academicJournals

Vol. 12(5), pp. 309-319, 2 February, 2017
DOI: 10.5897/AJAR2016.11874
Article Number: 55385F562563
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Performance of an improved manual cassava harvesting tool as influenced by planting position and cassava variety

Shadrack Kwadwo Amponsah*, Joseph Nketiah Berchie, Joseph Manu-Aduening, Eric Owusu Danquah, Jonas Osei Adu, Adelaide Agyeman and Enoch Bessah

CSIR - Crops Research Institute, Kumasi, Ghana.

Received 26 October, 2016; Accepted 3 January, 2017

Cassava has become an important food security crop in Ghana over the years and in most parts of sub-Saharan Africa; making it the single most important source of dietary energy. Harvesting, one of the serious bottlenecks in the cassava production value chain, has received little attention in terms of mechanisation. Earlier attempts at mechanising cassava harvesting have been challenged mainly by inappropriate method of planting, field topography and scale of cultivation. The objective of this study was to field evaluate the efficiency of an improved manual cassava harvesting tool under three different planting positions for four cassava varieties in terms of field capacity, level of drudgery and root tuber damage. Force requirement in uprooting different cassava varieties was also determined. The study was conducted at the research field of Crops Research Institute, Fumesua. Field capacity of improved manual harvesting tool ranged from 49.9 to 156 man-h/ha, root tuber breakage from 4.32 to 19.55% and harvesting energy consumption ranging from 470.34 to 773.72 W across cassava varieties and planting positions. Nkabom cassava variety was easiest in uprooting, irrespective of planting position while Sikabankye variety offered the best in terms of root tuber damage and drudgery. Again, it was faster harvesting vertically planted cassava though cassava planted slanted offered the least root tuber breakage and drudgery, regardless of cassava variety. Cassava uprooting force ranged from 86.8 to 143.3 kg, rooting depth from 22.39 to 26.86 cm and cassava yield per plant ranging from 5.84 to 13.14 kg. Further research to identify the relationship between uprooting force requirement and some cassava agronomic parameters is recommended.

Key words: Cassava, field capacity, drudgery, planting position, tuber breakage, uprooting force.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a perennial woody shrub native to Latin America (Bellotti et al., 2011; El-Sharkawy, 2012) and is primarily grown as an annual crop in the humid tropics. It is currently the world's fourth most important staple and carbohydrate rich food crop (El-Sharkawy, 2012). Sufficient cassava is consumed as food to provide one billion people with 20% of their dietary energy requirement, and more than 700 million people are highly dependent on cassava as a food (Cock, 2011). Cassava end products range from fresh roots cooked, boiled, baked or fried at the household level, to highly processed starch as a food additive (Tufan, 2013).

In Africa, cassava is the single most important source of dietary energy for a large proportion of the population living in the tropical areas (Cock, 2011). Tufan (2013) reiterated that no other continent depends on cassava to feed as many people as does Africa, where 500 million people consume it daily. Moreover, in Africa where 40% of the population consumes cassava as a staple crop, cassava is the second most important staple crop after maize; making the crop indispensable to food security in Africa. FAOSTAT (2013) indicates that out of a total world cassava production of 233,796,000 ton, Africa accounts for 51% followed by Asia with a production of 35%, and the remaining production of 14% going to the Americas. Though Africa's cassava production is largely small-scale, it accounts for more than half of the world's cassava, or about 86 million tons from over 10 million hectares (Tufan, 2013).

Currently in Ghana, serious attention is being paid to the development and promotion of some traditional starchy staples to bridge the food production gap (Amponsah et al., 2014). According to FAOSTAT (2013), Ghana is the sixth largest producer of cassava in the world in terms of value, with the crop constituting 22% of Ghana's Gross Domestic Product (GDP). Cassava has become important and popular staple for varied preparations including fufu (pounded cassava usually mixed with plantain or cocoyam), akple, ampesi (boiled cassava), yakeyake, tapioca, agbelikaklo, kokonte, gari, etc. Cassava's adaptability to most ecological zones and its hardiness to withstand extremes of weather has made it a life saver, particularly to the lower income bracket of Ghana (Amponsah, 2011). In recent times, aside the production of high quality cassava flour (HQCF) for use in wood industries, cassava has found new uses in the brewery industry for the preparation of beer and other alcoholic beverages. Despite the enormous importance of cassava for food security in Ghana and the sub-Saharan Africa as a whole, it has received relatively little research and development attention compared to other staples such as wheat, rice and maize, especially in the area of mechanisation.

Cassava harvesting, though very crucial, is one of the serious bottlenecks in the cassava production value chain. Agbetoye (2003) identified harvesting as the most difficult operation in cassava production. Studies by Addy et al. (2004) also revealed that cassava harvesting constituted the highest production cost. Harvesting too early or late also has serious consequences on the quality of harvested roots (Moore and Lawrence, 2003). Cassava is ready for harvest as soon as there are storage roots large enough to meet the requirements of the consumer, starting from six-seven months after planting, especially for most of the new cassava cultivars (Ekanayake et al., 1997). Cassava can either be harvested manually or mechanically. Manual cassava harvesting is usually done by hand; lifting the lower part of stem and pulling the roots out of the ground, then detaching them from the base of the plant by hand after the upper parts of the stem with the leaves are removed. Manual harvesting may also employ harvesting tools such as hoe, cutlass, mattock, earth chisel, etc. Studies by Amponsah et al. (2014) revealed that harvesting with an improved manual harvesting tool used to diminish about half the time required for manual cassava uprooting with bare hands. Mechanical harvesting of cassava involves the use of a harvesting implement integrally hitched to a tractor to uproot the cassava roots. Mechanical harvesting, though better, is often unavailable or unaffordable to these resource poor farmers (Amponsah, 2011).

