Ghana is ranked sixth in world cassava production (Ennin et al., 2009). Cassava production increased from 1,894,000 tonnes in 1979-1981 to 9,739,000 tonnes in 2005, representing 414.2% increase (FAOSTAT, 2006). It has been demonstrated in some Asian countries, notably Thailand and Indonesia that industrializing cassava utilization could make remarkable contribution to developing economies (United Nations, 2008). Mechanization of cassava harvesting has been identified by cassava experts as the most promising area for intervention and for realizing the potential of this crop (FAO, 2002; AATF, 2007). Research on mechanization of cassava production is very low (IFAD and FAO, 2005), especially in the area of harvesting so far as Ghana is concerned. Without question, a mechanical revolution is now needed to break the labor bottleneck in cassava harvesting among farmers in Ghana who are planting the improved varieties (Nweke, 2004; IFAD and FAO, 2005).

Manual harvesting is slow and associated with drudgery and high level of root damage, requiring approximately 53 man days per ha (Nweke et al., 2002). This tends to increase the total cost of production because more farm hands are required to harvest in order to meet industrial demands coupled with an increase in cassava prices on the market which also tends to affect local consumption of the crop during such dry periods. It has also been noted by Peipp and Maehnert (1992) and Agbetoye (2003) that the most difficult operation in cassava production is cassava harvesting. Research conducted by Addy et al. (2004) in Ghana revealed that cassava harvesting constituted the highest production cost.

In the 1990s, a mechanized cassava harvester developed at the University of Leipzig, Germany was tested for the first time in Ghana by the Department of Agricultural Engineering of the Kwame Nkrumah University of Science and Technology, Kumasi. The harvester was field evaluated in 1992-1994 with the aim of modifying the design to suit local conditions (Bobobee et al., 1994). Finally in 2009, a modified version of the Leipzig harvester was fabricated for evaluation before subsequent dissemination to farmers. Earlier attempts at mechanical harvesting have been affected by constraints such as soil characteristics, nature and size of tubers, depth and width of cluster, and bond between tubers and the soil, leading to high tuber damage. Damaged cassava deteriorates rapidly after three days of harvesting. Matured roots of some cassava varieties spread over 1 m across row and penetrate 50-60 cm, thus making it difficult to readily mechanize harvesting due to the way the tubers grow (Bobobee et al., 1994; Kolawole et al., 2010).

Cassava could be planted on the flat, on ridges or on mounds. Traditionally, cassava is planted on the flat. Research conducted by Ennin et al. (2009) proved that planting cassava on ridges had the advantage of higher cassava root yield coupled with better and easier field management and has the potential for mechanization to further decrease drudgery and increase the scale of production of cassava compared to planting on the flat. However, there is the need to verify and ascertain this fact to aid in future recommendations.

OBJECTIVE

The main objective of this study was to assess the response of five different cassava varieties to mechanical harvesting on ridge and flat seedbed preparations.

The specific objectives of the study were to:
1. evaluate the performance of the tek mechanical cassava harvester on ridge and flat seedbed preparation.
2. determine among five varieties, the cassava variety that best facilitates mechanical harvesting.
3. identify the ideal seedbed preparation that gives maximum mechanical cassava harvesting efficiency.

MATERIALS AND METHODS

STUDY AREA

The study was conducted at Anwomaso (fig. 1), Kwame Nkrumah University of Science and Technology (KNUST) arable farms (6°41’56.75” N, 1°31’25.85” W) in the forest zone of the Ashanti Region. Anwomaso experiences a bimodal rainfall pattern and wet semi-equatorial climate. It is characterized by double maxima rainfall that occurs from March to July and September to November, which is ideal for two seasons cropping. The mean annual rainfall is 1200 mm. Temperatures range between 20°C (minimum) in August and 32°C in March (maximum). Relative humidity is fairly moderate but quite high during the rainy seasons and early mornings. Soils at Anwomaso are predominantly Forest Ochrosols (FAO, 1998).

LAND PREPARATION AND PLANTING

The study site (1.0 ha) was first plowed using a disc plow and then harrowed with a disc harrow to produce finer soil tilth. The field was then divided into two parts; one half each as flat and ridged seedbed/landform, respectively. Ridges were constructed 1.2 m apart (from crest to crest) and had an average height of 0.3 m. The field was planted to five different cassava varieties namely: “Afisiafi,” “Nkabom,” “Bankyehemaa,” “Dokuduade,” and “Esambankye,” which were obtained from the multiplica-
tion plots of the Root and Tuber Improvement and Marketing Programme (RTIMP) under the Ministry of Food and Agriculture (MoFA), Kumasi.

The cassava stems containing at least 4 to 5 nodes were cut into sizes 20 to 25 cm before planting. Planting was done manually with the use of a cutlass at a spacing of $1.2 \times 0.8$ m. A hole was created in the soil using the cutlass and the cutting inserted with the nodes facing upwards at an inclined angle of about $45^\circ$ with at least half of its full length inside the soil. Stakes were planted the same day after they were cut. This was done so as to prevent them from getting dehydrated and performing poorly when planted.

