Performance evaluation of prototype mechanical cassava harvester in three agro-ecological zones in Ghana

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ABSTRACT

Large-scale cassava harvesting, especially during the dry season, is a major constraint to its industrial demand and commercial production. Manual harvesting is slow and associated with drudgery and high root damage in the dry season. Research on mechanisation of cassava production is very low especially in the area of harvesting, and currently there exists no known functional mechanical cassava harvesters in Ghana. The main objective of the study was to test and evaluate mechanical cassava harvesting techniques in different agro-ecological zones in Ghana. Performance of two prototype mechanical harvesters (TEK MCH 2 and 6) was evaluated against manual harvesting methods for field capacity, efficiency and root damage using two cassava varieties, namely 'Afisiafi' and 'Bankyehemaa', on ridged and flat landforms. Results from field trials showed prototype harvesters weighing 268 – 310 kg can achieve optimum performance on ridged landforms. When harvested mechanically, tuber damage ranges from 16 per cent to 27 per cent for both 'Afisiafi' and 'Bankyehemaa'. The mechanical harvester works best on dry fields with moisture content from one per cent to 17 per cent db containing minimum trash or weeds, and develops average drafts of 10.86 kN whilst penetrating depths from 13 to 40 cm. Optimum mechanical harvesting performance was achieved at tractor speeds of 5 – 8 km h^{-1}, fuel consumption of 15 – 19 litres ha^{-1}, and a field capacity of 2 h ha^{-1}. After mechanical harvesting, the field is left ploughed with savings on fuel, time and production costs. It is, however, recommended to test the harvesters for wear and durability in major agro-ecological zones and through a wide range of soil moisture regimes in Ghana to support nationwide adoption.

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Introduction

Manual cassava (*Manihot esculenta*, L.) harvesting is both time consuming and full of drudgery, especially during the dry season. According to Agbetoye (2003), the most difficult operation in cassava production is harvesting. Among the leading cassava producing countries in Africa, manual harvesting takes 44 – 62 days per hectare (Nweke, Dunstan & Lyman, 2002). Cassava is a highly perishable crop. It starts to deteriorate between 1 – 3 days after harvest. Harvesting cassava should be done at the right time and in the proper way (Kuiper *et al.*, 2007; IITA, 2004). Cassava is ready for harvest 6 – 7 months after planting (MAP), when the storage roots are large enough to meet the requirements of the consumer (Ekanayake, Osiru & Porto,1997). Matured roots are clustered around the base of the plant and extend about 60 cm on all sides. Harvesting too early results in low yield and poor eating quality. On the other hand, when the roots are left too long in the soil, the central portion becomes woody and inedible (USDA & NRCS, 2003). It also ties the land unnecessarily to one crop whilst exposing the roots to pests.

The cassava roots, which contain from 15 per cent to 40 per cent starch (Philippine Root Crops Information Service, 2005) make the crop to be cultivated for industrial starch, bio-ethanol and pellets for animal feed. Under the most favourable conditions, yields of fresh roots can reach 90 t ha^{-1} whilst average world yields from mostly subsistence agricultural systems are 10 t ha^{-1} (O'Hair, 1995; USDA & NRCS, 2003). Cassava is mostly harvested by hand, lifting the lower part of stem and pulling the roots out of the ground, then removing them from the base of the plant by hand. The upper parts of the stems with the leaves are removed before harvest. Levers, cutlasses, hoes, mattocks and ropes can be used to assist harvesting manually. A mechanical harvester can also be used. Mechanical harvesters, like those developed in Brazil would grab onto the stem and lift the roots from the ground (Kuiper *et al.*, 2007). According to Philippine Root Crops Information Service (2005), harvesting cassava during relatively dry soil is the best since the soil does not stick to the harvesting implement or roots easily. During the harvesting process, the cuttings for the next crop are selected. These are kept in a protected location to prevent desiccation (Kuiper *et al.*, 2007).

In Ghana and Africa, cassava is traditionally produced on small-scale farms, and prepared as subsistence crop for home consumption and for rural and urban markets. Presently, with the interest in using cassava for various industrial products such as high quality cassava flour, bio-fuel and for brewing beer and other alcoholic beaverages, large-scale cassava production is attracting attention. Cassava harvesting for large-scale industrial processing is a major constraint and, presently, there is no known commercial mechanical cassava harvesters in Ghana. The present situation demands technological interventions, especially during harvest to make cassava an industrial commercial crop for starch and food on a sustainable basis. To address the above constraints, researchers at the Kwame Nkrumah University of Science and Technology (KNUST), since 1993, have been collaborating with their counterparts from the University of Leipzig in Germany, to develop an appropriate mechanical cassava harvesting technology for the tropics. The TEK MCH is developed to mechanically harvest cassava root tubers by the 'dig and expose' principle.

The main objective of the paper was to evaluate the field performance of TEK MCH developed at KNUST, Kumasi. Specifically, the paper seeks to 1) evaluate the performance of modified mechanical cassava harvesting implement on ridges and flat land in different agro-ecological zones in Ghana, and 2) compare mechanical cassava harvesting techniques with various manual harvesting methods in terms of field capacity, efficiency of harvest and root damage.

Materials and methods

Sites

Three study areas located at Anwomaso KNUST arable farms (6° 41'56.75' N, 1° 31'25.85' W) and 274 m above sea level (asl), Mampong (7° 2'19.84' N, 1° 23'48.60' W) and 401m asl, both in the forest zone of the Ashanti Region, and Akatsi (6° 8'40.50' N, 0° 49'22.05' E) and 57m asl in the coastal savanna zone of the Volta Region were chosen for testing the harvester. These locations were selected based on their potential for higher cassava production levels, and consumption compared with other parts of the country. Anwomaso experiences bi-modal tropical rainfall pattern and wet semi-equatorial climate. It is characterised by double maxima rainfall lasting from March to July and again from September and normally ends in the latter part of November. The mean annual rainfall is 1200 mm, which is ideal for minor season cropping. Temperatures range between 20 °C in August and 32 °C in March. Relative humidity is fairly moderate but quite high during rainy seasons and early mornings. Soils in Anwomaso are mainly Forest Acrisols (FAO/UNESCO, 1998). Mampong-Ashanti has an average annual rainfall of 1270 mm and two rainy seasons. The major rainy season starts in March and peaks in May-June. There is a slight dip in July and a peak in August, tapering off in November. The period between December and February is usually dry, hot and dusty. Forest Lixisols (FAO/UNESCO, 1998), which are usually very shallow but are well-drained, are predominant in the study area. The climate in Akatsi is characterized by high temperatures (min: 21 °C max: 34.5 °C), high relative humidity (85%) and moderate to low rainfall regime (1,084 mm) with distinct wet and dry seasons of about equal lengths. The Akatsi site has Savanna Cambisols (FAO/UNESCO, 1998) soil types characterised as moderate to well-drained, deep red to brown loamy sand to sandy loam topsoil over coarse sandy loam to clay loam sub-soils.