Ghana's cassava production is predominantly small-scale (Nweke, 2005); covering just about 1 to 2 acres. Thus, even in places where such mechanised options are available, it becomes unwise to adopt because of the smaller field size. Again, most cassava fields are located in places where topography is a serious challenge, making use of tractors virtually impossible. Moreover, the farmer's practise of intercropping and the flat method of planting does not favour mechanisation (Amponsah et al., 2014). It is worth noting that in Ghana, because a larger proportion of cassava harvested on small-scale is mostly consumed domestically for varied food preparations, marketers would reject roots that are broken, damaged, cut or bruised since consumers would mostly buy and keep their cassava for a while before use. The farmer runs at a loss when damage to roots is severe. Amponsah (2011) concluded that cassava root tuber breakage or damage is therefore a major factor to consider in the selection and adoption of any type of harvesting method depending on the end use of the harvested produce. Thus, where cassava root tuber damage or breakage is of great concern, manual harvesting is preferred to mechanical harvesting method. Without doubt, developing and adopting simple but efficient energy-saving manual harvesting tools and equipment is a sure way forward in overcoming these challenges in cassava harvesting.

Different cassava planting positions or stake orientations could be followed depending upon the type and condition of soil (Ekanayake et al., 1997; CTCRI, 2012). Stakes can be planted vertically (buds facing up with two-thirds of the stake in the soil), horizontally (whole stake buried 3-5 cm in the soil) or inclined (buds facing up with two-thirds of the stake buried in the soil at an angle of about 45º). According to Ekanayake et al. (1997), when stakes are planted vertically, tuberous roots

*Corresponding author. E-mail: skamponsah@hotmail.com.

bulk deep into the soil. Although this gives more stability to the plant against lodging, it makes harvesting very difficult. This orientation is recommended for sandy soils. Stakes planted horizontally produce multiple stems and more tuberous roots but they are comparatively smaller in size. The roots are produced near the surface and they are easily exposed to mechanical damage and to rodents. However, in loamy and rich soils the multiple stems and roots are at an advantage resulting in high yields. Stakes that are inclined on the ridge produce tuberous roots in the same direction. The inclination of the stem and roots provide a leverage which makes harvesting easier than in the other orientations. In shallow and clayey soils, stakes should be inclined (Ekanayake et al., 1997). Studies by Abdullahi et al. (2014) and Legese et al. (2011) concluded that storage roots yield of cassava could be enhanced by planting cuttings in an inclined or slanted position. Keating et al. (1988) however, reported that planting orientation did not have significant effect on growth and yield of cassava. There's an unending controversy about the ideal planting position for cassava in Ghana and the sub- Saharan Africa as a whole. Unfortunately, there's currently no information on ideal planting position for improved yield and enhanced manual harvesting efficiency.

Furthermore, in the area of cassava harvesting in Ghana currently, there is little information on the drudgery levels, percentage tuber breakage and field capacities associated with such an improved manual cassava harvesting tool. Since its development and first field testing and evaluation in Ghana in 2010 (Amponsah, 2011), the improved manual harvesting tool has again been tested and evaluated in Trivandrum, India by Amponsah et al. (2014) after its modified design was finalised and fabricated. Moreover, there is no information on force requirement for manual harvesting under different soil conditions and cassava varieties. Due to the fact that different cassava varieties will respond differently under different planting conditions (Amponsah et al., 2014) such information will be useful to engineers in the design of appropriate harvesting tools and implements in the future.

Objective of study

The objective of the study was to assess the response of four different cassava varieties to manual harvesting under slanted, vertical and horizontal planting positions using an improved manual cassava harvesting tool. Specifically, the study sought to:

1. Evaluate the performance of the improved manual harvesting tool under different cassava planting positions.
2. Identify the ideal planting position that gives maximum manual harvesting efficiency.
3. Determine among four varieties, the cassava variety that best facilitates manual harvesting.
4. Determine the force requirement for harvesting the various cassava varieties under different planting positions.

MATERIALS AND METHODS

Study area

The study was carried out at the CSIR-Crops Research Institute research field, Fumesua (01° 28′ N 06° 41′ W), near Kumasi in the Ashanti Region of Ghana. Fumesua is classified under the moist semi-deciduous forest agro-ecological zone. It is characterized by a bimodal rainfall pattern. The major rainfall season starts in March or April and usually terminates in early August. The minor season is from September to December. The annual rainfall ranges between 1250 and 1500 mm and temperatures range between 20°C (minimum) in August and 32°C in March (maximum). Soils at the study area are predominantly Ferric Acrisol (FAO/UNESCO) or Oxic Haplustult (USDA – Soil Taxonomy) and are classified under "Bomso series" (Dedzoe et al., 2004). The soil at the study area was sandy loam in texture.

Experimental details

A split plot design with three replicates was used for this study. The main plot treatments were the four cassava varieties; *Bankyehemaa*, *Nkabom*, *Sikabankye* and *Ampong* whereas the three cassava planting positions; vertical, horizontal and slanted were the subplot treatments.

Cassava varieties and planting position

Cassava planting materials were obtained from the multiplication plots of the Root and Tuber section of CSIR - Crops Research Institute, Fumesua. Each cassava variety was planted under the flat method of planting in three different positions; vertical, horizontal and slanted (Figure 1) at a spacing of 1 m × 0.8 m (Adekunle et al., 2004).

The cassava sticks containing at least 4 to 5 nodes were cut into sizes 20 to 25 cm before planting. Cassava harvesting trials were conducted at the study site on all four cassava varieties at 12 months after planting (MAP) using the improved manual harvesting tool.