**FIELD MANAGEMENT**

Weeding was done manually using hoe and cutlass once every 2 months. However, at about 5 months, canopy formation prevents the weeds from growing so then selective hand picking of weeds was done from time to time. This is to make sure that the field is kept free of weeds so as not to impede or hinder mechanical harvesting.

**THE TEK MECHANICAL CASSAVA HARVESTER**

The TEK mechanical harvester (fig. 1) was developed and fabricated at the Department of Agricultural Engineering, Kwame Nkrumah University Science and Technology, Kumasi. The harvester basically consists of a digger, shakers including a slatted conical moldboard, the linkage points, and the vertical support.

The TEK mechanical cassava harvester is a fully mounted implement which operates according to the “dig and expose” principle. When hitched to the tractor, after having met the required field conditions, the implement is lowered to set the required depth to dig (depending on root depth of the cassava variety to be harvested). The digger goes into the soil and then digs out the cassava root cluster. Due to the inclination of the slatted conical moldboard (B), the roots are brought onto the surface for collection and detachment.

Mechanical cassava harvesting was done at 12 months after planting (MAP) at the peak of the dry season for each of the cassava varieties on both the flat and ridged landforms. Before harvesting, the cassava plants were coppiced, by manually cutting using a cutlass, to a stalk...
level of about 20 cm. This was to allow the tractor to be able to pass over the plants without any damage and also aid the operator to move in a more accurate path during harvesting. The farm was again cleared of all weeds 2 weeks prior to harvesting using post-emergence herbicides as these could block the shakers of the harvester and increase the draft on them. Before harvesting, the TEK mechanical harvesting implement was hitched to the tractor’s 3-point linkage system and the top link adjusted to obtain the required depth of penetration for the implement.

DATA COLLECTION

Soil Sampling

Soil samples were collected before plowing, after plowing and at harvest to identify trends and changes in soil conditions and assess their effects on mechanical harvesting. Five replicates were randomly taken for soil moisture content determination using a soil auger at depths of 0-10, 10-20, 20-30 and 30-40 cm whilst bulk density were determined at depths of 0-20 and 20-40 cm before plowing, after plowing and at harvest using a 5 cm diameter soil core sampler and a mallet. Soil samples were oven dried at a temperature of 105°C for 24 hours for soil moisture determination (DeAngelis, 2007).

Additionally, composite soil samples were taken using soil auger for chemical and physical analysis at depths of 0-20, 20-40 and 40-60 cm before plowing and at harvest. These soils were chemically analyzed for soil pH (1:1H2O), Organic Carbon content (%) using dichromate oxidation method (Walkley and Black, 1934), total Nitrogen (%) using the micro-diffusion method (Page et al., 1982), Exchangeable cations in me/100g (Ca, K, Mg, and Na) estimated in neutral 1 N ammonium acetate and determined using flame photometer (Systronics 128, Ahmedabad, India) (Knudsen et al., 1982), Base saturation (%), C.E.C (me/100g), Exchangeable Acidity (Al + H), Available P and K (ppm). Soil samples were also analyzed to determine their textural classes based on their sand (%), silt (%) and clay (%) content using the hydrometer method described by Day (1965). Penetrometer tests were carried out on-site at depths of 0-10, 10-20, 20-30, and 30-40 cm before plowing, after plowing and at harvest to determine the soil penetration resistances.

Agronomic Parameters

Cassava root orientation measurements which included the root cluster spread (cm) across and along the row, root depth penetration (cm), largest root diameter (cm) and longest root length (cm) were taken for both landforms. Root spread measurements were taken by carefully excavating the soil around the roots with the help of a cutlass. The root spread across and along row was measured. The foldable rule was placed along the direction of the row (flat or ridged) and then the tape placed perpendicular to it from the center of the plant to the end of the exposed roots and the measurement recorded as across. To take measurement along the row, the foldable rule was placed across the direction of row and then the tape placed perpendicular from the center of plant to the end of the farthest exposed root. For this study however, the interest was in the root tuber depth of penetration and total root tuber length across the row. Total root tuber length across the row was determined using equation 1.

\[
T_{ac} = L_1 + L_2
\]

where

\[
T_{ac} = \text{total root length across row},
\]

\[
L_1 \text{ and } L_2 = \text{root length in both directions across row}.
\]

Cassava yield measurements for both landforms at harvest were determined by manually uprooting and detaching the roots with a cutlass. Using an electronic balance, the yield by mass (kg) per plant was determined.

