PERFORMANCE EVALUATION OF THE TEK MECHANICAL CASSAVA HARVESTER IN THREE SELECTED LOCATIONS OF GHANA

by

Shadrack Kwadwo Amponsah

BSc. Agricultural Engineering

A Thesis submitted to the

Department of Agricultural Engineering, Kwame Nkrumah University of Science and Technology, Kumasi in partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE (Agricultural Machinery Engineering)

College of Engineering

School of Graduate Studies,

August, 2011

DECLARATION

I, AMPONSAH SHADRACK KWADWO, author of this thesis titled “Performance Evaluation of the TEK Mechanical Cassava Harvester”, do hereby declare that apart from the references of other people’s work which have been duly acknowledged, the research work presented in this thesis was done entirely by me in the Department of Agricultural Engineering, Kwame Nkrumah University of Science and Technology, from August 2009 to August 2011.

This work has never been presented in whole or in part for any other degree in this university or elsewhere.

Amponsah Shadrack Kwadwo (PG3768309) ....…………….
(Student and ID Number) Signature Date

Certified by:

Dr. E.Y.H. Bobobee …………………. ....
(Supervisor) Signature Date

Prof. Ebenezer Mensah ………………..... ....………..
(Head of Department) Signature Date

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 meeting its industrial demand through 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 labour 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 test and evaluate mechanical cassava harvesters for three (3) agro-ecological zones in Ghana. Performance of six (6) prototype mechanical harvesters (TEK MCH 1 to 6) was evaluated against various manual harvesting methods for five (5) cassava varieties on ridged and flat landforms. Results from field trials of the harvesters showed that the best performance was achieved on ridged landforms, which have better tuber yields and spread both across and along the ridge. '*Nkabom'* cassava variety on ridges gave the lowest average tuber damage of 9.91% when harvested mechanically. The mechanical harvesters worked best on ridged fields with minimal trash or weeds and relatively dry soils with moisture content from 1.0 – 16.0 % *d.b*, penetration resistance between 1.0 MPa and 3.99 MPa with bulk density from 1.56 - 1.68 g/cm^3 and drafts of up to 12.3 kN, requiring a minimum tractor engine power of 40.4 kW (54 hp) with penetration depth from 20.7 cm to 30.1 cm. The best harvesting performance was achieved at tractor speeds of 4 - 7 km/h giving a field capacity of 1.55 - 2.96 h/ha. After mechanical harvesting, the field is left ploughed with savings on fuel, time and cost for the next season. It is however recommended to test the harvesters in other agro-ecological zones under a wide range of soil moisture regimes in Ghana to promote nationwide adoption.

DEDICATION

I dedicate this project to the Almighty “I am that I am” God for his guidance and directions. I am nothing without you Lord! And to my dear dad, Mr. Patrick Freeman Osei for his support, prayers and encouragement and to my son, Emmanuel Marvin Osei Amponsah for bringing to me and my wife great joy and blessing.

ACKNOWLEDGEMENTS

My profound gratitude goes to my Dr. Emmanuel Y.H. Bobobee, whose original contributions, comments, criticisms and revisions made this project a success.

I am also greatly indebted to all lecturers of the Department of Agricultural Engineering, KNUST especially Dr. W. A. Agyare and Mr J. B. Okyere and also to the technicians at the department’s workshop for their cooperation, fatherly advice and assistance.

My sincerest appreciation goes to my wife, Portia for her support, prayers, sacrifices, patience and encouragement throughout this period.

Finally, I would like to thank all who in their own small ways contributed to the successful completion of this work not forgetting Kwame Mensah Oduro for his help during data collection and all my course mates especially Francis Kumi.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Cassava (*Manihot esculenta* Crantz) is a perennial woody shrub with an edible root, which grows in tropical and subtropical areas of the world, such as Asia, Central, West and Southern Africa (Oni and Eneh, 2004). Cassava can grow and produce dependable yields in places where other crops will not grow or produce well. It can tolerate drought and grow on soils with low nutrient capacity, but responds well to irrigation or higher rainfall conditions, and to use of fertilizers (Plucknett *et al.*, 1998).

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). Worldwide, cassava 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 hectares and annual root yield of more than 170 million tons (Anderson *et al.*, 2004). According to the International Food Policy Research Institute (IFPRI), the total world cassava utilization is projected to reach 291 million tons by 2020 (Scott *et al.*, 2000). Cassava provides food security, not only because it can be grown on less productive land, but because it is a source of income for producers and generally a low cost source of food (Plucknett *et al.*, 1998). Africa produces 62 percent of the total world production making it the largest producer of cassava, with Nigeria leading the world with 19% of global market share (Hillocks, 2002). Over the past years, cassava production in sub-Saharan Africa has risen substantially. This could be attributed to factors such as increased area under production, development and release of higher yielding varieties and favourable government policy (Ennin *et al.*, 2009). Based on current projections, it is expected that by 2020, over 60 percent of global cassava production will be in sub-Saharan Africa alone (IFAD and FAO, 2005).

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.*, 2007; 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).

Cassava found its way into Ghana before the 19th century from its native home of Brazil, having been introduced by the Portuguese in the 1600's to the tropical areas of Africa, the Far East and the Caribbean Islands (Jones, 1959). Cassava has become important and popular staple for varied preparations including *fufu, akple, ampesi, yakeyake, tapioca, agbelikaklo, kokonte, gari* etc. Preparation of these dishes is quite fast and adaptable to all ethnic groups of the country as well as foreigners. Cassava is extensively consumed as food either in the processed or unprocessed form and has thus played a key role in the reduction of under-nourishment with its consumption increasing from 126 to 232 kg/ person/year in Ghana (FAO, 2000). 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.

1.2 Problem Statement

Cassava has been found to be 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). Most farmers are therefore gradually shifting from the small-scale 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 on to 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 6-9 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 bigger in size and go deeper into the soil, it is manually difficult to harvest them all year round, thus shifting the labour constraint from weeding to harvesting especially in the dry season.

Manual harvesting is slow and associated with drudgery and high level of root damage, requiring approximately 53 man days per hectare (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 also conducted by Addy *et al.*, (2004) in Ghana revealed that cassava harvesting constituted the highest production cost.

1.3 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). Mechanisation of cassava harvesting has been identified by cassava experts as the most promising area for intervention and for realising 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 labour bottleneck in cassava harvesting among farmers in Ghana who are planting the TMS varieties (Nweke, 2004; IFAD and FAO, 2005).

In the year 2001, the then President of Ghana, Mr. J.A Kuffuor, launched the Presidential Special Initiative on Cassava Production. However, this initiative was constrained by the difficulty of accessing technologies required for mechanising cassava production especially in the area of harvesting (AATF, 2007). Mechanization in terms of harvesting, like most of the other root crops, is still in the development stage with very few commercial technologies in existence. Development of a labour-saving technology for cassava harvesting has become the most critical challenge in the cassava transformation in the country.

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 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).

Apart from earlier trials conducted in the 1960s, a mechanized cassava harvester developed at the University of Leipzig, Germany has - as the first - been tested for adaptation in Ghana by the Department of Agricultural Engineering of the Kwame Nkrumah University of Science and Technology, Kumasi. The development has however been halted due to lack of a market (International Starch Institute, 2002). Currently in Ghana, the Roots and Tuber Improvement and Marketing Programme (RTIMP) in collaboration with GRATIS, Agricultural Engineering Department of KNUST and Ghana Starch and Glucose Ltd have conducted field trials of four (4) prototype mechanical cassava harvesters in Ashanti-Mampong (Ashanti Region) and Ho in the Volta Region, with the aim of coming out with a unified design of a mechanical cassava harvester that can be adapted for use in the country taking into consideration the different agro-ecological zones.

1.4 Project Objective

The main objective of the project was to test and evaluate the TEK mechanical cassava harvesters in three agro-ecological zones of Ghana.