The improved manual harvesting tool

Cassava is mostly harvested by hand, lifting the lower part of stem and pulling the roots out of the ground, then detaching them from the base of the plant by hand after the upper parts of the stem with the leaves are removed. The use of manual harvesting tools helps in loosening or reducing the soil forces on the cassava root tubers in order to make it easier to uproot them (Amponsah et al., 2014). For this study, an improved manual harvesting tool (Figure 2) was used.

The harvesting tool was constructed at the CSIR-Crops Research Institute mechanical workshop with the idea of reducing the drudgery of farmers due to waist bending associated with the other harvesting tools which usually lead to waist pains and other bodily weaknesses. The original design was first adopted from the International Institute of Tropical Agriculture (IITA) in Nigeria. Several modifications have since been made to overcome some of its design constraints (Amponsah, 2011). The harvesting tool operates according to the 'grip and lift' principle. It consists of a

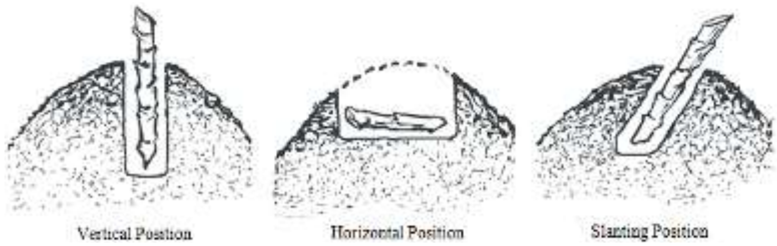

Figure 1. Different cassava planting positions.

Figure 2. The improved manual cassava harvesting tool.

Figure 3. The Eijkelkamp penetrologger in operation.

frame to which an immovable griping jaw is attached and a chisel tip which serves as the base for lifting cassava from the soil. The chisel tip can also be used to dig out cassava roots especially in hard and dry soils, where the grip and lift principle becomes difficult to employ due to the tendency of high root tuber damage or breakage. The harvesting tool, operating under the second class lever principle, has a mechanical advantage of 4.5. Its total weight of 5 kg makes it possible for even women and children to easily operate and use the tool for manual cassava harvesting.

Soil sampling

Three replicates of soil samples at harvest were randomly taken for soil moisture content and bulk density determination at depths of 0-10, 10-20, 20-30 and 30- 40 cm using a soil auger and a 5 cm diameter soil core sampler with a mallet respectively. Soil samples were oven dried at a temperature of 105˚C for 24 h for soil moisture determination (DeAngelis, 2007). Additionally, composite soil samples were also taken and analysed to determine their textural classes based on their sand (%), silt (%) and clay (%) content. Penetrometer tests using an Eijkelkamp penetrologger (Figure 3) were carried out on-site at depths of 0-10, 10-20, 20-30 and 30-40 cm at harvest to determine the soil penetration resistances (soil strength).

Harvesting force requirement

The force required for uprooting 50 plants of each cassava variety under different planting positions was determined using a force measuring apparatus (Figure 4).

The setup is composed of a metallic handle to which a modified spring balance is attached to show weight readings (in kilograms) during the cassava uprooting process. Modification of the spring balance was done by attaching a dummy dial beneath the original one. The idea is that the original dial comes back to zero at no load, thus there is the need to have a secondary (dummy) dial which will be dependent on the movement of the primary dial to assist in getting the right reading even after load is taken off the spring balance. However, the dummy dial was always reset to zero before each loading of the spring balance was done. The stem gripping

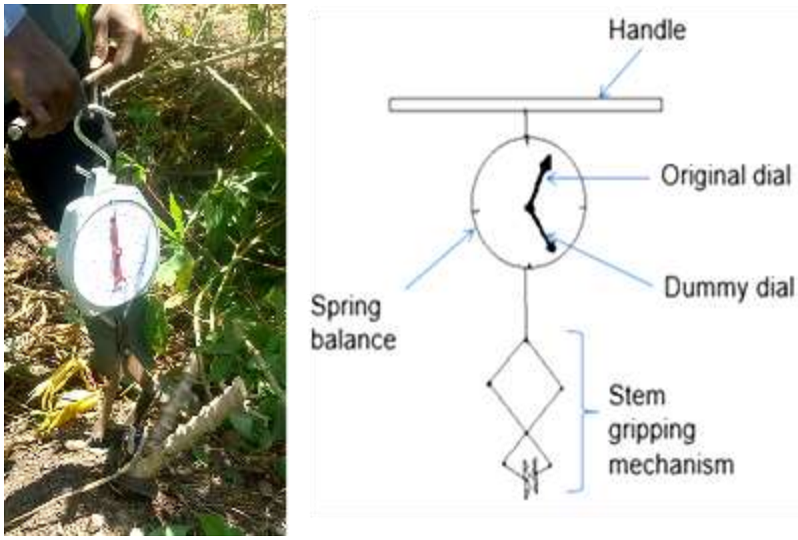

Figure 4. Cassava uprooting force measuring apparatus.