Seedbed preparation, field layout and cassava varieties

Each study site was tilled with a disc plough and harrowed with disc harrow to produce finer soil tilth. The experimental fields were divided into three parts; one-third was left as a flat landform and ridges were formed on the two-thirds portion. Each cassava variety was planted on seven ridges and five rows on the flat fields (Fig. 1). Ridges were constructed with an average height of 0.3 m and spaced 1.2 m apart (crest to crest) to accommodate the tractor track width. Ennin, Otoo & Tetteh (2009) reported 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 mechanisation to further decrease drudgery and increase the scale of production of cassava compared to planting on the flat.

Harvesting of cassava was done at the various sites 15 months after planting (MAP) during the dry season, a period more favourable for mechanical cassava harvest-

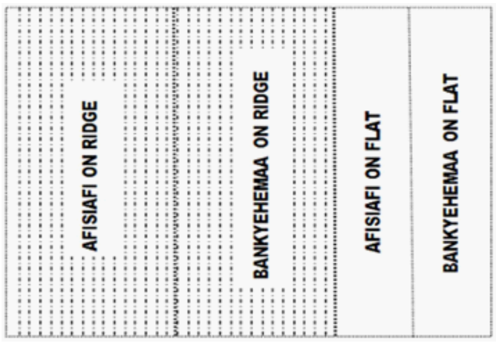


Fig.1. Field layout for the experimental sites at Anwomaso, Mampong and Akatsi.

ing but quite difficult for manual cassava harvesting. Before harvesting mechanically, the cassava plants were coppiced down to a stalk height of about 20 cm. This height was lower than the tractor under clearance, and it allows the tractor to pass over the plants without any damage, and also to aid the operator to move in a more accurate path during harvesting. The farm was maintained clean from weeds prior to harvesting to prevent debris from blocking the digging unit of the harvester so as not to increase implement draught.

Soil mechanical analysis

Soil samples were collected from each study site before ploughing and at harvest. Six sampling points located at the corners and mid-sections of the fields were used to measure soil penetration resistance, bulk density and moisture contents in the 0 – 40 cm layer at 10 cm intervals. Soil moisture content was determined gravimetrically from bulk density samples (DeAngelis, 2007). The measurements were made in each plot on the same day.

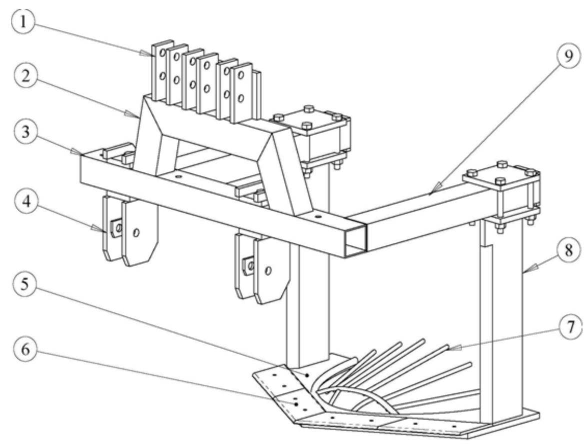
Mechanical harvester development (The TEK MCH)

A tractor-mounted harvester with a slatted conical mouldboard without any transport system was adapted from an original Leipzig model and developed to operate on the "dig and expose" principle. The TEK mechanical cassava harvester (MCH), as the name depicts, was developed and manufactured at the Department of Agricultural Engineering, Kwame Nkrumah University Science and Technology, Kumasi. The TEK MCH basically has the following parts; digger blades, shakers constituting a slatted conical mouldboard and the vertical support all attached to a horizontal plate (the frog), and the beam to which the hitching units were attached. The blades, which have specially formulated chemical compositions to resist abrasive wear, were produced through casting at a local foundry.

Fig. 2 shows the diametric view of the harvester. At the highest point where the top link is attached, the height of the implement is 135 cm. Between the two vertical legs the cutting width is 100 cm. The slatted conical mouldboard serves as soil shakers to sieve the soil clods and reduce adhesion, and allows the excavated roots to flow to the surface for manual collection. This helps accelerate the harvesting process and increases the efficiency of the harvester.

Draught, speed and slip measurements

The draught developed by the harvester as it travels in the soil to excavate the cassava root cluster was measured using a 10 - t commercial electronic dynamometer (RON 2125S® Israel) with a digital data logger. In operation, the dynamometer was attached between a pulling tractor and the



Legend

1 = Toplink plate
2 = Toplink frame
3 = Front beam
4 = Lower link plate
5 = Base plate (frog)
6 = Digging blade
7 = Slated conical mouldboard
8 = Leg
9 = Side beam

Fig.2. Diametric view of the TEK mechanical cassava harvester

instrumented tractor hitching the implement (Fig. 3). Draught forces were recorded for the harvester in the transport position (no load) and when engaged in the soil during harvesting (load). Load condition draught force recordings were taken after the implement has stabilised in the soil at the operating depth. Average speed of operation was derived from the time taken for the tractor implement assembly to traverse a fixed distance marked on the field with ranging poles after eliminating parallax. To measure harvester slip, the distance covered by 10 rear tyre revolutions when harvesting and in no-load positions were used. Fig. 3 also shows the implement draught measurement procedure with one tractor pulling the instrumented one hitching the harvester. The