Root Tuber Damage Assessment

Damaged cassava root tubers per plant after harvesting and detaching each variety on both landforms were determined. The cassava percentage root tuber damage associated with each cassava variety and seedbed preparation was calculated using equation 2.

\[
\text{Percentage Damage} = \frac{\text{Mass of damaged roots (kg)}}{\text{Total root yield (kg)}} \times 100
\]

Tractor Wheel Slip

Ranging poles were placed 40 m apart, a short distance away from the area to be harvested and parallax obtained using extra ranging poles at both ends with the help of a surveyor’s measuring tape. The sides of both rear tires were marked with a chalk across the tire radius to serve as a reference for determining the number of revolutions made per 40 m distance. A stop watch was used to determine the time used for the tractor to cover the 40 m distance and to determine harvesting speed. The mechanical cassava harvester was hitched to the tractor in transport position and the tractor was allowed to move within the 40 m distance at normal plowing speed whilst recording the number of revolutions and the time taken to cover that distance (i.e., no-load distance) following the procedure by Smith et al. (1994). The same process was repeated for the implement in working condition, when it was lowered onto the soil and engaged to harvest (i.e., load distance).

Depth of Harvester Penetration

Depth of penetration after mechanical harvesting was determined using a depth measuring probe together with a measuring tape. This instrument is graduated with a handle for easy handling. During harvesting, the mechanical harvesting implement goes under the soil at a certain depth which varies from point to point along the row. The soil passes through the shakers of the harvester and falls back after the cassava roots are uprooted. The depth measuring probe was vertically pushed with minimal force through the soil until it hits a hard surface making it difficult to push the probe further. The foldable rule is placed horizontally on the soil surface to intercept the probe after which it is drawn out of the soil and the depth read from the graduations on it. This was repeated 50 times along the rows harvested for both ridged and flat landforms for each cassava variety.
**Implement Draft Measurement**

Implement draft was determined for the mechanical harvesting implement using a 10 tonne RON 2125 Dynamometer (fig. 2) according to the procedure by Smith et al. (1994).

The instrument is equipped with a data-logger which stores the force required to pull each implement in Kilo Newton (kN) making it possible to download stored data onto the computer for analysis using popular spreadsheet programs. The instrument was linked to a towing bar placed between two tractors. The instrumented tractor has the implement hitched to it and is set to a neutral gear and pulled by another tractor. Load and no-load draft forces were obtained for each implement in working and transport positions respectively.

Equations 3, 4, and 5 according to ASABE Standard EP496.3 (2006) were useful in calculating for the tractor power requirement and soil specific resistance (SSR).

\[ \text{Drawbar Power (kW)} = \frac{\text{Draft Force (kN)} \times \text{Average Speed (m/s)}}{0.19} \]  

\[ \text{Brake Horse Power (kW)} = \frac{\text{Drawbar Power (kW)}}{0.19} \]  

\[ \text{Soil Specific Resistance (kN/m}^2) = \frac{\text{Draft Power (kN)}}{\text{Width of cut (m)} \times \text{Depth of cut (m)}} \]  

Figure 3 depicts the implement draft measurement procedure with the tractor in-front pulling the instrumented tractor whilst the force required for the pulling being logged onto the RON 2125 Dynamometer.

**Fuel Consumption**

The tractor with implement was placed on a level ground on the field and the fuel tank filled to the brim. After the tractor has worked within a known area, it was brought to the same level ground and then with the help of a 1000 mL graduated measuring cylinder, the fuel used determined by filling the measuring cylinder to a known level and pouring into the tractor’s fuel tank until it is full to the brim. The amount of fuel was used for the top-up was then recorded as the fuel consumed by the tractor to work that known area (L/ha) as was employed by Smith et al. (1994) and AlHashem et al. (2000).

**Drudgery Measurements**

Polar heart rate sensing devices (RS800CX) were used to obtain the heart rate for the tractor operators during harvesting. The Polar heart rate sensor is an instrument that measures the heart beat rate during every physical activity. It has a strap that is worn around the chest area and a watch (monitor) with a sensor which reads the heart rate and logs it per pre-determined interval in seconds. Data stored was downloaded onto a computer for analysis. Figure 4 shows the Polar heart rate (RS800CX) watch and how the chest strap (with heart beat sensor) should be worn before an activity.

Before and after any field activity, the person is allowed a 10 min period of rest so the heart rate could be stabilized which are referred to as the rest and recovery periods, respectively. The period between the rest and recovery is the work period. This instrument can also calculate how much calories are burnt during any physical activity. This gives an idea of the amount of energy used or the drudgery involved in carrying out any physical work.

Graph in figure 5 shows a typical heart rate profile for a person before, during and after a physical activity recorded using the Polar heart rate watch and sensor (RS800CX).

Heart rate recordings were obtained for field workers during coppicing of the cassava prior to mechanical and manual harvesting, detachment of cassava tubers and gathering after harvesting. Knowledge on the amount of...
energy is used for carrying out a particular physical work is useful in determining the rest period (min/h) required by a person after work using equation 6, according to Jones et al. (1988).

\[ Tr = 60 \times \left( 1 - \frac{250}{P} \right) \]  

(6)

where

- \( Tr \) = total rest period (min/h),
- \( P \) = gross energy consumption (W).