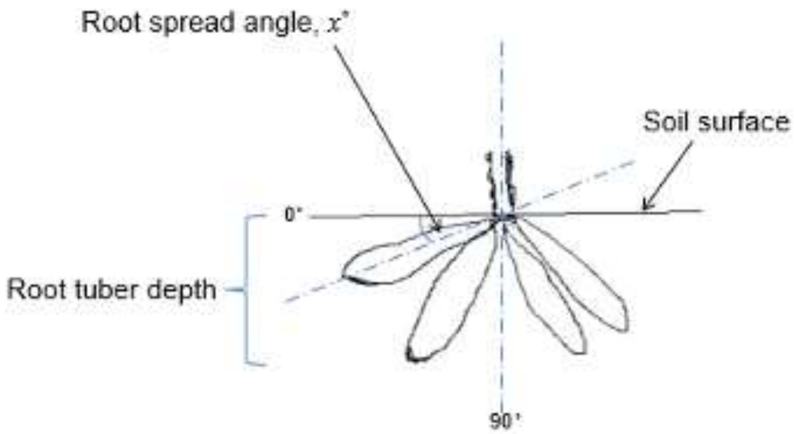

Figure 5. Cassava root orientation measurement.

mechanism is firmly attached to the cassava stem and with the help of the handle; a steady vertical force is applied to uproot the cassava. The reading as indicated by the dummy dial is then recorded after the uprooting process is ended.

Agronomic parameters

Agronomic parameters including stem girth (cm), maximum root diameter (cm) maximum root length (cm), maximum root depth (cm), number of root tubers and root spread (degrees) were determined at harvest for 30 plants of each cassava variety. Root spread was measured using a protractor with reference to the soil surface from both sides of the plant (Figure 5); stem girth and maximum root diameter were measured using a digital Vernier calliper, whereas maximum root length and depth were taken using a tape measure. Cassava root tuber yield and damaged (broken) root tubers after harvest were determined using an electronic balance. For purposes of this study however, only rooting depth and yield per plant were used.

Drudgery measurements

Polar heart rate sensing device (RS 400) was used to obtain the heart rate for each person during manual 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 6 shows the polar heart rate (RS 400) watch and how the chest strap (with heart beat sensor) should be worn before an activity.

Before and after any field activity, the person was allowed ten minutes' period of rest so the heart rate could be stabilized which are referred to as the rest and recovery periods respectively. Figure 7 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 (RS 400).

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

Figure 6. The Polar (RS 400) watch and chest strap as worn by a person.

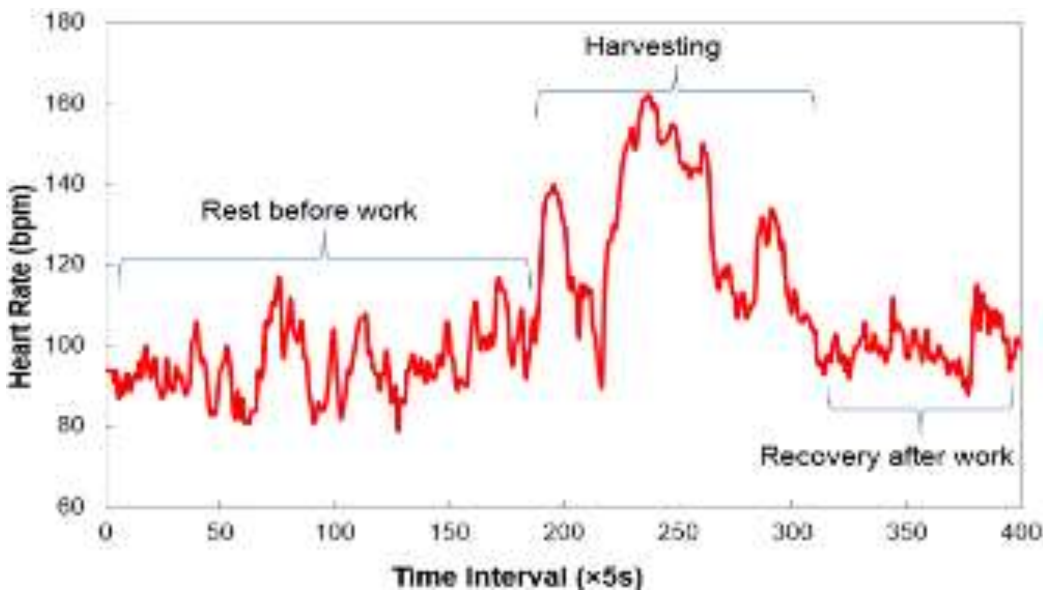

Figure 7. Typical heart rate profile before, during and after a physical activity.

energy used or the drudgery involved in carrying out any physical work. 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 1, according to Jones (1988).

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

Where, Tr = total rest period (min/h), and P = Gross energy consumption (Watts)

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, 1988), the gross energy consumption (Watts) was determined.

Field capacity

Before manual harvesting, cassava plants were coppiced or cut to a stem length of about 20 to 30 cm. Three field workers were then tasked to uproot ten cassava plants of each of the four varieties under each planting position using the improved manual harvesting tool. With the help of a stop clock, time (seconds) taken to harvest the 10 plants was recorded. The capacity (timeliness of operation) for each field worker during harvesting (man-hours/ha) was determined using Equation 2 according to Amponsah et al. (2014).

$$T = \frac{10000 \times t}{n \times 3600} \quad (2)$$

Where, T = total harvesting capacity (man-h/ha); t = total time spent in harvesting (seconds), and n = number of plants harvested.

Root tuber breakage

The percentage root tuber breakage associated with each cassava variety under the different planting positions was calculated using Equation 3 according to Amponsah et al. (2014).