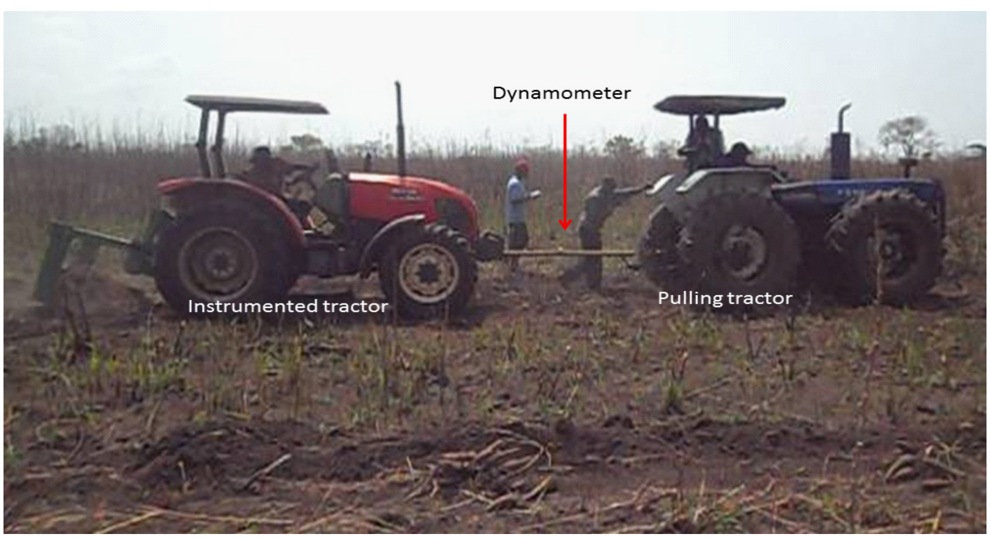


Fig. 3. Harvester draught recording on the field

RON 2125S dynamometer logs the force readings.

Fuel consumption

In each field experiment, the tractor was positioned on a level spot and the fuel tank filled full. After working on a measured piece of land, the tractor is brought to the same spot and the tank re-fueled to determine fuel used (AlHashem, Abbouda & Saeed, 2000).

Depth of harvester penetration determination

The dynamic depth of penetration, which varies from point to point, along the row for any harvesting implement, was determined using a graduated depth measuring probe. The probe was vertically pushed with minimum force through the soil until it hits the unploughed sub-soil to determine plough depth. This was repeated several times along the harvested rows for both ridged and flat landforms and for manual and mechanical harvests.

Root damage assessment

Cassava root damage caused by the harvester blade cutting or bruising the cassava roots during harvesting was due to either shallow harvesting depths or relatively longer horizontal root spread beyond the harvester width. Damaged and whole tubers after harvesting were separated and weighed using a spring balance (Fig. 4). The percentage damage for each harvesting method was computed by dividing the damaged cassava weight by the total yield. Enquiries made from market women and processors led to the qualitative definition of damage as any part of the harvested cassava that did not come out with the stem from the soil and is broken from the stem after harvest.

Size of the broken piece was also taken into consideration. Any size that is cut, bruised or damaged and could go bad within a relatively short period of time was considered damaged. From farmers and processors perspectives, cassava root damage was assessed when the tubers do not come out whole after harvesting but with cuts and bruises that could render them unsuitable for long storage.

Field capacity measurement

The field capacity of the TEK MCH was

Fig. 4: Cassava root tuber damage assessment in the field

determined by recording the time in seconds taken to harvest a given area of the field. Since the harvester working width was 1 m, a distance covered in metres during the harvesting process between two fixed ranging poles were used to calculate the field capacity in hours per hectare (h ha^{-1}) as shown in equation (1).

$$Ca = \frac{10000 \times t}{A \times 3600} \text{ (h ha}^{-1}\text{)..... } \quad (1)$$

where Ca = field capacity (h ha^{-1})
t = total time recorded during harvest (seconds) and
A = area harvested (m^2).

Manual harvesting was carried out using tools like cutlass, hoe or mattock. Manual workers were monitored to uproot 10 cassava plants each at their own pace on the ridge and flat landforms for different cassava varieties. The time taken and their heart rates were recorded. Manual harvesting capacity of the worker (man-hours/ha) was determined as shown in equation (2).

$$T = \frac{10000 \times t}{n \times 3600} \text{ (h ha}^{-1}\text{)..... } \quad (2)$$

where T = total harvesting capacity (man-hours/ha)
t = total time spent in harvesting (seconds)
n = number of plants harvested.

With a 1-m width of cut for the harvester and taking drawbar power to brake horse power (Brake Hp) ratio of 19 per cent, the SSR (kN m^{-2}), drawbar power and axle power (tractor engine power required) are calculated (Hunt,1977).

Data analysis

The data were analysed using the SAS Statistical Software package (1999). SAS PROC GLM procedures were used for the descriptive statistics and ANOVA of the depth of harvesting, draught forces. Statistical inferences were made at $P < 0.05$ levels of significance.

Results and discussion

Soil mechanical properties

Table 1 shows the soil mechanical properties at land preparation and at harvest. Soils at Akatsi were mainly loamy sand from 0 – 60 cm soil depth. Soils at the Anwomaso and Mampong were mainly sandy clay loams with higher clay and silt contents and better water holding capacities compared to that at Akatsi. The soil bulk densities at all sites before ploughing and at harvest are shown in Fig. 5. There was a general increase in bulk density with depth at all sites before ploughing and at harvest. At harvest soil bulk density ranged from 1.56 to 1.68 g cm^{-3} at Anwomaso, 1.45 to 1.57 g cm^{-3} at Mampong and 1.54 – 1.65 g cm^{-3} at Akatsi with increasing soil depth. This trend agrees with the findings of Arshad, Lowery & Grossman (1996) that bulk density increases with depth in soil profile.

The soil bulk densities at Mampong and Anwomaso were lower at ploughing than at harvest, except at Akatsi. The high bulk density during ploughing at Akatsi was attributed to the fact that the soils were more consolidated causing the clods to be more compact. The high bulk densities at harvest still made harvesting possible for the TEK MCH. Bobobee *et al.* (1994) reported a maximum soil bulk density of 1.82 g cm^{-3} at harvest for the Leipzig harvester.