1.4.1 Specific Objectives

The specific objectives were to:

1. Establish the optimum field conditions for mechanical cassava harvesting with respect to field preparation and soil conditions (i.e. landform (ridged or flat), soil moisture, bulk density and penetration resistance).
2. Determine the various agronomic parameters for *Bankyehemaa*, *Afisiafi*, *Esambankye*, *Dokuduade* and *Nkabom* cassava varieties with respect to root tuber spread and orientation and yield.
3. Determine among five (5) varieties, the cassava variety that easily lends itself to mechanical harvesting with respect to the lowest percentage root tuber damage.
4. Identify the performance characteristics of the TEK mechanical cassava harvesting implement with respect to working speed, fuel consumption, draught power requirement, wheel slip, working depth and percentage root tuber damage.
5. Compare mechanical cassava harvesting to manual harvesting methods in terms of cost, percentage root tuber damage, capacity and drudgery.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin of Cassava

Cassava as a root crop belongs to the family *Euphorbiaceae* and may manifest itself under different species; *Manihot esculenta* Crantz, *Manihot ultissima* Phol or *Manihot aipi* Phol. For different parts of the world, cassava may be commonly referred to as *Agbeli*, *Bankye*, *Yuca*, *Tapioca*, *Mandioca* or *Manioc* depending on the locality in which it finds itself and its use as food (O'Hair, 1995; Alves, 2002). Cassava originated in Brazil and Paraguay and according to Okigbo (1980), it was one of the first crops to be domesticated, and there is archaeological evidence that it was grown in Peru 4,000 years ago and in Mexico 2,000 years ago. From Mid and South America, cassava spread to other parts of the world in post-Columbian times and was introduced into the West Coast of Africa and Zaire in the late sixteenth century, probably in slave ships after which it was introduced into East Africa (Madagascar and Zanzibar) via Réunion by the end of the eighteenth century, and by 1800 it had reached India and was widely grown in Africa and Southeast Asia by the 1850s (Okigbo, 1980). According to O'Hair (1995), cassava has today assumed the status of a cultigen with no wild forms of this species being known.

2.2 Ecology and Cultivars

Cassava is a tropical and sub-tropical crop, requiring at least 8 months of warm weather to produce a crop (O'Hair, 1995; Philippine Root Crops Information Service, 2005). It is a perennial shrub reaching up to 4 meters in height with varying stem colour from pale to dirty-white to brown marked by numerous nodes formed by scars left by fallen leaves (O'Hair, 1995; Alves, 2002). Cassava grows in regions with more or less evenly distributed rainfall throughout the year and an ambient temperature that ranges from 18^{o}-30^{o} C and grows best when planted at the start of the rainy season and also thrives well in sandy loam or clay loam soils, which must be well-drained and not prone to water-logging Cassava is adapted to the zone within latitudes 30 north and south of the equator, at elevations of not more than 2,000 m above sea level, with rainfall of 50 to 5,000 mm annually, and to poor soils with a pH from 4 to 9.0 (O'Hair, 1995; Philippine Root Crops Information Service, 2005; Okigbo, 1980). In drought prone areas it loses its leaves to conserve moisture, producing new leaves when rains resume. It could take up to 18 or more months to produce a crop under adverse conditions such as cold or dry weather. Cassava does not tolerate freezing conditions but is most productive in full sun (O'Hair, 1995; Philippine Root Crops Information Service, 2005).

O'Hair (1995) reported that there were relatively few cassava cultivars before the introduction of national and international breeding programs with cassava because cassava was propagated vegetatively as clones. Recent releases from breeding programs include clones with resistance to many of the major diseases and pests. Specific cultivar names are mostly regional, with the exception of introductions from international research centres, which carry with them an institutional code. This code is often retained as the name of the cultivar. Cultivar classification is usually based on pigmentation and shape of the leaves, stems and roots. Cultivars most commonly vary in yield, root diameter and length, disease and pest resistance levels, time to harvest, cooking quality, and temperature adaptation. Alves (2002) also reported that there exist many cultivars in several germplasm banks held at both international and national research institutions.

2.3 Cassava Varieties

According to IFAD and FAO (2005), farmers in Africa grow several cassava varieties. From a survey conducted by researchers from the Collaborative Study on Cassava in Africa (COSCA), over 1000 local cassava varieties in six counties of the study, namely the Congo, Côte d'Ivoire, Ghana, Nigeria, Tanzania and Uganda were identified. The farmers group the local cassava varieties into the bitter and the sweet varieties. The sweet varieties are more popular in Côte d'Ivoire, Ghana and Uganda while the bitter varieties are more common in the Congo, Nigeria and Tanzania. The COSCA farmers reported that the bitter varieties are more resistant to pests, higher yielding and store better in the ground than the sweet varieties. However, as the productivity of the cassava system increases and more cassava is processed as *gari*, the issue of the sweet or the bitter cassava varieties will become irrelevant (IFAD and FAO, 2005).

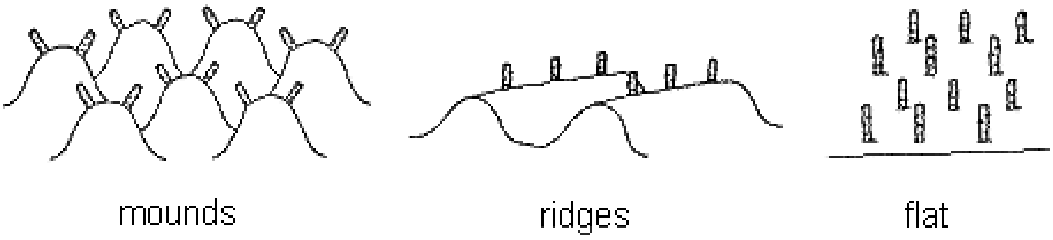
According to RTIMP (2010), there are over fourteen (14) high-yielding cassava varieties available for multiplication in all agro-ecological zones of Ghana. Some of which include: *Afisiafi, Nkabom, Dokuduade, Esambankye, Bankyehemaa, IFAD, Gblemoduade, Agbelifia* and *TEK-bankye.*

2.4 Production Practices

Production practices associated with cassava may include; land preparation, planting materials preparation, planting, fertilizer application, farm sanitation and weeding, pest and disease control, harvesting and processing.

2.4.1 Land Preparation

Field is usually prepared after the land has been cleared, by first ploughing followed by harrowing. Cassava could be planted on the flat, on ridges or on mounds. Figure 1 from Ekanayake *et al.*, (1997) shows the various landforms used in cassava planting.



Source: Ekanayake *et al*, 1997

Figure 1: Various landforms used for planting cassava

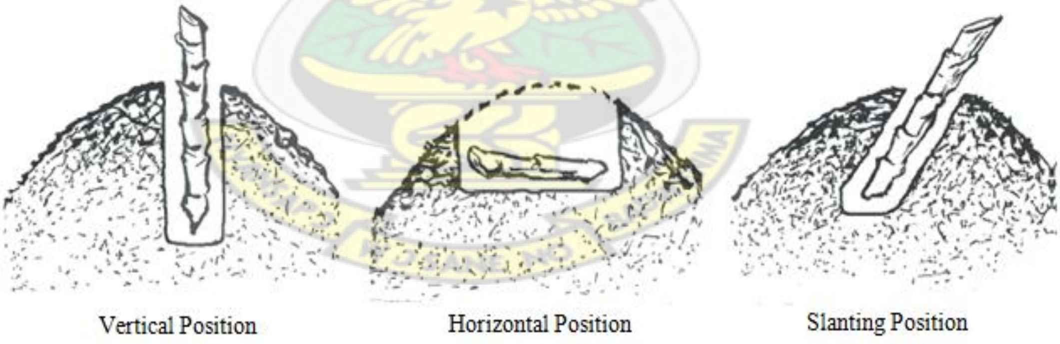
Where ridges are preferred, they are constructed using a ridger after primary and secondary tillage and may range from 15-30 cm in height and 75-100 cm in crest to crest distance (between ridges). Ridging could however be done before or after planting and is best suited for areas with drainage problems (International Starch Institute, 2002; Philippine Root Crops Information Service, 2005). 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.

2.4.2 Planting Materials

Planting materials for cassava is obtained from stem cuttings. It is best to select only fresh, mature and healthy stems. Fresh stem is identified if the latex or sap comes out within six (6) seconds after cutting. Mature stem is identified if the diameter of the pitch or cork is not more than half the diameter of the cortex. Healthy stem should be pest free and the diameter not less than 1.5cm Stalks are usually kept for not more than five days, under shade in upright position in order to give a higher chance of sprouting after planting. The recommended length of stakes is 20-25 cm with 5 or more nodes. Cutting of the stems is usually done with a sharp cutlass or a saw making sure that cuttings are handled carefully to avoid damage to the nodes (Adekunle *et al.*, 2004; Philippine Root Crops Information Service, 2005).