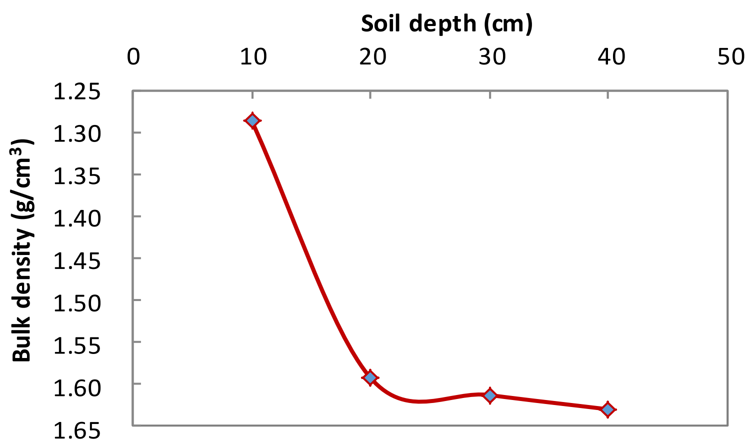

Figure 8. Mean bulk density versus soil depth.

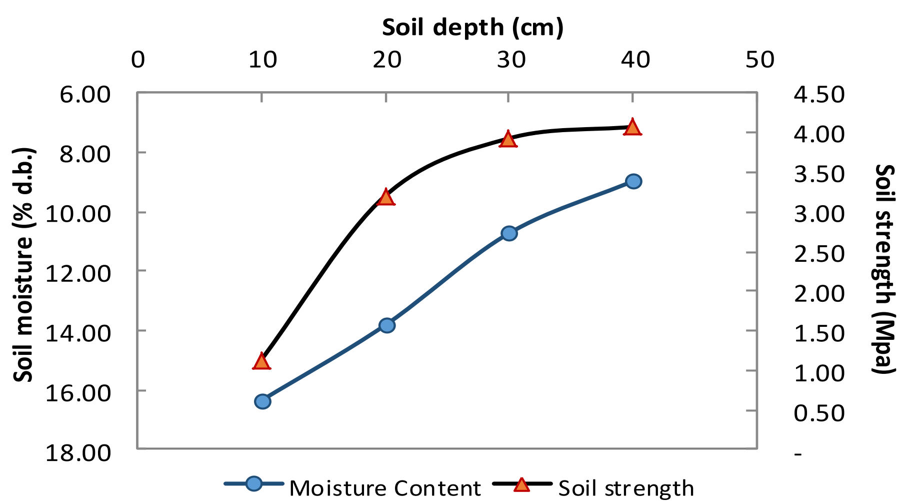

Figure 9. Mean moisture content and soil strength versus soil depth.

$$\text{Percentage Breakage} = \frac{\text{Mass of broken or damaged roots (kg)}}{\text{Total root yield (kg)}} \times 100 \quad (3)$$

Statistical analysis

The results of harvesting trials and field measurements were statistically analysed as a split plot layout in randomized complete block design (RCBD) using GenStat Discovery Edition 3 (VSN International, 2011). The least significant difference (LSD) was used at the $p < 0.05$ level of probability to test difference between treatment means. Analysis of variance (ANOVA) was performed to determine the effects of planting position and/or cassava varieties and their interaction.

RESULTS AND DISCUSSION

Soil physical properties

Figure 8 shows the mean bulk density under flat method of planting at harvest. At harvest, soil bulk density ranged from 1.29 to 1.63 g/cm^3 at increasing soil depth of 0 to 40 cm. Figure 8 generally depicts an increase in soil bulk density with increasing soil depth. This could be alluded to the decreasing moisture content down the soil profile (Figure 9), causing soil particles to be more compact due to the extra voids.

Figure 9 shows the mean soil moisture and soil penetration resistance (soil strength) at harvest under the flat method of planting. Mean soil moisture at harvest ranged from 8.97 to 16.36% d.b. whilst mean soil strength (penetration resistance) ranged from 1.13 to 4.08 MPa at increasing soil depth of 10 to 40 cm. It could also be deduced from graph in Figure 9 that soil moisture decreased with increasing soil depth whilst soil strength increased with increasing depth. This trend was expected since soil strength generally decreases with increasing soil moisture and agrees with what was reported by Utset and Cid (2001).

Table 1. Field capacity, percentage root tuber breakage, heart rate and corresponding gross energy consumption and rest period for harvesting *Bankyehemaa* (BH), *Nkabom* (NK), *Sikabankye* (SK) and *Ampong* (AM) cassava varieties under vertical (V), horizontal (H) and slanted (SL) planting positions.

Cassava variety - Planting position	Field capacity (man-h ha^{-1})**	Root tuber breakage (%)	Heart rate (bpm)	Gross energy consumption (W)	Rest period (min h^{-1})
BH-V	65.2^{cd}	10.75	96.1	479.08	28.69
BH-H	64.1^{cd}	8.73	122.0	773.72	40.61
BH-SL	64.5^{cd}	6.82	105.9	591.6	34.65
NK-V	49.9^{cd}	8.99	115.4	701.54	38.62
NK-H	50.7^{cd}	4.52	111.3	651.22	36.97
NK-SL	56.0^{cd}	5.15	112.5	665.54	37.46
SK-V	72.9^{c}	4.87	118.6	738.42	39.69
SK-H	156.1^{a*}	4.32	106.8	602.06	35.09
SK-SL	136.4^{a}	4.93	95.3	470.34	28.11
AM-V	90.9^{c}	11.76	105.1	583.45	34.29
AM-H	115.7^{ab}	19.55	115.1	696.84	38.47
AM-SL	76.4^{c}	6.38	108.8	624.82	35.99

*Values followed by the same letter(s) in the same group are not significantly different at $p < 0.05$; **Assuming 4 working hours per day, excluding rest periods.

Manual harvester performance evaluation

Table 1 shows the field performance evaluation results (field capacity, percentage root tuber breakage, heart rate and corresponding energy consumption and rest period) of the improved manual harvesting tool under flat planting method for cassava variety and planting position interaction.