TABLE 1

The Mechanical Analysis and Soil Texture Results Carried out on the Soils at Akatsi, Anwomaso and Mampong before Ploughing (BP) and at Harvest (AH) Periods

Location (Soil depth cm)	Sand %	Silt %	Clay %	Soil texture		FAO classification (1998)
				BP	AH	
Akatsi						
0-20	8.302	14.98	20.00	Loamy sand	Loamy sand	Cambisols
20-40	81.70	14.30	4.00	Loamy sand	Loamy sand	
40-60	80.46	15.54	4.00	Loamy sand	Loamy sand	
Anwomaso						
0-20	64.94	25.06	10.00	Sandy loam	Sandy loam	Forest Acrisol
20-40	50.70	21.30	26.00	Sandy clay loam	Sandy clay loam	
40-60	43.10	26.90	28.00	Clay loam	Sandy clay loam	
Mampong						
0-20	65.54	26.46	8.00	Sandy loam	Sandy loam	Forest Lixisols
20-40	61.40	24.60	14.00	Sandy loam	Sandy clay loam	
40-60	51.66	26.34	22.00	Sandy clay loam	Sandy clay loam	

Soil penetration resistance

The mean soil penetration resistances before ploughing (BP) and at harvest (AH) at Anwomaso, Mampong and Akatsi increased with depth (Fig. 6), except for Mampong, where penetration resistance was low at harvest. Penetration resistances were higher at harvest than at ploughing at all other sites. At harvest penetration, resistance ranged from 1.77 to 2.24 MPa at Anwomaso, 0.73 to 1.53 MPa at Mampong and 0.92 to 3.03 MPa at Akatsi with increasing soil depth. Comparing Fig. 6 and 7, it is clear that soil penetration resistance increased with increasing bulk density. Ploughing generally reduced the penetration resistance, which agrees with the findings of Reichert, Silva & Reinert (2004).

Soil moisture content

From Fig. 7, mean soil moisture content before ploughing and at harvest at Anwomaso, Mampong and Akatsi increased with increasing depth,` with the Akatsi soil being the driest. For the range of soil depth analysed, soil moisture increased with depth and ranged from 12.06 to 15.69 per cent (d.b.) at Anwomaso, 15.78 to 21.43 per cent (d.b.) at Mampong and 1.02 to 3.71 per cent (d.b.) at Akatsi. The soil moisture content for Akatsi before ploughing decreased with increasing soil depth. This change was attributed to the fact that it had rained the day before ploughing when the samples were taken, and moisture had not infiltrated completely into lower horizons. Mampong had higher moisture content at harvest than at ploughing, and this had contributed to the low soil penetration resistance at harvest.

Depth of tuber development

Fig. 8 shows the mean root tuber depth of penetration for ‘Bankyehemaa’ and ‘Afisiafi’ on both ridge and flat landforms at 15

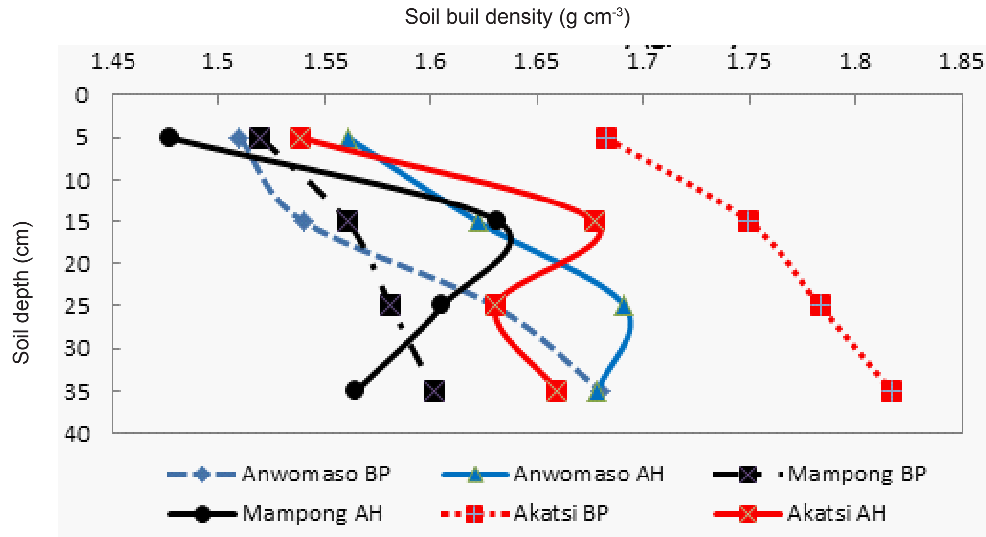


Fig. 5. Mean bulk density (g cm^{-3}) before ploughing (BP) and at harvest (AH) versus soil depth for the various trial sites.

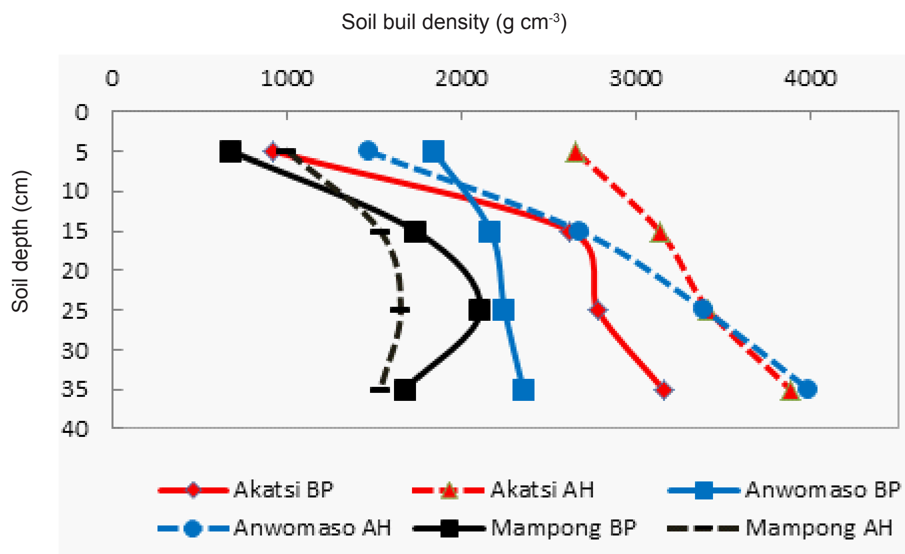


Fig. 6. Soil penetration resistance (MPa) before ploughing (BP) and at harvest (AH) for the various trial sites.