2.4.3 Planting

Cassava stem cuttings (also referred to as 'stakes') could be planted 1 per hole in a horizontal, vertical or slanting position to a depth of 5-10 cm depending on soil type and condition (International Starch Institute, 2002; Adekunle *et al.*, 2004). Figure 2 from Adekunle *et al.*, 2004 shows the different planting positions.



Source: Adekunle *et al*, 2004

Figure 2: Different cassava planting positions

Planting is mostly done by hand in a slanting position at an angle of 45^o when the soil is fairly dry to promote the formation of compactly arranged roots, in a horizontal position when the soil is dry to increase stem production and in vertical position when planting is done during the wet season to produce deeper lying storage roots for anchorage making sure that at least two-thirds of the cutting length is buried or covered with soil (Adekunle *et al.,* 2004; Philippine Root Crops Information Service, 2005).

Cassava stem cuttings may be planted at a spacing of 1.2 x 0.8 m (approximately 10,417 plants/ha) depending on the cultivar. Cuttings planted in moist soil under favourable conditions produce sprouts and adventitious roots within a week. In areas where freezing temperatures are possible, the cuttings are planted as soon as danger of frost has past. Mechanical planters can be employed to reduce labour inputs. Observing the polarity of the cutting is essential in successful establishment of the cutting. The top of the cutting must be placed up with nodes also pointing upwards. Expected germination is 100% with healthy planting material. Filling-in or re-planting can be done 2 weeks after planting to replace dead stem cuttings or those which could not sprout (International Starch Institute, 2002).

2.4.4 Fertilizer Application

External Market Task Force (2004) reported cassava as having the ability to grow in poor soils while giving reasonable yields for food production and although it is assumed to be a ‘poor man’s crop and usually grown without any inputs, it is very demanding in nutrients and responds readily to the use of fertilizers. Cassava removes substantial amounts of nutrients with the harvested roots, the highest being Potassium (K), followed by Nitrogen (N), Calcium (Ca), Magnesium (Mg) and Phosphorus (P). Adequate K is very important for starch synthesis and translocation and increases the plant's resistance to anthracnose (El-Sharkawy and Cadavid, 2000). As cassava has assumed an industrial crop status in Ghana, it is now being grown on large scale, repeatedly season after season, on the same piece of land. Under this condition, the fertility of the soil and crop yields decline over time (Cadavid *et al.*, 1998). According to Gutteridge and Shelton (1994), loss of soil fertility is especially serious in tropical regions where the soil lacks adequate plant nutrients and organic matter due to leaching and erosion of vulnerable topsoil by intense rainfall. The application of supplementary nutrients is therefore a sure means by which the fertility of the soil could be sustained to ensure continuous cropping of cassava on the same piece of land (Asare *et al.*, 2009). Fertilizer is only applied during the first few months of growth (O'Hair, 1995; Kuiper *et al.*, 2007). From Table 1 after Ayoola and Makinde (2007), the average yield of cassava was very low (7.91 t ha^{-1}) for the situation where no fertilizer was applied compared to 11.77 t ha^{-1} when inorganic fertilizer was applied, an increase of 48.8%.

Table 1: The effects of planting pattern and type on yield of cassava (Source: Ayoola and Makinde, 2007)

Treatment		Cassava root yield (t ha^{-1})		
		1994	1995	Average
Planting pattern				
	Regular	9.40a	12.53a	10.97
	Triangular	7.61b	11.19a	9.40
Fertilizer				
	No fertilizer	7.04c	8.78d	7.91
	Inorganic	9.55a	13.98a	11.77
	Organic	8.23b	11.97c	10.10
	Inorg. + org.	9.21a	12.72b	10.97

Values followed by the same letter in the same column are not significantly different at $P \leq 0.05$ (DMRT)

The condition where no fertilizer was applied had the lowest cassava yield among all the four conditions with the organic fertilizer giving 10.10 t ha^{-1} and the combination of organic and inorganic fertilizer giving 10.97 t ha^{-1} yields. This indicates that application of fertilizer increases the yield of cassava production.

The Philippine Root Crops Information Service (2005) suggested that ideally, soil analysis should be carried out prior to planting to determine the kind of fertilizer needed. However, the general recommendation for soils which have not been analyzed is eight (8) sacks of complete (14-14-14) fertilizer per hectare (400kg/ha) which is usually applied from 2-6 weeks after planting at 5-10 cm depth and 15-20cm away from the plant. Moreover, the use of compost or organic fertilizer is highly recommended. Cassava is noted to produce a crop with minimal inputs (Howeler *et al.*, 2008). However, optimal yields are recorded from fields with average soil fertility levels for food crop production and regular moisture availability (Kuiper *et al.*, 2007).

Even though cassava contributes greatly to the Agricultural Gross Domestic Project (AGDP) of Ghana (GTZ and Stumpf, 1998), the application of fertilizer in its production is very minimal (FAO and IFAD, 2000). According to IFAD and FAO (2005), some of the reasons were that farmers generally believe that fertilizers reduce the quality of cassava tubers, cooking quality and storage. This makes it difficult for them to adopt the use of fertilizers in cassava productions. Again, because of the inherent capacity of cassava to produce reasonable yields under adverse edaphic and climatic conditions, increasingly more marginal lands are being used for its production without the application of any fertilizer (Cadavid *et al.*, 1998, El-Sharkawy, 1993). In cassava producing countries, better soils are always devoted to more profitable crops, leaving those areas with soil problems (i.e. high Al content, low exchangeable base content, high P fixation, various degrees of erosion) for cassava cultivation (Howeler, 1991, Molina and El- Sharkawy, 1995). The low yields of cassava achieved in these poor soils are considered acceptable since most crops do not perform well there. Moreover, cassava is a marginalized crop in food policy debates and burdened with the stigma of being an inferior food, ill-suited and uncompetitive with the glamour crops such as imported rice and wheat because of several long-standing myths and half-truths. Many food policy analysts consider cassava as an inferior food because it is assumed that its per capita consumption will decline with increasing per capita incomes (Nweke *et al*., 2001). Lastly, as cassava is usually intercropped or is the last crop in the rotation before the fallow, the crop most likely benefit from the residuals of fertilizers applied to the companion or proceeding crops (IFAD and FAO, 2005).

2.4.5 Weeding

According to Melifonwu *et al* (2000), weeds may be defined as plants growing where they are not wanted. Many different types of weeds occur in cassava farms and cause considerable losses to the farmer. This is because weeds compete with the cassava crop for nutrients, sunlight, and space. Weeds may harbour pests and diseases or physically injure cassava plants and storage roots. Weeds occurring in cassava farms can be put into three main groups, namely, grasses, sedges, and broadleaf weeds (Melifonwu *et al,* 2000). Like many other crops grown in the tropics, cassava is susceptible to early weed competition. Slow initial development of sprouts from cassava cuttings makes all cassava cultivars susceptible to weed interference during the first 3 to 4 months after planting. Crop losses due to weeds can be as high as 50–70% depending on the type of weed and duration of competition (IITA, 2004). Weed control methods mostly employed are manual, mechanical, agronomic and chemical. The manual method (using hoes and cutlasses) is effective when the farm size is small, and it is the most widely used method in cassava producing areas because the crop is grown mainly by small-scale farmers in Ghana (Bolfrey-Arku *et al.,* 2007). Weeding is recommended at 4-5 weeks after planting and at 8 weeks after planting until crop ground cover is complete (International Starch Institute, 2002). According to Muma (2000), weeding alone may require 30 to 45 person-hours per hectare. Hand picking of weeds and spot weeding 3-4 weeks after planting is also advisable to effectively control weeds (Philippine Root Crops Information Service, 2005). Mechanical weeding is also possible at the very start using an inter-row cultivator or spring tine cultivator. Weeds are however, best controlled through a proper crop rotation scheme and with proper pre-planting cultivation to prevent germination of weeds. Pre-emergence herbicides are also very effective to control weeds in cassava (International Starch Institute, 2002).