Using the mean heart rate obtained for a particular field activity to trace for a corresponding energy consumption value on the heart rate - energy conversion chart (Jones et al., 1988), the Gross energy consumption (W) was determined.

### Field Capacity

The field capacity of the TEK mechanical cassava harvesters was determined by recording the time (seconds) taken to harvest a given area of the field. Since the harvester working width is 1 m, a distance of 40 m covered during the harvesting process between two fixed ranging poles meant that an area of 40 m\(^2\) (40 m \times 1 m) has been covered. Using equation 7, the field capacity in hours/hectare (h/ha) is then calculated.

\[ C = \frac{10000 \times t}{A \times 3600} \]  

(7)

where

- \( C \) = field capacity (h/ha),
- \( t \) = total time recorded during harvest (s),
- \( A \) = area harvested (m\(^2\)).

### Statistical Analysis

Descriptive statistics, i.e. means (using four 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 analyzed with Minitab Version 15 (2007). Statistical significance was carried out using Tukey and Fisher’s approach at \( p<0.05 \).

### Results and Discussion

#### Soil Mechanical Properties

Figures 6(a), (b), and (c) present the mean soil bulk density, moisture content, and cone index, respectively, before plowing, after plowing, and at harvest for study site.

Figure 6(a) shows a general increase in bulk density with depth before plowing, after plowing, and at harvest. This trend is in agreement with what Arshad et al. (1996) reported that bulk density increases with depth in the soil profile. Bulk density before plowing generally was lower than that after plowing. This could be attributed to the fact that the process of plowing breaks the soil into smaller clods causing these clods to be easily compacted when the tractor wheels pass over the soil during the plowing process. Again, soil samples were taken some days after plowing when the soil had achieved some degree of compaction. A report by the USDA (1999) considered that compacted soil layers have higher bulk densities. Bobobee et al. (1994) reported a maximum soil bulk density of 1.82 g/cm\(^3\) at harvest for the Leipzig harvester. Incidentally, harvesting was possible for the TEK mechanical cassava harvester with soil bulk density in the range of 1.48 to 1.69 g/cm\(^3\).

The graph in fig. 6(b) depicts that soil moisture generally increased with increasing depth before and after plowing and at harvest. At harvest, soil moisture ranged from 12.1\% to 15.7\% d.b. for respective increasing depths of 0-10, 10-20, 20-30, and 30-40 cm. The increasing moisture content down the soil profile could be due to the fact that the topsoil is exposed to the atmosphere and moisture evaporation is eminent and moving further down the profile, water that has infiltrated into the soil profile is kept intact because evaporation rate is slower.

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Results presented in figure 6(c) shows that soil penetration resistance generally increased with increasing depth and moisture content. At harvest penetration resistance ranged from 1.47 to 3.99 MPa with increasing soil depth of 0-10, 10-20, 20-30, and 30-40 cm and increasing moisture content. It was also realized that soil penetration resistance generally increased with increasing bulk density. Plowing
the soil generally reduced the penetration resistance as was observed up to soil depth of 25 cm which agrees with what was reported by Reichert et al. (2004).

SOIL CHEMICAL ANALYSIS

Table 1 shows the results and description of the chemical analysis done on soils at the study site to determine soil pH, O.C., C.E.C., and N after plowing and at harvest.

AGRONOMIC PARAMETERS

Depth of Root Tuber Penetration

Figure 7 shows the mean root tuber depth of penetration for “Afisiafi” (AF), “Nkabom” (NK), “Bankyehemaa” (BH), “Esambankye” (ES), and “Dokuduade” (DK) on both ridged (R) and flat (F) landforms at 12 MAP for study site before harvesting.

The mean depth of root tuber penetration for all five cassava varieties ranged from 21.6 to 29.4 cm. “Afisiafi” on ridge had the highest mean root tuber penetration depth of 29.4 cm while the same variety on the flat landform recorded the lowest depth of 20.6 cm.

At 5% significance level, the mean depth of root tuber penetration for “Afisiafi,” “Nkabom,” and “Bankyehemaa” varieties on ridged landforms were significantly different from all the others on respective landforms. However, there was no significant difference between root penetration depths for “Esambankye” and “Dokuduade” on both ridged and flat landforms at p<0.05. Generally, depth of root penetration irrespective of cassava variety on ridge landform was significantly higher than on flat, which quite disagrees with what was reported by Odigboh and Moreira (2002) and Sam and Dapaah (2009) that ridges are able to control cassava root tuber development to reasonable depths to allow for optimum mechanical harvesting. The reason for this disparity could be due to cassava varietal and soil differences. However, it could rather be deduced from this event that it is rather easier for cassava roots to bore through ridged landform than the flat.