MAP at Akatsi, Mampong and Anwomaso at harvest. 'Afisiafi' on ridge at Anwomaso had the highest mean root tuber penetration depth of 29.40 cm, followed by 'Bankyehemaa' on ridge at Anwomaso with a mean root penetration of 28 cm. 'Afisiafi' on flat landform at Mampong had the lowest mean root tuber penetration of 20.60 cm. The mean root tuber penetration for 'Bankyehemaa' and 'Afisiafi' at Akatsi, Mampong and

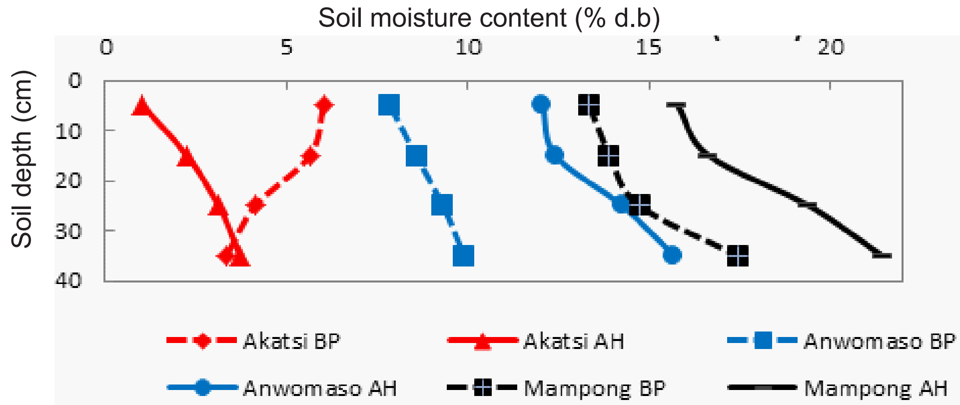


Fig. 7. Mean moisture content (% d.b.) before ploughing (BP), after ploughing (AP) and at harvest (AH) for the trial sites.

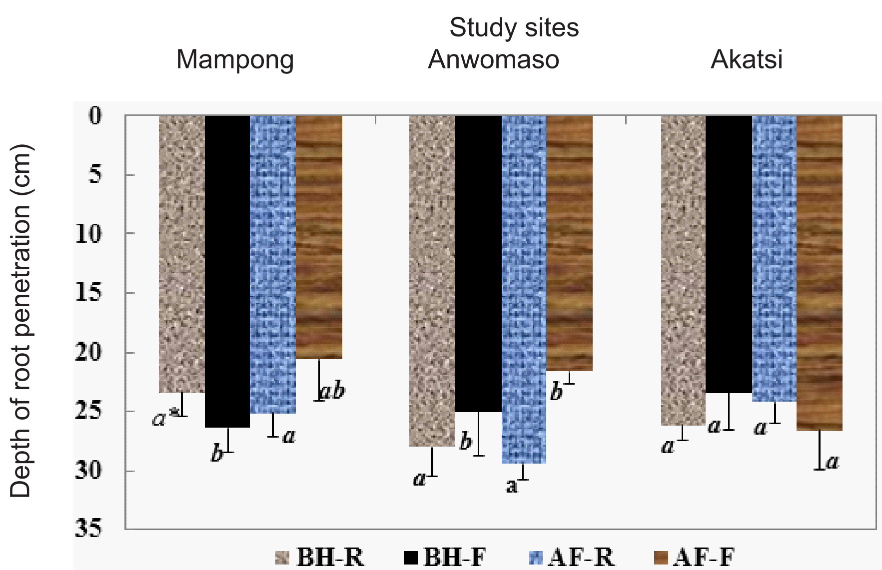


Fig. 8. Mean depth of cassava root tuber penetration (cm) for Bankyehemaa and Afisiafi on both ridge and flat landforms (BH-R, BH-F, AF-R, and AF-F) at Akatsi, Mampong and Anwomaso at 15 MAP. *Values followed by the same letter for the same cassava variety and landform are not significantly different at $P < 0.05$

Anwomaso ranged from 20.60 to 29.40 cm.

There was no significant difference ($P < 0.05$) for the mean depth of tuber penetration for 'Bankyehemaa' on either ridge or flat landform and for 'Afisiafi' on ridge landform at Akatsi, Mampong and Anwomaso. However, the mean depth of tuber penetration for 'Afisiafi' on flat landform at all the sites was significantly different ($P < 0.05$).

Root length across and along row

Table 2 shows the mean total root tuber length across row and along rows for 'Afisiafi' and 'Bankyehemaa', on both ridged and flat landforms at the three sites 15 MAP. 'Afisiafi' on ridge at Anwomaso had the highest mean total root tuber length across row (80.80 cm), whilst 'Bankyehemaa' on flat landform at Akatsi had the lowest root length (31.20 cm) across row. At Anwomaso, 'Afisiafi' on the flat landform, had the highest mean total root tuber length of 95.8 cm along row, whilst 'Bankyehemaa' on ridge at Akatsi had the least (44.20 cm). 'Afisiafi' on the average had longer lengths along row at all three sites than 'Bankyehemaa'. The total root length along row on the ridge for all three sites was generally lower than on the flat landform for both 'Afisiafi' and 'Bankyehemaa', though no statistical difference ($P < 0.05$) was observed. This reduced root spread along ridge could also contribute to lower tuber damage with mechanical harvesters.

maso, Mampong and Akatsi. Bobobee *et al*. (1994) reported that cassava root spread beyond 100 cm makes it difficult to readily mechanize its harvesting because it leads to high percentage root tuber damage. There was no significant difference ($P < 0.05$) between the values obtained for the two landforms and other cassava varieties.

Harvester performance evaluation

Harvester performance was evaluated under varied working depths for percentage root tuber damage, field capacity, fuel consumption, working speed, percentage wheel slip and draught force. The mean depth of mechanical harvester penetration on the ridges at Anwomaso, Mampong and Akatsi ranged from 21 to 31 cm. From Fig. 8, the

TABLE 2

Mean Root Length Across and Along Row for Bankyehemaaa on Ridge (BH-R) and Flat (BH-F) and Afisiafi on the Ridge (AF-R) and on the Flat (AF-F) at Akatsi, Anwomaso and Mampong Sites at 15 MAP.

Cassava variety and landform	*Akatsi*		*Anwomaso Root length (cm)*		*Mampong*	
	Across row	*Along row*	*Across row*	*Along row*	*Across row*	*Along row*
BH-R	66.20a	44.20	69.00	82.60	52.60a	60.40
BH-F	31.20b	45.20	61.00	78.80	69.40a	80.40
AF-R	60.80a	45.80	80.80	68.40	47.80b	70.20
AF-F	45.00a	57.40	59.20	95.80	67.00a	69.00
LSD	ns	ns	ns	ns	ns	ns

*Values followed by the same letter in the same column are not significantly different at $P < 0.05$.