2.4.6 Pest and Disease Control

Various pest and diseases attack cassava, such as the mealybug, green mite, mosaic disease and the bacterial blight. The biological control method has been used to bring the mealybug under control while the biological control of the green mite is still in progress (IFAD and FAO, 2005). The most promising method of controlling the mosaic disease and the bacterial blight is breeding resistant varieties, which involves a long and painstaking process of breeding and diffusion. Meanwhile, the green mite, mosaic disease and the bacterial blight continue to cause yield losses in various parts of Africa (Kuiper *et al.*, 2007; IITA, 2004). African farmers usually do not attempt to control the cassava pests and diseases with pesticides because of the limited access to chemicals and because it is not economically profitable to apply pesticides on cassava (IFAD and FAO, 2005). However, farmers use the following agronomic practices to achieve partial control of the cassava pests and diseases: land rotation, crop rotation and selection of the pests and diseases-resistant local varieties (Philippine Root Crops Information Service, 2005; IITA, 2004). Most of the major cassava pests and diseases are new in Africa as they were introduced only within the last 30 years (Gutteridge and Shelton, 1994). Improved quarantine inspection is needed to prevent, as much as possible, further introduction of new problems. There is a need for better preparedness to control new problems before they spread and take root in Africa (IFAD and FAO, 2005)

2.4.7 Harvesting

According to Agbetoye (2003), the most difficult operation in cassava production is cassava harvesting. Cassava is a highly perishable crop. It starts to deteriorate as early as one to three days after harvest; thus harvesting cassava should be done at the right time and in the proper way (Kuiper *et al.*, 2007; USDA and NRCS, 2003; IITA, 2004). 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 and NRCS, 2003). It also ties the land unnecessarily to one crop whilst exposing the roots to pests. Cassava is ready for harvest as soon as there are storage roots large enough to meet the requirements of the consumer, starting from 6-7 months after planting (MAP), especially for most of the new cassava cultivars (Ekanayake *et al.*, 1997; USDA and NRCS, 2003). Matured roots are clustered around the base of the plant and extend about 60 cm on all sides. It is for these roots, which contain from 15 to 40 percent starch that the crop is cultivated. Under the most favourable conditions, yields of fresh roots can reach 90 t/ha while average world yields from mostly subsistence agricultural systems are 10 t/ha (USDA and 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 and ropes can be used to assist harvesting. 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). It is not advisable to harvest cassava right after a heavy rain or when the soil is too wet (Ekanayake *et al.,* 1997) because at this time, the roots have high water content which makes them difficult to store. Also, wet soil particles would stick easily to the roots and harvesting implement especially if the soil is clayey, thus, making the roots hard to clean and implement difficult to use (Philippine Root Crops Information Service, 2005; International Starch Institute, 2002). According to Philippine Root Crops Information Service (2005), harvesting cassava during relatively dry weather 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).

2.4.8 Processing

The shelf life of cassava is only a few days unless the roots receive special treatment. Removing the leaves two weeks before harvest lengthens the shelf life to two weeks (O'Hair, 1995; Kuiper *et al.,* 2007). Dipping the roots in paraffin or a wax or storing them in plastic bags reduces the incidence of vascular streaking and extends the shelf life to three or four weeks (External Market Task Force, 2004). Roots can be peeled and frozen. Traditional methods include packing the roots in moist mulch to extend shelf life. Dried roots can be milled into flour. Maize may be added during the milling process to add protein to the flour. The flour can be used for baking breads. Typically, cassava flour may be used as partial substitute for wheat flour in making bread (Kuiper *et al.*, 2007). Bread made wholly from cassava has been marketed in the U.S.A. to meet the needs of people with allergies to wheat flour (O'Hair, 1995). Fresh roots can be sliced thinly and deep fried to make a product similar to potato chips. They can be cut into larger spear-like pieces and processed into a product similar to French fries. Roots can be peeled, grated and washed with water to extract the starch which can be used to make breads, crackers, pasta and pearls of tapioca. Unpeeled roots can be grated and dried for use as animal feed. The leaves can add protein to animal feed. Industrial uses of cassava in the processing procedures or manufacture of products include paper-making, textiles, adhesives, high fructose syrup and alcohol (O'Hair, 1995).

2.5 Global Cassava Status and Importance

Cassava is a perennial woody shrub, grown as an annual. Cassava is a major source of low cost carbohydrates for populations in the humid tropics. The largest producer of cassava is Nigeria. The country has since 1990, doubled the production of other major producers of cassava such as Thailand and Indonesia and has surpassed Brazil as the world’s leading producer of cassava with a total harvested crop area of 3.1 million hectare in 2001 and an average yield of about 11 t/ha (Kolawole *et al.*, 2010; IFAD, AU and NEPAD, 2008). According to O’Hair (1995), production in Africa and Asia continues to increase, while that in Latin America has remained relatively level over the past 30 years. Thailand is the main exporter of cassava with most of it going to Europe (Phillips, 2009). It is a staple food in many parts for western and central Africa and is found throughout the humid tropics (O'Hair, 1995). Ghana’s cassava production soared from 3.3 million metric tons grown on 446,000 hectares in 1989 to 9.7 million tons on 800,000 hectares in 2009 (Bill and Melinda Gates Foundation, 2010). Currently, Ghana ranks as the third largest producer of cassava in Africa after Nigeria and the Democratic Republic of Congo producing an estimated 10 million tonnes (FAO, 2009).

Cassava is grown for its enlarged starch-filled roots, which contains nearly the maximum theoretical concentration of starch on a dry weight basis among food crops (EAC, 2010). Fresh roots contain about 30% starch and very little protein (O’Hair, 1995). Roots are prepared much like potato. They can be peeled and boiled, baked, or fried. It is not recommended to eat cassava uncooked, because of potentially toxic concentrations of cyanogenic glucosides that are reduced to innocuous levels through cooking. In traditional settings of the Americas, roots are grated and the sap is extracted through squeezing or pressing. The cassava is then further dried over a fire to make a meal or fermented and cooked. The meal can then be rehydrated with water or added to soups or stews. In Africa, roots are processed in several different ways. They may be first fermented in water. Then they are either sun-dried for storage or grated and made into dough that is cooked. Alcoholic beverages can be made from the roots. Young tender leaves can be used as vegetable for the preparation of soup, containing high levels of protein (8-10% F.W.). One clone with variegated leaves is planted as an ornamental (O’Hair, 1995). According to Nweke (2004), cassava is by far the most widely cultivated and consumed starchy staple in Ghana. It is consumed in one form or the other by a large spectrum of Ghanaians, irrespective of their ethnic background. Seini (2002) reported that though yields of cassava are higher in the forest and transitional zones, it is also grown in every part of Ghana except in the extreme north where conditions are not too suitable for its cultivation. Cassava is also a famine crop in the sense that it can survive adverse weather conditions, particularly drought, and can actually remain planted in the soil over the dry season where there is practically very little or no rainfall. This makes it less risky to cultivate and also a popular crop among farmers not only in Ghana but also throughout tropical Africa (Seini, 2002).

2.6 Methods of Cassava Harvesting

2.6.1 Manual Harvesting

This is the traditional method of harvesting cassava using a hoe, cutlass or mattock to dig round the standing stem to pull out the root before detaching the uprooted roots from the base of the plant. Figure 3 shows two different manual cassava harvesting methods; one with the help of a cutlass and the other using a hoe.

Figure 3: Different manual harvesting methods (hoe and cutlass respectively)

This method is laborious especially during the dry season when soil moisture is at lower levels (IITA, 1992). According to Nweke *et al* (2002), manual harvesting requires about 22-62 man days per hectare.

2.6.2 Semi-manual Harvesters

The International Institute of Tropical Agriculture (IITA) in Nigeria designed and produced a manually operated cassava root tuber lifter to be used by small scale farmers for cassava growing areas in Africa (Figure 4).

Figure 4: The IITA cassava lifter in use

The National Centre for Agricultural Mechanization (NCAM) in Nigeria also developed and commercialized a semi-mechanised cassava lifter/harvester as shown in Figure 5 after Oni and Eneh (2004).