From results in Table 1, it could be seen that harvesting *Sikabankye* cassava variety under horizontal planting position recorded the highest significant ($p < 0.05$) field capacity of 156 man-h ha^{-1} whereas the least significant value of 49.9 man-h ha^{-1} was recorded by *Nkabom* variety under the vertical planting position.

Similarly, harvesting *Ampong* variety under horizontal planting position recorded the highest root tuber breakage (19.55%) whilst *Sikabankye* under horizontal planting position recorded the least (4.32%). However, no significant difference ($p < 0.05$) was recorded for percentage root tuber breakage across cassava varieties and planting positions.

Again, harvesting *Bankyehemaa* cassava variety under the horizontal planting position recorded the highest heart rate (122 bpm) with a corresponding gross energy consumption of 773.72 W whilst harvesting *Sikabankye* variety under slanted planting position recorded the least value of 95.3 bpm with a corresponding gross energy consumption of 470.34 W. Generally, however, there was no significant difference ($p < 0.05$) in average heart rate and corresponding gross energy consumption across cassava varieties and planting positions. From Table 1, it could also be deduced that mean heart rate, gross energy consumption and rest period are directly proportional; the higher the heart rate, the higher the gross energy consumption, leading to longer period of rest to compensate for the used or lost energy. This relationship between energy consumption and rest period is in agreement with studies by Amponsah et al. (2014), Ericsson et al. (2006), Crouter et al. (2004) and Freedson and Miller (2000).

Table 2 shows the field evaluation summary results after harvesting with the improved tool for the different cassava varieties and planting positions under the flat planting method.

Under cassava variety in Table 2, it could be seen that *Sikabankye* cassava variety recorded the highest significant ($p < 0.05$) field capacity of 121.8 man-h ha^{-1} whereas *Nkabom* recorded the least (52.2 man-h ha^{-1}) across all planting positions. The significantly high field capacity recorded for *Sikabankye* could be attributed to its generally high uprooting force requirement and yield per plant as recorded in Tables 3 and 4. This result goes on to confirm the fact that *Sikabankye* cassava variety is high-yielding compared to the other varieties, making it difficult to uproot, particularly under the flat method of planting. Interestingly, in terms of root tuber breakage, *Ampong* cassava variety recorded the highest significant value of 12.56% whereas *Sikabankye* variety recorded the least (4.71%) across all planting positions. In terms of drudgery, though not significant ($p < 0.05$), *Ampong* cassava variety recorded the highest average heart rate (113.1 bpm) at harvest whilst *Sikabankye* variety recorded the least (106.9 bpm).

Similarly, under planting positions in Table 2, horizontally planted cassava recorded the highest significant ($p < 0.05$) field capacity of 96.6 man-h ha^{-1} during harvesting with the improved tool, whereas vertically planted cassava recorded the least (69.7 man-h

Table 2. Field capacity, percentage root tuber breakage and heart rate after manual harvesting with the improved tool for different cassava varieties (*Bankyehemaa*, *Nkabom*, *Sikabankye* and *Ampong)* and under different planting positions (vertical, horizontal and slanted).

Parameter		Field capacity (man-h ha^{-1})	Root tuber damage (%)	Heart rate (bpm)
Cassava variety	Bankyehemaa	64.6^{c}	8.77^{ab}	108.0
	Nkabom	52.2^{c}	6.22^{bc}	113.1
	Sikabankye	121.8^{a*}	4.71^{bc}	106.9
	Ampong	94.3^{b}	12.56^{a}	109.7
Planting position	Vertical	69.7^{c}	9.09	108.8
	Horizontal	96.6^{a*}	9.28	113.8
	Slanted	83.3^{b}	5.82	105.6

*Values followed by the same letter(s) in the same group are not significantly different at $p < 0.05$.

Table 3. Cassava uprooting force requirement, rooting depth and yield per plant for *Bankyehemaa* (BH), *Nkabom* (NK), *Sikabankye* (SK) and *Ampong* (AM) cassava varieties under vertical (V), horizontal (H) and slanted (SL) planting positions.

Cassava variety - planting position	Force requirement (kg)	Rooting depth (cm)	Yield (kg/plant)
BH-V	130.1^{a}	26.72	6.18^{c}
BH-H	130.7^{a}	25.09	6.68^{bc}
BH-SL	117.8^{ab}	26.86	5.84^{c}
NK-V	86.8^{bc}	23.37	6.85^{bc}
NK-H	112.3^{ab}	26.11	7.19^{bc}
NK-SL	124.8^{ab}	25.47	8.09^{bc}
SK-V	143.3^{a*}	22.83	13.14^{a}
SK-H	128.2^{a}	22.39	10.48^{b}
SK-SL	97.8^{bc}	24.30	6.69^{bc}
AM-V	118.0^{ab}	23.62	10.15^{b}
AM-H	116.8^{ab}	25.38	9.52^{b}
AM-SL	108.6^{ab}	24.26	7.31^{bc}

*Values followed by the same letter(s) in the same group are not significantly different at $p < 0.05$.

Table 4. Cassava uprooting force requirement, rooting depth and yield per plant under the flat planting method for different cassava varieties (*Bankyehemaa*, *Nkabom*, *Sikabankye* and *Ampong)* and different planting positions (vertical, horizontal and slanted).