Generally all the mean total root tuber length across and along rows recorded for the various study sites, cassava varieties and landforms did not exceed the standard working width (100 cm) of the TEK MCH. There was no significant difference ($P < 0.05$) between the mean total root tuber length across row for both 'Afisiafi' and 'Bankyehemaa' on either flat or ridge landforms for Anwomaso, Mampong and Akatsi.

mean depth of root penetration for 'Afisiafi' on ridge at Anwomaso was higher than the mean depth of harvester penetration, implying eminent root damage at harvest. The harvester went deepest when harvesting both 'Afisiafi' and 'Bankyehemaa' on ridge than on the flat landform at Akatsi and Mampong. This was because the roots of 'Afisiafi' went deeper than 'Bankyehemaa' and to minimise damage, the harvester has to go deeper beyond the depth of root penetration. Odigboh & Moreira (2002) and Sam & Dapaah, (2009) reported that ridges are able to control cassava root tubers to reasonable depths to allow for optimum mechanical harvesting. Another reason could be due to the ease with which ridges were easily pulverised. The harvester blade during harvesting goes deeper under ridges and shatters the soil better than on the flat landform.

Tuber damage assessment

The mean percentage tuber damage for 'Afisiafi' and 'Bankyehemaa' at Anwomaso, Akatsi and Mampong after mechanical harvesting ranged from 12 per cent to 27 per cent, for ridge and flat landforms, respectively (Table 3). The mean percentage tuber damage of 12 per cent to 22 per cent was recorded for harvesting 'Afisiafi' on the ridge , compared to 18.25 per cent to 20 per cent to harvest 'Afisiafi' on flat landform at the three sites. Tuber damage for 'Bankyehemaa' ranged from13.5 per cent to 20 per cent on the ridge compared to 14.8 per cent to 27 per cent on the flat landform for the three sites. The low damage values obtained for the two varieties on ridge compared to flat landforms on all sites indicate that with proper operator training and implement handling, ridge harvesting will produce acceptable tuber damage for all processors. This was due to the relatively shorter root spread both along and across the row for ridge planting, giving bunchy nature of roots compared to wider spread for both varieities on the flat landforms at all sites (Tables 2). Bobobee *et al.* (1994) reported 10.7 – 22 per cent average tuber damage for the Leipzig mechanical harvester whilst Kolawole *et al.* (2010) reported 23.3 per cent tuber damage for another mechanical harvester.

Table 3

Cassava Tuber Damage (%) for all Three Sites

Cassava variety-Landform	*Akatsi*	*Anwomaso*	*Mampong*
BH-R	16	13.5	20
BH-F	18	14.8	27
AF-R	12	15	22
AF-F	19	18.2	20
LSD	ns	ns	ns

Generally, the percentage root tuber damage was highest at Mampong compared to Anwomaso and Akatsi. This was attributed to the relatively high moisture content (Fig. 7) at harvest at Mampong making the soil to stick to harvester blades (non-scouring), which could make the harvester to float and decrease its penetration.

Field capacity of TEK MCH

Field capacity of TEK MCH on both ridged and flat landforms at the study sites ranged from 1.55 to 2.96 h ha^{-1} (Table 4). Mechanical harvesting at Akatsi on the flat landforms recorded the lowest field capacity of 2.96 h ha^{-1}, whilst harvesting at Mampong on the ridge gave the highest field capacity of 1.55 h ha^{-1}. Bobobee *et al.* (1994) reported a range of 2.63 – 4.0 h ha^{-1} for the Leipzig. Ospino *et al*. (2007) also reported a mean field capacity range of 1.0 – 1.6 h ha^{-1} for the CLAYUCA cassava harvester model P600, whilst Oni (2005) reported a range of 0.83 – 1.25 h ha^{-1} for the NCAM harvester.

Manual harvesting capacity

Manual cassava harvesting capacities ranged from 24.50 to 85 man-days/hectare for 'Afisiafi' and 'Bankyehemaa' on ridged and flat landforms (Table 5). Harvesting durations were highest at Akatsi for both cassava varieties compared to those obtained at Mampong and Anwomaso. The low moisture content at Akatsi compared to Mampong and Anwomaso (Fig. 7) made it difficult to harvest both on the ridge and on the flat landforms. This confirms the fact that mechanical harvesting is most suitable during the dry season whilst manual harvesting on the other hand is preferred during the wet season as reported by Bobobee *et al*. (1994) and Ospino *et al*. (2007).

TABLE 4

Field Capacity (h ha^{-1}) for TEK MCH 2 on Ridge (MCH2-R) and Flat (MCH2-F), and TEK MCH 6 on Ridge (MCH6-R) Flat (MCH6-F) at Anwomaso, Akatsi and Mampong.

TEK MCH-Landform	*Akatsi*	*Mampong*	*Anwomaso*
MCH 6-F	2.96a	-	-
MCH 6-R	1.78b	1.89b	2.30
MCH 2-F	2.04b	-	-
MCH 2-R	2.03b	1.55a	2.05
LSD	0.25	0.04	ns

*Values followed by the same letter in the same column are not significantly different at $P < 0.05$

TABLE 5

Manual Cassava Harvesting Capacity (man-days ha^{-1}) for Afisiafi on Ridge (AF-R), and Flat (AF-F), Bankyehemaa on Ridge (BH-R) and Flat (BH-F) at Akatsi, Anwomaso and Mampong

Cassava variety-Landform	*Akatsi*	*Anwomaso*	*Mampong*
AF-R	75.73	34	24.50
AF-F	79.42	47.68	32.24
BH-R	84.96	33.17	23.21
BH-F	77.57	41.46	29.66

Manual harvesting capacity varied from as low as 23.21 man-days per hactare at Mampong to as high as 85 man-days per hectare at Akatsi (Table 6). The manual harvesting capacities for 'Bankyehemaa' and 'Afisiafi' on both ridged and flat landforms at Akatsi were significantly different ($P < 0.05$) from those obtained at Mampong and Anwomaso. Nweke, Dustan & Lyman (2002) reported a labour requirement of 22 – 63 man-days per hectare for manual harvesting of cassava. Comparing the capacities obtained for mechanical and manual harvesting methods (Tables 5 and 6), it is confirmed that manual cassava harvesting is more time consuming and is full of drudgery than mechanical harvesting. The high man-days required to harvest at Akatsi strongly correlates with the low moisture content and high soil penetration resistance of the soil, confirming that the harder the soil, the more difficult to harvest manually.