Figure 5: The NCAM cassava lifter (Source: Oni and Eneh, 2004)

The IITA cassava lifter consists of a frame to which an immovable griping jaw is attached and a lever (handle) which is hinged to the frame for lifting cassava roots. The NCAM on the other hand, consists of a frame to which a footboard and immovable griping jaws are attached and a lever (handle) which is hinged to the frame. Both implements have been tested to harvest up to 200 plants per man-hour and can be classified under semi-manual types of cassava harvesters since they require some degree of human effort to be able to use them effectively for harvesting compared to the mechanised types (Oni and Eneh, 2004).

2.6.3 Mechanised Cassava Harvesting

Mechanical harvesting of cassava involves the use of a harvesting implement integrally hitched to a tractor to uproot the cassava roots. Manual effort is however required after the uprooting has been completed to collect and detach the cassava root tubers. The following field requirements/conditions are also necessary to allow for an optimum mechanical cassava harvesting operation: a field free from hidden obstructions (rocks, roots, stumps etc. down to 40 cm deep) of sizes that can interfere with lifting the tubers; good weed control as weeds block the lifters; Cutting down (coppicing) the cassava plant to a stalk level of about 30cm prior to harvesting (USDA and NRCS, 2003; Bobobee *et al,* 1994) to allow the tractor operator to work in a regular manner as shown in Figure 6; Ridge cultivation of cassava in rows is preferred to facilitate better orientation of stems for tractor operation during harvest as shown in Figure 7.

Figure 6: A cassava field being coppiced prior to mechanical harvesting at Mampong

Figure 7: A ridged cassava field in rows at Akatsi

Planting cassava on ridges has several advantages, which include; higher root yield (Ennin *et al.,* 2009) due to increased number of roots per plant, effective means of reducing erosion (FAO and IFAD, 2001), better weed control and field management (Ennin *et al.*, 2009) coupled with ease of mechanisation with respect to harvesting as compared to other landforms such as on flat and mounds (Ekanayake *et al.,* 1997; Ennin *et al.,* 2009). Ridges have the advantage of controlling the spread of the cassava root cluster to suitable lengths across and along the row and reasonable root tuber depth to allow for optimum mechanical harvesting (Odigboh and Moreira, 2002; Sam and Dapaah, 2009).

2.7 Existing Mechanical Cassava Harvesters

2.7.1 The Leipzig Mechanical Cassava Harvester

The digging, lifting and transport of cassava root cluster into a windrow have been demonstrated under a Ghanaian condition using a prototype cassava harvester developed at the Leipzig University, Germany (Bobobee *et al.,* 1994). The harvester reduces to the minimum the heavy physical work involved in manual cassava harvesting using the hoe and cutlass, especially in the dry season. Design goals for the Leipzig mechanical harvester prototype included: cutting of soil, digging of soil, raising of soil containing the cassava root cluster, transporting the cassava root cluster into windrow behind the tractor to ease manual tuber detachment from stem, reducing the number of moving parts, improvement in the flow of soil and residue to prevent blockade and fuel conservation during seedbed preparation for next cropping. The structural arrangement of the harvester consist of: a digging share rising into a conical shaped mouldboard between two legs, a frame of digging tool, a stem guiding device, a frame for stem pulling device and hydraulically operated belt pulling elements. The 1 m wide harvester which is a fully mounted implement operates according to the “dig and pull” principle. It cuts and loosens the growth area of the root cluster by two vertical beams, and a share attached to the base plate. Figure 8 shows the Leipzig mechanical harvester prototype in operation. The cassava root cluster is loosened carefully, lifted to about 20 cm and delivered to the transport unit made of two belts and a set of steel/plastic press rollers. The windrowed root clusters are then detached with hand or cutlass and finally collected. The harvesting process produces a well pulverised field, thus effectively eliminating the tedious and energy intensive conventional primary tillage operation. Additional advantages for using the harvester include: (1) lowering of the total production cost, (2) increase in labour productivity, (3) considerable decrease in harvesting losses and root damage.

Figure 8: Leipzig Mechanical Cassava Harvester Prototype in operation (Source: Bobobee et al., 1994)

Table 2 shows the summarized performance evaluation results after testing the Leipzig mechanical cassava harvester prototype on the *TMS 30572* cassava variety for some agro-ecological zones in Ghana.

Table 2: Summarized Performance Evaluation Results for the Leipzig Mechanical Cassava Harvester Prototype (Bobobee et al, 1994)

Parameter	Value
Draft requirement (kN)	11.94 – 16.2
Working Depth (cm)	25
Soil moisture content (% db)	3.5 – 5.8
Soil bulk density (g/cm^3)	1.82
Cone Index (MPa)	0.88 – 2.5
Average Fuel Consumption (l/ha)	40.3
Working speed (km/h)	2.4 – 4.1
Field Capacity (ha/h)	0.25 – 0.38
Tractor Power requirement (kW)	55 - 80

According to Bobobee *et al* (1994), tests to date show that several factors are critical for successful mechanised harvesting of fully matured cassava crop. These include: tractor speed, soil moisture content at time of harvesting, cone index, depth of penetration of digging share, height of ridge at plant maturity, stem size and inclination, depth of root cluster, spread of root cluster as it affects damage to roots beyond the width of the cutting share, and the plant population density as it affects specific feed rate. The harvester was introduced into Ghana in 1991. However, field testing only started in 1993. As a result, it could not be evaluated extensively and further investigation on the performance of the harvester was expected to be conducted in other agro-ecological zones in the country (Bobobee *et al,* 1994).

2.7.2 CLAYUCA Cassava Harvester Model P600 (two rows)

The Latin American and Caribbean Consortium to Support Cassava Research and Development (CLAYUCA) conducted some research on the adaptation and evaluation of semi-mechanized harvesting systems for cassava in Columbia. This evaluation process became important due to the excessive cost of manual harvesting, which demands approximately 22-62 man-days per hectare (Nweke *et al*., 2002). Two semi-mechanised cassava harvester prototypes developed in Brazil were imported and their performance was evaluated under specific conditions in the main cassava growing regions of Columbia (Ospino *et al.*, 2007). By way of technical characteristics, the prototype weighed approximately 200 kg with an output of 5-8 ha/day when working for 8 hours/day. It had a working capacity of harvesting two rows at the same time with cassava planting distances between rows of 80-100 cm with minimum soil disturbance whilst leaving the cassava plant at the same site where it was harvested. The prototype had a front cutting disk that facilitated the harvesting process and was able to work even on dry soils where manual harvesting was not possible (Ospino *et al.*, 2007). For a smooth operation, however, it required the cutting of cassava stems prior to harvesting to a height of 20-40 cm. The principal parameters evaluated were; performance with each harvesting method (ha harvested per day), root losses (% whole roots, % cut roots and % buried roots), labour use (ha harvested per man per day and tonnes of roots harvested per man per day). Figure 9 shows the Cassava harvester model P600.

Figure 9: CLAYUCA Semi-mechanised Cassava Harvester Model P600 (Source: Ospino et al, 2007)

Table 3 presents the results obtained after the evaluation of the CLAYUCA Semi-mechanised Cassava Harvester Model P600 prototype.

Table 3: Evaluation results of CLAYUCA Cassava Harvester Prototype. (Values presented are the average of several repetitions and trials).

Parameter	Value
Operational Speed	7.0 km/h
Working depth	30-40 cm
Tractor power requirements	90 hp
Maximum working width	2.4 meters
Performance	1.1 ha/hr

Source: Ospino *et al*, 2007

The main effect of the use of the harvester is the improvement in the efficiency of labour. Under the traditional system, in which the cassava roots are harvested by hand, a good performance for a worker is around 500 kg roots/day (Ospino *et al.*, 2007). With the use of the harvester Model P600, CLAYUCA has been able to measure the harvest of around 1,100kg roots/day. In more developed cassava producing systems, such as those found in South Brazil, a good performance using mechanical harvesters is around 1,500 kg roots harvested/day. The economic importance of the use of mechanical harvesters is in the reduction in the number of workers that are needed to harvest a cassava field. Tables 4 and 5 present the results obtained during the evaluation of the prototype and its comparison with the manual harvesting system.

Table 4: Costs per ha of Manual Harvesting of Cassava in the Valle del Cauca, Columbia in the year 2000 for a production of 12 t/ha.