Parameter		Force requirement (kg)	Rooting depth (cm)	Yield (kg/plant)
Cassava variety	Bankyehemaa	126.2^{a*}	26.22^{a}	6.23^{d}
	Nkabom	108.0^{b}	24.98^{a}	7.38^{c}
	Sikabankye	123.1^{a}	23.17^{ab}	10.10^{a}
	Ampong	114.5^{b}	24.42^{ab}	8.99^{b}
Planting position	Vertical	119.5	24.13	9.08^{a*}
	Horizontal	122.0	24.74	8.46^{a}
	Slanted	112.3	25.22	6.98^{b}

*Values followed by the same letter(s) in the same group are not significantly different at $p<0.05$.

ha^{-1}) regardless of cassava variety. However, in terms of root tuber breakage and drudgery, horizontally planted cassava recorded the highest value (9.28% and 113.8 bpm respectively) whilst obliquely (slanted) planted cassava recorded the least (5.82% and 105.6 bpm respectively). It is worth noting that there was no significant difference ($p < 0.05$) in percentage root tuber breakage and drudgery among the planting positions, irrespective of cassava variety. This trend of lower percentage root tuber damage and drudgery at harvest agrees with report by Ekanayake et al. (1997) that planting cassava sticks in a slanted position provide a leverage for the stem and roots which makes harvesting easier than in the other orientations.

Cassava uprooting force, rooting depth and yield

Table 3 shows the cassava uprooting force requirement, rooting depth and yield per plant under flat method of planting for cassava variety and planting position interaction.

From Table 3, it could be deduced that vertically planted *Sikabankye* cassava variety recorded the highest significant ($p < 0.05$) uprooting force requirement of 143.3 kg whereas vertically planted *Nkabom* variety recorded the least (86.8 kg). The generally low uprooting force requirement recorded for *Nkabom* cassava variety could be due to the fact that morphologically, *Nkabom* variety is bunchy (Amponsah et al., 2014) with minimal root spread in the soil, making it easier to uproot compared to the other varieties which have much wider root spread.

Cassava rooting depth, though with no significant differences ($p < 0.05$), recorded the highest value of 26.86 cm for obliquely (slanted) planted *Bankyehemaa* cassava variety with horizontally planted *Sikabankye* variety recording the least value (22.39 cm).

In terms of yield per plant however, vertically planted *Sikabankye* cassava variety recorded the highest significant value of 13.14 kg whereas obliquely (slanted) planted *Bankyehemaa* recorded the least (5.84 kg).

Table 4 shows the cassava uprooting force, rooting depth and yield per plant under the flat planting method for the different cassava varieties and planting positions.

Under cassava variety as depicted in Table 4, *Bankyehemaa* recorded the highest significant uprooting force requirement of 126.2 kg whereas *Nkabom* variety recorded the least (108 kg) irrespective of planting position under the flat planting method. It was therefore not surprising that *Bankyehemaa* again recorded the highest significant ($p < 0.05$) rooting depth (26.22 cm) with *Sikabankye* recording the least (23.17 cm). This situation reiterates the fact that cassava uprooting force requirement is significantly influenced by cassava rooting depth as reported by Amponsah et al. (2014). Conversely however, in terms of yield per plant, *Sikabankye* recorded the highest significant ($p < 0.05$) value of 10.10 kg whereas *Bankyehemaa* recorded the least (6.23 kg) regardless of planting position under the flat method of planting.

For planting position, though no significant ($p < 0.05$) difference existed among treatments, planting cassava horizontally resulted in the highest uprooting force requirement (122 kg) irrespective of cassava variety whereas planting obliquely (slanted) recorded the least (112.3 kg). In terms of rooting depth, though there was no significant difference ($p < 0.05$) among planting positions, obliquely (slanted) planted cassava recorded the highest rooting depth of 25.22 cm whereas vertically planted cassava recorded the least (24.13), regardless of cassava variety. On the other hand, vertically planted cassava resulted in the highest significant ($p < 0.05$) yield per plant (9.08 kg) whereas obliquely (slanted) planted cassava recorded the least (6.98 kg) irrespective of cassava variety under the flat method of planting. This result, however, opposes what was reported by Abdullahi et al. (2014) and Legese et al. (2011) that storage roots yield of cassava could be enhanced by planting cuttings in an inclined or slanted position.

CONCLUSIONS AND RECOMMENDATION

The improved manual cassava harvesting tool generally performed satisfactorily under the flat method of planting with field capacity ranging between 49.9 and 156 man-h ha^{-1}, root tuber breakage between 4.32 and 19.55% and heart rate with corresponding gross energy consumption ranging between 95.3 bpm (470.34 W) and 122 bpm (773.72 W) across cassava varieties and planting positions.

Generally, it required less time to harvest *Nkabom* variety using the improved manual harvesting tool compared to the other cassava varieties irrespective of planting position. However, in terms of percentage root tuber breakage and drudgery during harvesting, *Sikabankye* cassava variety is the best.

Similarly, harvesting vertically planted cassava under flat planting method using the improved manual harvesting tool provides the best timeliness of harvest irrespective of cassava variety. However, though not significant, harvesting obliquely (slanted) planted cassava is best in terms of percentage root tuber breakage and drudgery.

Cassava uprooting force ranged from 86.8 to 143.3 kg, rooting depth from 22.39 cm to 26.86 cm and cassava yield per plant ranging from 5.84 to 13.14 kg across cassava varieties and planting positions. *Nkabom* cassava variety was easier to uproot compared to the others irrespective of planting position. Though, planting cassava in a slanted position offers the best in terms of uprooting force requirement and rooting depth, it produces the poorest yield per plant, regardless of cassava variety. Best yield, however, is achieved when cassava stakes are planted vertically.

Last but not least, it could be concluded from the study that cassava uprooting force was significantly influenced by cassava rooting depth. However, as a recommendation further research should be carried out to determine the relationship between cassava uprooting force and some cassava agronomic parameters for different cassava varieties under the various planting positions and methods of planting.