Root Tuber Length across Row, along Row, and Yield

Table 2 presents the mean total root tuber length across row, along row and root tuber yields for all five cassava varieties on both ridged and flat landforms at harvest (12 MAP).
“Afisiafi” on ridge had the highest mean total root tuber length across row of 80.8 cm, whilst “Esambankye” on flat had the least (47.8 cm). On the other hand, “Dokuduade” on ridges had the highest mean total root tuber length along row of 99.2 cm whilst “Nkabom” on flat had the least (59.6 cm). Interestingly, there were no significant differences between the total root tuber length across and along row for all five cassava varieties on both ridged and flat landforms at p<0.05.

“Afisiafi” on ridges recorded the highest root tuber yield of 40.17 t/ha whilst “Dokuduade” on flat recorded the lowest yield of 18.20 t/ha. Though yield differences for all five cassava varieties between landforms were not significant at p<0.05, it still buttresses the report by Ennin et al. (2009) that planting cassava on ridges had the advantage of higher cassava root yield than on flat landform.

Generally all the mean total root tuber length across row recorded for the various cassava varieties on both landforms did not exceed the standard working width (100 cm) of the TEK mechanical harvester. Bobobee et al. (1994) reported that cassava root spread beyond one meter makes it difficult to readily mechanize. Thus it is expected that mechanically harvesting these cassava varieties should result in less root tuber damage.

**Harvesting Performance Evaluation**

### Depth of Harvester Penetration

Figure 8 presents the mean depth of harvester penetration for “Afisiafi” (AF), “Nkabom” (NK), “Bankyehemaa” (BH), “Esambankye” (ES), and “Dokuduade” (DK) on both ridged (R) and flat (F) landforms at harvest.

From graph in figure 8, “Afisiafi” on ridge recorded the highest significant (p<0.05) penetration depth of 28.8 cm during harvesting compared with the other varieties on respective landforms except that there was no significant difference when compared to “Dokuduade” on ridge.

“Esambankye” and “Nkabom” varieties on ridge both recorded the lowest harvester penetration depths of 22.7 cm. Generally, except for “Afisiafi” and “Dokuduade,” there was no significant difference (p<0.05) between

### Table 1. Chemical analysis and description of results (pH, O.C., C.E.C. and N) carried out on the soil at study site after plowing (AP) and at harvest (AH).

<table>
<thead>
<tr>
<th>Soil Depth (cm)</th>
<th>pH (1:1 H₂O)</th>
<th>O.C. (%)</th>
<th>C.E.C (me/100g)</th>
<th>N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>5.50</td>
<td>0.96</td>
<td>3.64</td>
<td>0.23</td>
</tr>
<tr>
<td>20-40</td>
<td>5.00</td>
<td>0.52</td>
<td>3.72</td>
<td>0.13</td>
</tr>
<tr>
<td>40-60</td>
<td>5.00</td>
<td>0.43</td>
<td>3.53</td>
<td>0.10</td>
</tr>
</tbody>
</table>

*Description of results: Strongly acidic, Very strongly acidic, Very low (<2%), Very low (<6), Low (0.2-0.5), Very low (<0.1)*

*Values followed by the same letter in the same group are not significantly different at p<0.05 according to Tukey and Fisher’s test.

### Table 2. Mean total root tuber length across row, along row (cm), and yield (t/ha).

<table>
<thead>
<tr>
<th>Cassava Variety – Landform[^a]</th>
<th>Total Root Length across Row (cm)</th>
<th>Total Root Length along Row (cm)</th>
<th>Root Tuber Yield (t/ha) [^b]</th>
</tr>
</thead>
<tbody>
<tr>
<td>BH-R</td>
<td>69.0</td>
<td>82.6</td>
<td>21.53b</td>
</tr>
<tr>
<td>BH-F</td>
<td>61.0</td>
<td>78.8</td>
<td>19.17b</td>
</tr>
<tr>
<td>AF-R</td>
<td>80.8</td>
<td>68.4</td>
<td>40.17a</td>
</tr>
<tr>
<td>AF-F</td>
<td>59.2</td>
<td>95.8</td>
<td>38.00a</td>
</tr>
<tr>
<td>ES-R</td>
<td>61.0</td>
<td>69.4</td>
<td>24.60b</td>
</tr>
<tr>
<td>ES-F</td>
<td>47.8</td>
<td>79.8</td>
<td>21.00b</td>
</tr>
<tr>
<td>DK-R</td>
<td>73.4</td>
<td>99.2</td>
<td>21.47b</td>
</tr>
<tr>
<td>DK-F</td>
<td>73.0</td>
<td>94.2</td>
<td>18.20b</td>
</tr>
<tr>
<td>NK-R</td>
<td>60.0</td>
<td>62.0</td>
<td>35.50a</td>
</tr>
<tr>
<td>NK-F</td>
<td>50.4</td>
<td>59.6</td>
<td>34.67a</td>
</tr>
<tr>
<td>LSD</td>
<td>ns</td>
<td>ns</td>
<td>4.64</td>
</tr>
</tbody>
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[^a]: “Bankyehemaa” on ridge and flat (BH-R and BH-F), “Afisiafi” on ridge and flat (AF-R and AF-F), “Esambankye” on ridge and flat (ES-R and ES-F), “Dokuduade” on ridge and flat (DK-R and DK-F) and “Nkabom” on ridge and flat (NK-R and NK-F) at 12 MAP.