Fuel consumption

Table 6 shows the mean fuel consumption for TEK MCH 2 and 6 for harvesting various cassava varieties on the ridged and flat landforms at Akatsi, Anwomaso and Mampong. TEK MCH 2 recorded the highest mean fuel consumption of 25.14 l ha^{-1} at Akatsi compared to 15.01 l ha^{-1} at Mampong whilst TEK MCH 6 had the lowest (16.85 l ha^{-1}) at Mampong. On the whole, harvesting on the flat landforms has higher fuel consump-

TABLE 6

Mean Fuel Consumption (l ha^{-1}) for TEK MCH at Akatsi, Anwomaso and Mampong

Cassava variety-Landform	*Akatsi*	*Anwomaso*	*Mampong*
MCH 2 –R	25.14	24.72	15.01
MCH 6- R	19.45	16.85	16.22
MCH 2-F	23.59	18.75	16.44
MCH 6-F	20.85	21.43	17.52

tion than harvesting on the ridged landform. Several factors such as wheel slip, moisture content, operator experience, etc. affected this difference in mean fuel consumption for mechanical harvesting. The higher fuel consumption values at Akatsi were due to the relatively dryer soil coupled with a higher penetration resistance.

Percentage tractor wheel-slip

Table 7 shows the mean tractor wheel-slip recorded for TEK MCH 2 and 6 during harvesting at Akatsi, Anwomaso and Mampong. Wheel-slip ranged from 6.99 per cent to 14.93 per cent, which are all within acceptable ranges for a deep soil engaging implement like the cassava harvester on firm and tilled soils. Akatsi recorded the highest mean wheel-slip whilst Mampong recorded the lowest. The sandy soils at Akatsi had the lowest moisture content and are more likely to fail under the tyres, thus, impeding soil grip and traction relative to the other sites.

TABLE 7

Mean Tractor Wheel-slip (%) for TEK MCH 2 and TEK MCH 6 at Akatsi, Anwomaso and Mampong

TEK MCH	*Akatsi*	*Anwomaso*	*Mampong*
MCH 2	14.93	8.19	6.99
MCH 6	12.92	14.80	10.56

Harvester working speed

Fig. 7 shows the mean harvesting speeds recorded at the three sites. The highest mean working speed of 5.88 km h^{-1} was obtained at Mampong, whilst the lowest speed of 4. 39 km h^{-1} occurred at Anwomaso. However, no statistical difference existed between the mean working speeds recorded for the two harvesters (TEK MCH 2 and 6) at $P < 0.05$. The above speeds are higher than the 2.4 – 4.1 km h^{-1} Bobobee *et al*. (1994) reported for the Leipzig mechanical harvester but lower than the values Ospino *et al,* (2007) reported for the CLAYUCA cassava harvester prototype, which had an operational speed of 7.0 km h^{-1}.

Draught force and working speed

Table 8 shows the mean draught force, average working speed, depth of harvester penetration, soil specific resistance (SSR), drawbar power and brake horse power (Brake Hp) observed for TEK MCH 2 and 6 at the three sites during harvesting. The draught values ranged between 4.9 kN at Mampong and 13.2 kN at Akatsi for TEK MCH 2 and from 8.6 kN to 14.52 kN for MCH6 for the two sites. The range of mean draught forces obtained (4.9 – 14.52 kN) was higher than what was reported for the Leipzig harvester (11.94 – 16.2 kN) by Bobobee *et al*. (1994). This shows that the TEK MCH generated a lower resistance force and could be pulled by smaller horse power rated tractors than the Leipzig prototype. The power rating for the tractor engine required to effectively pull the TEK MCH harvesters ranges from 46 to 85 kW. Bobobee *et al*. (1994) reported a tractor power requirement of 55 – 80 kW for the Leipzig harvester while Ospino *et al.* (2007) reported 68 – 70 kW for the CLAYUCA cassava harvester prototype. With the above power ratings, the harvester could be operated with the existing tractors used for land preparation in the farming system.

Conclusion and recommendations

From the development, field trials and performance of the TEK MCH, the following conclusions were drawn: 1) The prototype

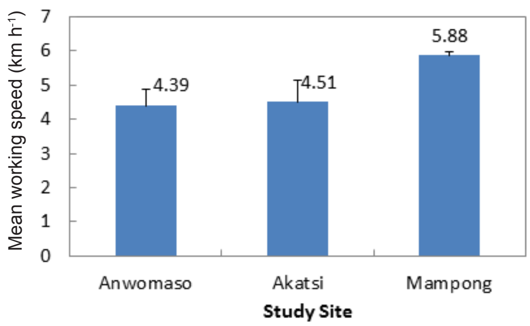


Fig. 9. Mean mechanical harvesting speeds at all 3 sites.

optimum mechanical harvesting performance was achieved at tractor speeds of 5 – 8 km h^{-1} and fuel consumption of 15 – 19 l ha^{-1}, 6) wheelslip ranged from 6.99 per cent to 14.93 per cent, which are all within acceptable ranges for a deep soil engaging implement like the cassava harvester on firm and tilled soils, and 7) after mechanical harvesting, the field is left ploughed with savings on fuel, time and tillage inputs for the next crop production.

Table 8

Draught Forces of TEK MCH 2 & 6 used to Calculate the Tractor Engine Power Requirement at Anwomaso and Mampong.

Site	*TEK MCH*	*Draught force (kN)*	*Average speed (m/s)*	*Depth of penetration (m)*	*SSR (kN m^{-2})*	*Drawbar power (kW)*	*Brake Hp (kW)*
Anwomaso	MCH 2	9.21	1.22	0.27	34.82	11.24	59.48
	MCH 6	11.03	1.32	0.24	46.03	14.56	76.75
Mampong	MCH2	4.90	1.79	0.28	17.80	8.77	46.95
	MCH6	8.60	1.47	0.25	34.55	12.64	66.83
Akatsi	MCH2	13.2	1.22	0.24	54.10	16.10	84.76
	MCH6	14.52	1.11	0.30	48.40	16.12	84.83

harvesters weighing 268 – 310 kg achieved optimum performance on ridged landforms in the three agro-ecological zones in the country, 2) depending on soil condition and operator performance, the TEK MCH can harvest a hectare of mature cassava field within 1.55 – 2.3 h, and the same area will take 24 – 85 manual harvesters one man-day of 8 h to accomplish, 3) the TEK MCH harvester develops average drafts of 10.86 kN on dry fields with moisture content from one per cent to 17 per cent db at depths of 13 – 30 cm requiring a tractor power of 47 – 85 kW to pull it just like any other conventional tillage implements, 4) when harvested mechanically, tuber damage ranges from 16 per cent to 27 per cent for both 'Afisiafi' and 'Bankyehemaa' elite cassava varieties, 5)

It is recommended to test the harvesters for wear and durability in major agro-ecological zones, and through a wide range of soil moisture regimes in Ghana to support nationwide adoption.