Conflict of Interests

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the financial support from the Brazilian Government through the Brazilian Agricultural Research Cooperation (EMBRAPA) sponsored project “Comparative evaluation of different manual cassava harvesting tools” under the Agricultural Innovation Marketplace partnership. They also wish to express their profound gratitude to the staff of the Crops Research Institute (CRI), Fumesua under the Council for Scientific and Industrial Research (CSIR), Ghana for their technical support towards the construction and field testing of the prototype manual harvester. Finally, they want to appreciate everyone who directly or indirectly contributed to the success of this research.

REFERENCES

Abdullahi N, Sidik JB, Ahmed OH, Zakariah MH (2014). Effect of planting method on growth and yield of cassava (Manihot esculenta Crantz) grown with polythene covering. J. Exp. Biol. Agric. Sci. 1:480-487.

Addy PS, Kashaija IN, Moyo MT, Quynh NK, Singh S, Walekhwa PN (2004). Constraints and opportunities for small and medium scale processing of cassava in the Ashanti and Brong Ahafo Regions of Ghana. International centre for development oriented research in agriculture (ICRA).

Adekunle AA, Dixon A, Ojurongbe J, Ilona P, Muthada L, Adisa S (2004). Growing Cassava Commercially in Nigeria - An Illustrated Guide. USAID, ICS-Nigeria and IITA.

Agbetoye LAS (2003). Engineering challenges in developing indigenous machinery for cassava production and processing. In: Proc. Ann. Conf.of the Nigerian Soc. Eng. (Lagelu 2003). Ibadan, Nigeria pp. 80-86.

Amponsah SK (2011). Performance evaluation of the TEK mechanical cassava harvester in three selected locations of Ghana.

Amponsah SK, Bobobee EYH, Agyare WA, Okyere JB, Aveyire J, King SR (2014). Mechanical Cassava Harvesting as Influenced by Seedbed Preparation and Cassava Variety. Appl. Eng. Agric. 30:391-403.

Amponsah SK, Sheriff JT, Byju G (2014). Comparative evaluation of manual cassava harvesting techniques in Kerala, India. Agric. Eng. Int. CIGR J. 16:41-52.

Bellotti AC, Herrera CJ, Hernández M del P, Arias B, Guerrero JM, Melo EL (2011). Cassava Pests in Latin America, Africa and Asia. In: Howeler, R.H. (Ed.), The Cassava Handbook. A Reference Manual Based on the Asian Regional Cassava Training Course, Held in Thailand. Centro Internacional de Agricultura Tropical (CIAT) pp. 199-257.

Cock JH (2011). Cassava: A Basic Energy Source in the Tropics. In: Howeler RH (Ed.), The Cassava Handbook: A Reference Manual Based on the Asian Regional Cassava Training Course, Held in Thailand. Centro Internacional de Agricultura Tropical (CIAT) P 23.

Crouter SE, Albright C, Bassett DR (2004). Accuracy of Polar S410 Heart Rate Monitor to estimate energy cost of exercise. Med. Sci. Sports Exerc. 36:1433-1439.

CTCRI (2012). Description of Recommended/Released Varieties under AICRP on Tuber Crops. Cent. Tuber Crop. Res. Inst. Tech. Bull. Serial No. 51.

DeAngelis KM (2007). Measurement of soil moisture content by gravimetric method.

Dedzoe CD, Dwomo O, Adjei-Gyapong T, Senayah JK, Tetteh FM, Adjei S (2004). Land suitability Assessment for Cashew varietal evaluation in selected Agro-ecologies in Ghana. Detailed soil characterization in the Ejura- Sekyedumasi District, Forest-savannah transitional agro-ecological zone.

Ekanayake IJ, Osiru DSO, Porto MCM (1997). Agronomy of cassava. IITA.

El-Sharkawy MA (2012). Stress-Tolerant Cassava: The Role of Integrative Ecophysiology-Breeding Research in Crop Improvement. Open J. Soil Sci. 2:162-186.

Ericsson F, Dalarna U, Björklund G (2006). The relationship between heart rate and power output during cycling competitions [WWW Document]. URL http://www.toppfysik.nu/userfiles/ (accessed 6.12.14).

FAOSTAT (2013). FAO Statistical Yearbook, World food and agriculture.

Freedson PS, Miller K (2000). Objective monitoring of physical activity using motion sensors and heart rate. Res. Q. Exerc. Sport 71(suppl. 2):21–9.

Jones NL (1988). Clinical Exercise Testing, 3rd ed. W.B. Saunders.

Keating BA, Wilson GL, Evenson JP (1988). Effects of length, thickness, orientation, and planting density of cassava (Manihot esculenta Crantz) planting material on subsequent establishment, growth, and yield. East African Agric. For. J. 53:145-149.

Legese H, Gobeze L, Shegro A, Geleta N (2011). Impact of Planting Position and Planting Material on Root Yield of Cassava (*Manihot esculenta* Crantz). J. Agric. Sci. Technol. 5:448-454.

Moore LM, Lawrence JH (2003). Plant guide – Cassava: manihot esculenta Crantz. National Plant Data Centre, Baton Rouge, Louisiana and Pacific Islands, Mongmong, Guam.

Nweke FI (2005). A Review of Cassava in Africa with Country Case Studies on Nigeria, Ghana, the United Republic of Tanzania, Uganda and Benin 2. FAO IFAD.

Tufan HA (2013). Next Generation Cassava Breeding Project [WWW Document]. URL http://www.nextgencassava.org/about.html (accessed 3.31.15).

Utset A, Cid G (2001). Soil penetrometer resistance spatial variability in a Ferralsol at several soil moisture conditions. Soil Tillage Res. 61:193-202.

VSN International (2011). GenStat Discovery 3rd Edition.