Activity	Unit	Amount (US$)	Unit Value (US$)	Total Value (US$)
Labour (harvesters)	Man-day	30	4.60	138.00
Packing	Sacks	180	0.04	7.20
Others	Roll			2.50
Total Harvest costs				147.70
Total costs of cassava production per ha				566.00
Harvest costs as percentage of total costs:				26.1%

Source: Ospino *et al*, 2007

It could be observed that the introduction of the harvester prototype allows a reduction of 53% in labour cost for harvesting resulting in a reduction of 43% of the cost of harvest, and a further reduction of 12% of the total production costs (Ospino *et al.*, 2007).

Table 5: Costs per ha of Semi-mechanised Harvesting of Cassava in the Valle del Cauca, Columbia in the year 2000

Activity	Unit	Amount (US$)	Unit Value (US$)	Total Value (US$)
Labour (harvesters)	Man-day	14	4.60	64.40
Packing	Sacks	180	0.04	7.20
Others	Roll			2.50
Fixed and variable costs of harvester (per ha)				9.50
Labour (Tractor operator)				1.20
Total Harvest costs				84.80
Total costs of cassava production per ha				498.00
Harvest costs as percentage of total costs:				17.1%

Source: Ospino *et al*, 2007

2.7.3 NCAM Tractor-drawn Tuber Harvester

According to Oni (2005), the National Centre for Agricultural Mechanization (NCAM) in Nigeria designed and manufactured a mechanized cassava harvester which was adapted for use in most farming communities in Nigeria. The harvester consists of a combination of a standard chisel plough preceding a serrated disc plough, both mounted on a tractor-drawn toolbar. The equipment has a field capacity of 0.8 - 1.2 ha per hour. Figure 10 shows the NCAM tractor-drawn cassava harvester.

Figure 10: NCAM Mechanized Cassava Harvester (Source: Oni, 2005)

Odigboh and Moreira (2002) reported that mechanisation of cassava harvesting naturally, has attracted a great deal of research attention but with very modest successes achieved. Catalogues of agricultural machines produced by Brazilian manufacturers contain no cassava harvesters (Odigboh and Moreira, 2002). What exists in Brazil, as elsewhere in the world, are few models of cassava harvesting aids in limited production and on trial use by a few farmers. Also, there are many problems associated with cassava harvesting; some of which arise from the serious difficulties created by the random growth patterns of the roots and the equally random branching of the stems. In addition, cassava does not have a specific harvesting season. Therefore, an effective harvester must be able to operate in the parched hard soils of the dry season, the drenched muddy soils of the tropical rainy season, as well as in soils the consistencies of which vary between those two extremes (Odigboh and Moreira, 2002). Agbetoye *et al* (2000) reported that most of the experimental cassava harvesters in literature are based on the elevator digger principle whereby the share cuts through the soil 0.3-0.4 m deep and 0.7-0.8 m wide and handling about 0.23 m^3 or about 500 kg of soil to harvest a plant. All these unique characteristics must be appropriately considered to design an effective harvester (Odigboh and Moreira, 2002).

2.8 Current Trend of Mechanical Cassava Harvesting Technology in Ghana

Apart from earlier trials conducted in the 1960s, a mechanized cassava harvester developed at the University of Leipzig, Germany has - as the first - been tested for adaptation and adoption in Ghana by the Department of Agricultural Engineering of the Kwame Nkrumah University of Science and Technology, Kumasi. The development has however been halted due to lack of a market (International Starch Institute, 2002).

Recently in Ghana, the Roots and Tuber Improvement and Marketing Programme (RTIMP) in collaboration with GRATIS, the Agricultural Engineering Department of KNUST and Ghana Starch and Glucose Ltd have conducted field trials of four (4) prototype mechanical cassava harvesters in Ashanti-Mampong (Ashanti Region) and Ho in the Volta Region, with the aim of coming out with a unified design of a mechanical cassava harvester that can be adapted for use in the country taking into consideration Ghana's climatic and soil conditions. The four prototype models were as follows: The Leipzig (Germany) model, the GRATIS model, TEK model 1 and TEK model 2. TEK model 1 and 2 were produced by the Department of Agricultural Engineering (KNUST) and the GRATIS model was produced by the GRATIS Foundation. The German Leipzig model was used as a control against the other three (3) models. The main objective was to test all the different models of mechanical harvesters under similar conditions and integrate all good aspects of the different designs so as to come out with a unified design which will be effective and highly efficient for use in the country (RTIMP, 2010). It is expected that this technology after successful trials, would be adapted and fully incorporated into Ghana's agricultural system.

Sims and Kienzle (2006) reported that the latter half of the last century saw a tremendous investment in research and development aimed at producing equipment for smallholder farmers. Regrettably, however, adoption by farmers was often disappointing to the developers, and numerous items of 'improved' equipment have ended up on the scrap heap emphasizing on the importance of farmers' participation in the whole process of technology development.

According to Sam and Dapaah (2009), the Agricultural Sub-Sector Investment Programme (AgSSIP) has developed a semi-mechanized cassava harvester for large scale farm use, which though yet to be tested for its viability, is said to be able to handle about 800 - 1000 kg of cassava per person/day capacity unlike 400 kg/person/day when harvesting is done manually. The performance of the harvester is however facilitated when cassava is planted on ridges. Again, the harvester does not eliminate manual labour completely since after uprooting root tuber detachment would have to be done manually.

2.9 Soil Mechanical Properties

2.9.1Cone Index

According to Jahn and Hamburg (2002), many research applications within agriculture require some measure of soil strength as a part of a thorough study. Plant and soil scientists frequently use a cone penetrometer and the Cone Index (CI) to characterize soil strength in agronomic studies. Traction models have been developed that utilize CI as the measure of surface soil strength. The use of cone penetrometers has been simplified by the development of hand-operated recording devices, and tractor mounted versions that reduce manual labour requirements. General use of Cone Index is enhanced by the existence of a standard (ASAE S313.2) addressing the physical and operational aspects of cone penetrometers and the calculation of the CI, making comparisons from different studies reasonable. Cone penetrometers alone have limitations as a means of characterizing soil strength. The easily measured parameter (cone index), represented by the force to push a cone into the soil divided by the cross sectional area of the cone, is a complex but ill-defined measure of soil strength and compressibility (Macmillan, 2002).

The cone index of a soil which is the degree of its strength has been shown to be affected by its water content and bulk density (Agodzo and Adama, 2003; Vaz *et al.*, 2001) and is usually measured in kilo-Pascal (kPa). According to USDA (1999), penetration resistance (Cone Index) depends strongly on the soil water content: the dryer the soil, the greater the resistance to penetration. Therefore, the water content of the soil should be noted when taking a measurement.

2.9.2 Soil Moisture Content

The water content of the soil is an important property that controls its behaviour. As a quantitative measure of wetness of a soil mass, water content affects the level of compaction of soil, which is indicated by its bulk density (Agodzo and Adama, 2003).

2.9.3 Soil Bulk Density

USDA (1999) defines bulk density as the ratio of oven-dried soil (mass) to its bulk volume, which includes the volume of particles and the pore space between the particles. It is dependent on the densities of the soil particles (sand, silt, clay, and organic matter) and their packing arrangement. Bulk density is a dynamic property that varies with the structural condition of the soil (USDA, 1999). This condition can be altered by cultivation; trampling by animals; agricultural machinery; and weather; i.e., raindrop impact (Arshad et al., 1996). Compacted soil layers have high bulk densities, restrict root growth, and inhibit the movement of air and water through the soil (USDA, 1999). Arshad et al., (1996) reported that typical soil bulk densities range from 1.0 to 1.7 g/cm^3, and generally increase with depth in the soil profile.

2.10 Wheel-slip

Macmillan (2002) defines wheel-slip as the proportional measure by which the actual travel speed of the wheel falls short of (or exceeds) the "theoretical" speed and in terms of measurement, prediction and presentation of tractor performance, slip is the single most important, dependent parameter.

According to Naderi *et al* (2008), percentage of drive wheel slip in traction mode is defined in ASAE Standard S296.4 as:

$$slip\,\% = \left[1 - \frac{V_a}{V_t}\right] \times 100 \qquad \text{Equation 1}$$

Where; V_t is the theoretical speed or speed without slip and V_a is the actual speed. For measuring the speed, travel distance and the time for 10 revolutions were measured. Also on the concrete and without any tractive force, the actual speed of tractor was measured in circumstances similar to the field experiments (engine speed and transmission position).