[^b]: Values followed by the same letter in the same group are not significantly different at p<0.05 according to Tukey and Fisher’s test.
depth of harvester penetration on ridged and flat landform during harvesting.

With reference to figure 7, it is expected that “Afisiafi” on ridge for instance would certainly experience some level of root tuber damage due to the fact that the harvester mean depth of penetration recorded was lower than the mean depth of root tuber penetration (29.4 cm). It is therefore vital for a tractor operator to have an idea of the mean root tuber depth for the cassava variety to be harvested in order to prevent or minimize root tuber damage during harvesting.

**Root Tuber Damage, Field Capacity, Harvesting Speed and Wheel Slip**

Table 3 presents the mean percentage root tuber damage, field capacity, harvesting speed and wheel slip for all five cassava varieties on both ridge and flat landforms at harvest.

The table of results clearly depicts that for all four parameters (root tuber damage, field capacity, harvesting speed, and wheel slip) there were no significant differences (p<0.05) between landforms and cassava varieties. However, it could generally be stated that percentage root tuber damage was lower on ridge landform compared to the flat. “Afisiafi” on flat recorded the highest root tuber damage of 19.1% whilst “Nkabom” on ridge recorded the lowest (9.5%). Bobobee et al. (2000) reported 10.7% tuber damage for the Leipzig mechanical harvester while Kolawole et al. (2010) reported 23.3% tuber damage for a mechanical harvester field evaluated in Nigeria.

Though there was no significant difference in percentage root tuber damage between landform and cassava variety, it could clearly be seen that the “Nkabom” variety generally recorded the least. This could be due to the bunchy nature of its roots compared to the other varieties, making it easier to mechanically harvest with less root tuber damage.

Field capacity values ranged between 2.52 h/ha for “Nkabom” on flat and 1.89 h/ha for “Bankyehemaa” on ridge. Bobobee et al. (1994) reported a range of 2.63 to 4.0 h/ha for the Leipzig harvester. Ospino et al. (2007) also, reported a mean field capacity range of 1.0 to 1.6 h/ha for the CLAYUCA Cassava Harvester Model P600 and Oni (2005) reported a range of 0.83 to 1.25 h/ha for the NCAM harvester. It could, however, be deduced from the field capacity values that though no significant difference exists (p<0.05), it would practically require less time to harvest a hectare of cassava field mechanically on the ridge than on flat landform. This is in agreement with findings of Sam and Dapaah (2009), Ennin et al. (2009), and Ekanayake et al. (1997) that ridges lend themselves easily to mechanization in terms of harvesting compared to the flat landform.

Harvester working speed ranged between 5.19 km/h for “Bankyehemaa” on flat and 4.72 km/h for “Nkabom” on the ridge landform. This working speed range was however higher than what Bobobee et al. (1994) reported for the Leipzig mechanical harvester with a working speed range of 2.4 to 4.1 km/h but lower than what Ospino et al. (2007) also reported for the CLAYUCA Cassava harvester prototype with an operational speed of 7.0 km/h. It must however be noted that operator experience during mechanical harvesting could also affect the timeliness of the operation and working speed.

Wheel slip values recorded at harvest ranged between 12.06% for “Bankyehemaa” on flat and 20% for “Nkabom” on ridge landform. Figure 9 depicts a linear correlation plot between tractor wheel slip and moisture content. From the graph in figure 9, it could be deduced that wheel slip increased with increasing moisture content at harvest on both ridge and flat landforms. Also, according to

![Figure 9. Correlation between soil moisture content and tractor wheel slip at harvest.](image)