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REFERENCES

Agbetoye, L.A.S. (2003) Engineering challenges in developing indigenous machinery for cassava production and processing. In *Proceedings of the Annual Conference of the Nigerian Society of Engineers. Ibadan, Nigeria, 8–12 December 2003*. pp. 80 – 86.

Alhashem, H. A., Abbouda, S. K. & **Saeed, M. O.** (2000) The effect of rear wheel track width and working depth on performance of A 2WD tractor. *Res. Bult., No. (93), Res. Cent. Coll. of Agri., King Saud Univ*. pp. 5 – 21.

Arshad, M. A., Lowery, B. & **Grossman, B.** (1996) Physical tests for monitoring soil quality. In *Methods for assessing soil quality. Soil Sci.* (J. W. Doran and A. J. Jones, eds), pp. 123 – 142. Soc. Am. Spec. Publ. 49. SSSA, Madison, WI.

Bobobee, E.Y. H., Okyere, J. B. & **Asare, E.** (2000) *Mechanical cassava harvesting technique: Final Report*. National Agricultural Research Project (NARP)- Council for Scientific and Industrial Research (CSIR), Accra, Ghana.

Bobobee, E. Y. H., Okyere, J. B., Twum, A., Neumann, R. H. & **Knechtges, H.** (1994) Performance evaluation of a mechanical cassava harvester. *Proceedings of the International Commission of Agricultural Engineering (CIGR) XII World Congress, Ag. Eng' 94, Milano 94. Report No. 94-D-066.*

DeAngelis, K. M. (2007) Measurement of soil moisture content by gravimetric method. *http://www.cnr.berkeley.edu/soilmicro/methods/Soil moisturcontent.pdf. Accessed: 28th October, 2010.*

Ekanayake, I. J., Osiru, D. S. O. & **Porto, M. C. M.** (1997) Agronomy of cassava. IITA Research Guide 60. *http://betuco.be/manioc/Agronomy of cassava IITA nr 60.pdf. Accessed: 22-06-2011*

Ennin, S. A., Otoo, E. & **Tetteh, F. M.** (2009) Ridging, a mechanized alternative to mounding for yam and cassava production. *West African Journal of Applied Ecology* **15**, 1 – 8.

Hunt, D. (1977) Farm power and machinery management. *Laboratory Manual and Workbook,* 7th edn. Iowa State University Press, Ames, Iowa.

IITA (2004) *Pre-emptive management of the virulent cassava mosaic disease through an integrated cassava development approach for enhanced rural sector economy in the south-south and south-east zones of Nigeria*. International Institute of Tropical Agriculture, Ibadan, Nigeria. 79 pp.

International Starch Institute (2002) Cassava plantation, Science Park Aarhus, Denmark. *http://www.starch.dk/isi/papers/TM29 Cassava Plantation EB.pdf. Accessed: 23-06-2011*

Iowa State University Extension (2009) Estimating farm machinery costs. Ag Decision Maker, PM-710, pp. 1 – 8. *http://www.extension.iastate.edu/publications/pm710.pdf. Accessed: 08-08-2011*

Kuiper, L., Ekmekci, B., Hamelinck, C., Hettinga, W., Meyer, S. & **Koop, K.** (2007) Bio-ethanol from cassava. Ecofys Netherlands BV, pp. 1 – 38. Netherlands. *http://www.probos.net/biomassa-upstream/pdf/FinalmeetingEcofys.pdf. Accessed: 24-06-2011.*

Nweke, F. I., Dunstan, S. C. S. & **Lynam, J. K.** (2002) *The cassava transformation: Africa's best kept secret*. Michigan State University Press, Lansing, Mich., USA.

Odigboh, E. U. & **Moreira, C. A.** (2002) Development of a complete cassava harvester 1 – Conceptualisation. *Journal of Agricultural Mechanisation in Asia, Africa and Latin America* **4** (33), 1 – 7.

O'Hair, S. K. (1995) New crop factsheet: Cassava. Tropical Research and Education Center,University of Florida. *http://www.hort.*

purdue.edu/newcrop/cropfactsheets/cassava.html. Accessed: 24-06-2011.

Oni, K. C. (2005) Cassava processing as a tool for employment generation and rural development. *Workshop on cassava research and development, Raw Materials Research and Development Council (RMRDC), Abuja, Nigeria.*

Ospino, B., Cadavid, L. F., Garcia, M. & **Alcalde, C.** (2007) Mechanisation of cassava production in Columbia. *Latin American and Caribbean Consortium to Support Cassava Research and Development (CLAYUCA), CIAT, Apartado Aereo 67-13, Cali, Columbia.*

Philippine Root Crops Information Service, (2005) Cassava, VISCA, bay¬bay, Leyte. *http://www.da.gov.ph/tips/Cassava.pdf. Accessed: 23-06-2011.*

Reichert, J. M., da Silva, V. R. & **Reinert, D. J.** (2004) Soil moisture, penetration resistance, and least limiting water range for three Soil management systems and black beans yield. In *13th International Soil Conservation Organisation Conference – Brisbane, July 2004. Paper No. 721,* pp. 1-4. *http://www.tucson.ars.ag.gov/isco/isco13/PAPERSR.../REICHERT.pdf. Accessed: 15-07-2011.*

Sam, J. & **Dapaah, H.** (2009) Baseline Survey Report, West African Agricultural Productivity Programme (WAAPP), Ghana. pp. 13 – 18. *http://waapp.coraf.org/documents/WAAPP/Rapports/Final WAAPP Baseline Survey Report Ghana.pdf. Accessed: 23-06-2011.*

USDA (1999) Soil Quality Test Kit Guide. Section II, pp. 57-58. United States Department of Agriculture *http://ocw.tufts.edu/data/32/383298.pdf. Accessed: 29-06-2010.*

USDA and NRCS (2003) Plant Guide – Cassava: *Manihot esculenta* Crantz. National Plant Data Centre, Baton Rouge, Louisiana and Pacific Islands, Mongmong, Guam. *http://plants.usda.gov/plantguide/pdf/cs_maes.pdf. Accessed: 24-06-2011.*