2.11 Implement Draught

For the purposes of matching an implement that is being pulled, the important parameter to consider is the horizontal force commonly known as the 'draught' force (from the word to 'draw' or to 'pull') to move the implement. This force is equal and opposite to the forces that arise from the process that the implement is performing and will of course vary with the nature of that process (represented broadly by the implement type), the size of the implement and the travel speed. The draught of an implement is expressed as a force, usually in kN. However draught may also be expressed in terms of parameters that take into account the size of the implement or the magnitude or intensity of the process or of the work that is being done (Macmillan, 2002).

2.12 Fuel Consumption

According to Grisso *et al* (2010), farmers may consider numerous ways to estimate and reduce fuel consumption but the first step is to determine how much fuel is being used for a particular field operation and compare it to average usage. This measurement can be completed by filling the fuel tank of the tractor before and after a field operation, noting the number of hectares covered. The number of litres used, divided by the number of hectares covered, gives the fuel consumption in litres per hectare (l/ha).

Depending on the type of fuel and the amount of time a tractor or machine is used, fuel and lubricant costs will usually represent at least 16 percent to over 45 percent of the total machine costs (Siemens and Bowers, 1999). With reference to the above statement, Grisso *et al* (2010) emphasized on the fact that fuel consumption plays a significant role in the selection and management of tractors and equipment.

2.13 Field Capacity

The field capacity of a farm machine is the rate at which it performs its primary function, i.e., the number of hectares that can be worked per hour or the number of tonnes of cassava that can be harvested per hour. Measurements or estimates of machine capacities are used to schedule field operations, power units, and labour, and to estimate machine operating costs. The most common measure of field capacity for agricultural machines is expressed in hectares covered per hour of operation (Hanna, 2001).

2.14 Heart Rate and Drudgery

Heart rate monitoring can be used as a simple yet effective method of estimating exercise oxygen uptake and energy expenditure in the field because it has a strong relationship with oxygen consumption (Ericsson *et al.*, 2006; Crouter *et al.*, 2004; Freedson and Miller, 2000). According to Ericsson *et al* (2006), heart rate is a valid and reliable predictor of exercise intensity and energy expenditure for activities lasting less than 120 minutes. Keim *et al* (2004) however reported that a limitation of employing heart rate as a surrogate for energy expenditure was that the relationship between heart rate and Oxygen consumption is weak at low activity levels, which are the levels characteristic of most sedentary individuals. Montoye (1996) also reported that a person's heart rate can also rise or fall solely in response to emotions, caffeine intake, ambient temperature, or illness.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study areas were located at Anwomaso KNUST arable farms (6°41'56.75"N, 1°31'25.85"W) and 274m 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 savannah zone in the Volta Region. These sites were selected based on their potential for relatively higher cassava production and consumption. Figure 11 presents the map of Ghana showing the locations where the trials were carried out in the study.

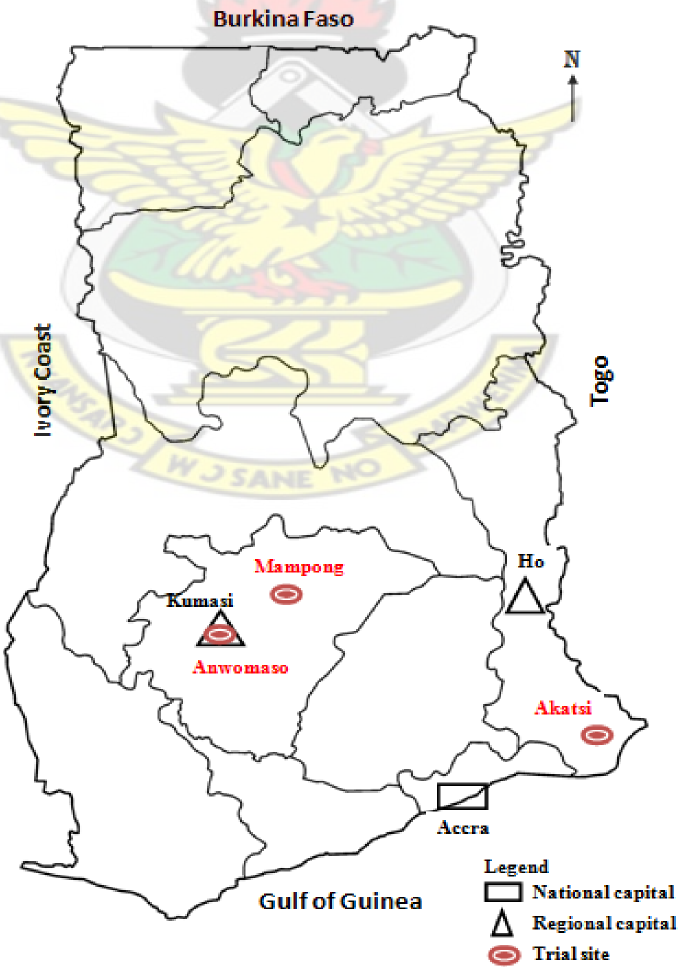


Figure 11: Map of Ghana showing the trial sites for study

3.1.1 Climate and Soils

Anwomaso experiences tropical rainfall, i.e. bi-modal 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 (Baryeh, 1997).

Asanti-Mampong 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 Lithosols, which are usually very shallow but are well-drained, are predominant in this study area (Brammer, 1962).

The climate in Akatsi is characterized by relatively higher minimum and maximum 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. Three main soil types characterize this study area; moderate to well-drained, deep red to brown loamy sand to sandy loam topsoil over coarse sandy loam to clay loam sub-soils and may fall under Gleysols or Cambisols (FAO, 1998).

3.2 Methodology

3.2.1 Land preparation

Each study site was first ploughed using a disc plough and then harrowed with a disc harrow to produce finer soil tilth. The field was then divided into three parts; one-third was left as a flat landform and ridges were constructed on two-thirds. Ridges were constructed 1.2 m apart (from crest to crest) and had an average height of 0.3m.

3.2.2 Field Layout and Cassava Varieties

Except for the Anwomaso field (on-station), which had a land size of 1.0 ha (being the main research site), the two on-farm study sites (i.e. Mampong and Akatsi) had 0.4 ha (1 acre) of land being used for the experiment. Also, all the two on-farm study sites were planted to only two cassava varieties namely; "*Bankyehemaa*" and "*Afisiafi*" in rows on both ridged and flat landforms as shown in Figure 12.

Figure 12: Field Layout for the on-farm study sites

The Anwomaso field however, was planted to five different cassava varieties namely; "*Afisiafi", "Nkabom", "Bankyehemaa", "Dokuduade"* and "*Esambankye*" as shown in Figure 13.