**Table 3. Mean root tuber damage (%), field capacity (h/ha), harvesting speed (km/h) and wheel slip (%).**

<table>
<thead>
<tr>
<th>Cassava Variety – Landform</th>
<th>Root Tuber Damage (%)</th>
<th>Field Capacity (h/ha)</th>
<th>Harvesting Speed (km/h)</th>
<th>Wheel Slip (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BH-R</td>
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<td>1.89</td>
<td>4.98</td>
<td>15.56</td>
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<tr>
<td>BH-F</td>
<td>14.8</td>
<td>2.12</td>
<td>5.19</td>
<td>12.06</td>
</tr>
<tr>
<td>AF-R</td>
<td>11.6</td>
<td>2.10</td>
<td>4.96</td>
<td>15.93</td>
</tr>
<tr>
<td>AF-F</td>
<td>19.1</td>
<td>2.27</td>
<td>4.83</td>
<td>18.11</td>
</tr>
<tr>
<td>ES-R</td>
<td>9.7</td>
<td>2.14</td>
<td>4.98</td>
<td>15.54</td>
</tr>
<tr>
<td>ES-F</td>
<td>12.4</td>
<td>2.18</td>
<td>4.91</td>
<td>16.75</td>
</tr>
<tr>
<td>DK-R</td>
<td>13.4</td>
<td>2.15</td>
<td>4.80</td>
<td>18.58</td>
</tr>
<tr>
<td>DK-F</td>
<td>15.0</td>
<td>2.39</td>
<td>4.83</td>
<td>18.17</td>
</tr>
<tr>
<td>NK-R</td>
<td>9.5</td>
<td>2.27</td>
<td>4.72</td>
<td>20.00</td>
</tr>
<tr>
<td>NK-F</td>
<td>10.0</td>
<td>2.52</td>
<td>4.94</td>
<td>16.24</td>
</tr>
</tbody>
</table>

LSD: ds ns ds ns

*Values followed by the same letter in the same group are not significantly different at p<0.05 according to Tukey and Fisher’s test.*

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**Figure 8. Mean Depth of harvester penetration (cm) for five cassava varieties on both ridged and flat landforms.**

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**Figure 9. Correlation between soil moisture content and tractor wheel slip at harvest.**
Pearson correlation test, there was significant difference (n=28; r=0.59 at 0.05 probability level) between soil moisture content and wheel slip. This trend agrees with what was reported by Zoz and Grisso (2003) and Inchebron et al. (2012).

**Fuel Consumption**

Figure 10 depicts the mean fuel consumption for “Afisiafi” (AF), “Nkabom” (NK), “Bankyehemaa” (BH), “Esambankye” (ES), and “Dokuduade” (DK) on both ridged (R) and flat (F) landforms at harvest.

Fuel consumption ranged between 26.85 L/ha for “Esambankye” on ridge and 21.85 L/ha for “Afisiafi” on flat. It was however realized from results recorded that irrespective of the landform or cassava variety, fuel consumption was not significantly different at p<0.05.

**Heart Rate and Drudgery**

Table 4 presents the mean heart rate, energy expenditure, and rest period for tractor operator during mechanical harvesting and for three field workers during manual harvesting for all five cassava varieties on both ridge and flat landforms.

For mechanical harvesting, the highest mean heart rate recorded for the operator was 102.50 bpm with a corresponding energy expenditure of 550.52 W and rest period of 32.25 min/h during harvesting of “Dokuduade” on flat, whilst harvesting “Nkabom” variety on flat gave the lowest mean heart rate of 95.53 bpm corresponding to 471.48 W of energy and rest period of 28.19 min/h. Though both extremes of heart rate values recorded for the operator were significantly different at 5% level of significance, there was generally no significant difference between operator heart rate during harvesting on ridge and flat landforms for all cassava varieties except “Bankyehemaa.”

Manually harvesting “Afisiafi” on flat recorded the highest mean heart rate value of 126.59 bpm with a corresponding energy expenditure of 831.12 W and rest period of 41.95 min/h whilst harvesting “Nkabom” variety on ridge recorded the lowest significant (p<0.05) mean heart rate of 99.41 bpm with corresponding energy expenditure of 513.14 W and 30.77 min/h rest period.

It could be deduced from the tractor operator’s heart rate values that it was easier (less drudgery) harvesting “Nkabom” variety than the others. Interestingly, it is also easier to manually harvest “Nkabom” cassava variety, especially on the ridge as compared to the others. However, it could be concluded from table 4 that heart rate, energy expenditure and rest period during mechanical harvesting

*No significant differences among treatments at p<0.05 according to Tukey and Fisher’s test.*

![Figure 10. Mean fuel consumption (L/ha) for five cassava varieties on both ridged and flat landforms at harvest.](image)

<table>
<thead>
<tr>
<th>Table 4. Mean heart rate (bpm), energy expenditure (Watts) and rest period (min/h).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical Harvesting</td>
</tr>
<tr>
<td><strong>Cassava Variety - Landform</strong></td>
</tr>
<tr>
<td>BH-R</td>
</tr>
<tr>
<td>BH-F</td>
</tr>
<tr>
<td>AF-R</td>
</tr>
<tr>
<td>AF-F</td>
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<tr>
<td>ES-R</td>
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<td>ES-F</td>
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<td>DK-F</td>
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<tr>
<td>NK-R</td>
</tr>
<tr>
<td>NK-F</td>
</tr>
<tr>
<td>LSD</td>
</tr>
</tbody>
</table>

[b] “Bankyehemaa” on ridge and flat (BH-R and BH-F), “Afisiafi” on ridge and flat (AF-R and AF-F), “Esambankye” on ridge and flat (ES-R and ES-F), “Dokuduade” on ridge and flat (DK-R and DK-F) and “Nkabom” on ridge and flat (NK-R and NK-F) during mechanical and manual harvesting.

[b] Values followed by the same letter in the same group are not significantly different at p<0.05 according to Tukey and Fisher’s test.
were significantly (p<0.05) lower than those recorded during manual harvesting. This means that in terms of energy expenditure (drudgery), it is more difficult to manually harvest cassava compared to mechanical harvesting irrespective of variety and landform, which is in agreement with what was reported by Bobobee et al. (1994) and Ospino et al. (2007).

It could also be seen from table 4 that the more energy expended during harvesting, the longer the rest (recovery) period required, compensating for the lost energy. Thus the energy consumption is directly proportional to the total rest period required. This relationship between energy consumption and rest period agrees with what was reported by Crouter et al. (2004), Freedson and Miller (2000), and Ericsson et al. (2006).

Implement Draft and Tractor Power Requirement

Table 5 presents the mean draft force of the mechanical harvester as used to determine the tractor power (Brake horsepower) requirement during mechanical harvesting for all five cassava varieties on both ridge and flat landforms.

From the table of results, “Afsiafi” on flat recorded the highest significant (p<0.05) implement draft of 10.33 kN with a corresponding tractor power requirement of 72.96 hp, whilst “Esambanky” on ridge recorded the lowest draft of 8.15 kN with a corresponding tractor power requirement of 59.34 hp. Draft force range of 11.94 to 16.2 kN was reported for the Leipzig mechanical cassava harvester by Bobobee et al. (1994).

From results presented in table 5, it means that the tek mechanical cassava harvester requires a tractor of at least 59.34 hp for optimal operation under given soil conditions. Bobobee et al. (1994) reported a tractor power requirement of 69 to 107 hp for the Leipzig harvester prototype while 90 hp was reported for the CLAYUCA Cassava Harvester Prototype by Ospino et al. (2007). It means that in terms of draft and tractor power requirement, the tek mechanical cassava harvester is better than both the Leipzig and CLAYUCA harvester prototypes. It is also worth noting that implement draft and soil specific resistance were generally lower on the ridge compared to the flat landform at p<0.05 irrespective of cassava variety.

CONCLUSION AND RECOMMENDATION

Mechanical harvesting was possible at a bulk density of 1.48 to 1.69 g/cm³, soil moisture content of 12% to 16% d.b., soil penetration resistance of 1.47 to 3.99 MPa and at a penetration depth of 22.7 to 28.8 cm. The tek mechanical harvester performs optimally at a speed of 4.72 to 5.19 km/h and a wheel slip of 12.06% to 20% at a field capacity of 1.89 to 2.52 h/ha and requires between 21.85 and 26.85 L of fuel per hectare.

The tek mechanical harvesting implement in working condition produces a draft of 8.35 to 10.33 kN with corresponding specific draft (soil specific resistance) of 32.42 to 42.12 kN/m² and requires a tractor of at least 60 hp to operate it. However, best performance of the tek mechanical harvester was achieved on ridge landform with minimum trash. It is without doubt that mechanical harvesting irrespective of landform or cassava variety is less difficult compared to manual harvesting.

Among all the cassava varieties, “Nkabom” was generally found to best facilitate mechanical harvesting due to its bunchy nature. It is therefore recommended that breeders come out with varieties that have similar traits like the “Nkabom” to aid in efficient mechanical harvesting. It is also recommended that further test and evaluation of the tek mechanical cassava harvester be carried out under different soil types and soil moisture regimes to promote nationwide adoption. Moreover, detailed research should be carried out concerning the economic viability of mechanical cassava harvesting.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the financial support from the Ghana Government through MOFA/CSIR-WAAPP Project NCRG No. 007, the Kwame Nkrumah University of Science and Technology (KNUST), and the technical supports from the staff of the Department of Agricultural Engineering Workshop and GAMBOPAT Engineering Limited. We also wish to thank MOFA-RTIMP and CALTECH Ventures for their collaborative supports during preliminary field testing. Finally, the authors are grateful to the anonymous reviewers of this article for their constructive criticisms.

<table>
<thead>
<tr>
<th>Cassava variety-Landform[^b]</th>
<th>Draft (kN)</th>
<th>Speed (m/s)</th>
<th>Depth of Penetration (cm)</th>
<th>Width of Cut (m)</th>
<th>SSR (kN/m²)</th>
<th>Drawbar Power (kW)</th>
<th>Power Requirement (hp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BH-R</td>
<td>9.85a</td>
<td>1.38</td>
<td>0.26</td>
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<td>38.04</td>
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</table>

[^b] “Bankyehemam” on ridge and flat (BH-R and BH-F), “Afsiafi” on ridge and flat (AF-R and AF-F), “Esambankye” on ridge and flat (ES-R and ES-F), “Dokudua” on ridge and flat (DK-R and DK-F), and “Nkabom” on ridge and flat (NK-R and NK-F)

[^a] Values followed by the same letter in the same group are not significantly different at p<0.05 according to Tukey and Fisher’s test.
REFERENCES