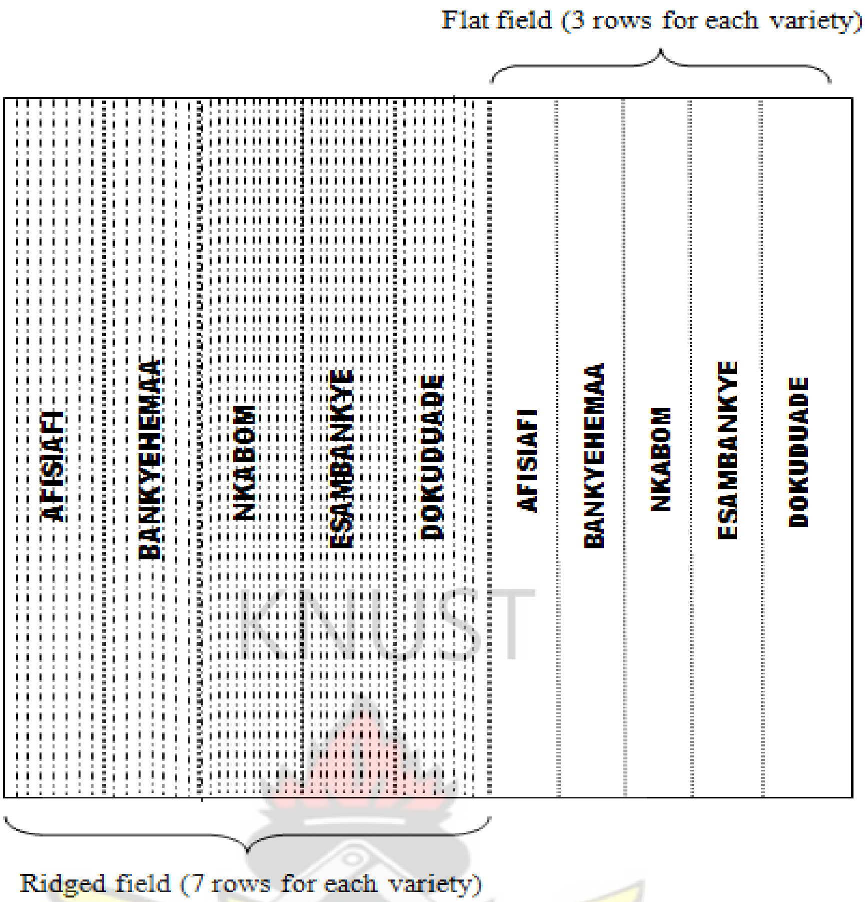


Figure 13: Field Layout for the Anwomaso study site

3.2.3 Cassava Planting

The cassava planting materials for the various varieties were obtained from the multiplication plots of the Root and Tuber Improvement and Marketing Programme (RTIMP) under the Ministry of Food and Agriculture (MoFA), Kumasi. The cassava sticks containing at least 4-5 nodes were cut into sizes 20-25 cm before planting. Planting was done manually with the use of a cutlass at a spacing of 1.2 x 0.8 m. A hole was created in the soil with the cutlass and then the cutting was inserted with the nodes facing upwards at an inclined angle of about 45^{o} with at least half of its full length inside the soil as shown in Figure 14. 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.

Figure 14: Planting of cassava cutting

3.2.4 Field Management

Weeding of the fields 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 farm is kept free of weeds so as not to impede or hinder mechanical harvesting.

3.3 Data Collection

3.3.1 Soil Chemical and Mechanical Analysis

Soil samples were collected from all study sites before ploughing, after ploughing and at harvest. Five replicates were taken at each study site for soil moisture content determination 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 ploughing, after ploughing and at harvest. A soil core sampler of size 5 cm in diameter and a mallet was used to take soil sample for bulk density determination. A soil auger was used to take soil samples for moisture content determination. Soil samples were oven dried at a temperature of 105°C for 24 hours in accordance with the gravimetric soil moisture determination method (DeAngelis, 2007).

Additionally, composite soil samples were taken using soil auger for chemical and physical analysis at depths of 0-20, 20-40 and 40-60cm before ploughing and at harvest. These soils were chemically analysed for soil pH (1:1H_2O), Organic Carbon content (%), total Nitrogen (%), Exchangeable cations in me/100g (Ca, K, Mg and Na), Base sat (%), C.E.C (me/100g), Exchangeable A (Al + H), Available P and K (ppm). Soil samples were also analysed to determine their textural classes based on their sand (%), silt (%) and clay (%) content.

Penetrometer tests were carried out on-site at depths of 0-10, 10-20, 20-30 and 30-40 cm for each study site before ploughing, after ploughing and at harvest to determine the soil penetration resistance at known soil depths and soil moisture contents.

3.3.2 Agronomic parameters

Various agronomic measurements on the cassava were taken on a monthly basis starting from 6 months after planting (MAP). These measurements included plant height (cm), stem girth (cm), canopy size (cm), height at first branching (cm), number of stems per stand and number of leaves per plant. Nine cassava plants were selected and tagged with ribbon and then labelled at each of three selected areas for each variety along the row. This allowed for easy identification and traceability of the various cassava plants as measurements were taken each month.

Counting of the number of leaves and the number of stems per stand was done manually. The vernier calliper was used for the measurement of stem girth, and largest root diameter. A tape measure was used to measure the plant height, height at first branching and longest root length. Canopy size was measured with a canopy measuring tool similar in procedure to the one employed by *Arzai and Aliyu*, 2010. The tool has a graduated bar in centimetres with one side fixed and the other free. The free end is moved until the longest canopy width is reached and the reading is taken on the graduated bar as shown in Figure 15.

Figure 15: A canopy measuring tool in use

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 first excavating the soil around the roots of the plant gently with the help of a cutlass, whilst making sure there are no bruises to the roots to cause rot in the soil. The root spread across and along was measured using a foldable rule and the carpenter's tape. The foldable rule was placed along the direction of the row (flat or ridged) and then the tape placed perpendicular to it from the centre of the plant to the end of the exposed roots and the measurement recorded as across. To take a measurement along the row, the foldable rule was placed across the direction of row and then the tape placed perpendicular from the centre 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 2.

$$T_{ac} = L_1 + L_2 \qquad \text{Equation 2}$$

Where; T_{ac} = Total root length across row

L_1 and L_2 = Root length in both directions across row

Figure 16 shows the procedure used in determining the cassava root spread along and across the row and the depth of root cluster.

Figure 16: Cassava root orientation measurement procedure

Cassava yield measurements (bulking) by mass for both landforms some months before harvesting and just after harvesting was determined by manually uprooting and detaching the roots with a cutlass. Using an electronic mass balance and a plastic bucket, the yield by mass (kg) per plant was determined (Figure 17).

Figure 17: Apparatus used for yield measurements

3.3.3 Mechanical Cassava Harvesting

The TEK Mechanical Cassava Harvester (TEK MCH)

The TEK mechanical cassava harvester as the name depicts, was developed and manufactured at the Department of Agricultural Engineering, Kwame Nkrumah University Science and Technology - Kumasi. The TEK mechanical cassava harvester basically has the following parts; digger, shakers consisting of a slatted mould conical mouldboard, the linkage points and the vertical support. Figure 18 shows the TEK mechanical cassava harvester with labelled parts (A - G). The TEK mechanical cassava harvester is a fully mounted implement which operates according to the 'dig and pull' 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 mouldboard (B), the roots are brought onto the surface for collection and detachment.

A – Beam to which digging unit is attached
B – Conical mouldboard
C – Top link hitching point
D – Digger
E - Vertical support
F – Lower link hitching points
G – Slatted rods for shaking off soil

Figure 18: The TEK Mechanical Cassava Harvester with labelled parts (A-G)

Due to the large quantity of soil and trash that is dug out together with the roots, there is often an increase in the resistance behind the tractor leading to increased fuel consumption. When the soil is moist and sticky, the slatted conical mouldboard serves as shakers to sieve the soil clods and reduce adhesion. This helps accelerate the harvesting process, which in turn increases the efficiency of the tractor and harvesting implement. Figure 19 shows a mechanical cassava harvester in working condition.

Figure 19: TEK Mechanical cassava harvester in working condition

An added advantage after mechanical harvesting of cassava is that the land is ploughed for subsequent crop establishment. Harrowing and ridging are needed. By this, total cost of production is reduced. Figure 20 shows cassava fields after mechanical harvesting. The need for manual labour is drastically reduced since the implement works at a faster rate.

Careless use of machinery for harvesting however, can damage tubers, resulting in rapid deterioration that will lower the value of the end product. Once the roots have been harvested, they start deteriorating within 2 to 3 days, and rapidly become of little value for consumption or industrial applications.

Figure 20: Cassava fields after mechanical harvesting

Harvesting of the cassava was done at the various sites 15 months after planting (MAP) during the dry season, which is more favourable for mechanical cassava harvesting but quite the opposite for manual cassava harvesting. Six (6) mechanical cassava harvesting implements were tested at the Anwomaso (KNUST arable farm) site after which the best two (2) were selected for testing at the three other study sites. This was because of the relatively higher transportation cost involved in sending all the six implements to the other sites for testing. The two harvesters performed best in all the preliminary trials conducted compared to the other four.

Before harvesting mechanically, the cassava plants were coppiced by cutting them down 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 some few days prior to harvesting using post-emergence herbicides as these could block the shakers of the harvester and increase the draught on them. Before harvesting, the 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 when working in the soil.

Wheel Slip Measurement

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 tyres were marked with a chalk across the tyre radius to serve as a reference for determining the number of revolutions made per 40 m distance. Stop watches were used to determine the time used for the tractor to cover the 40 m distance to determine harvesting speed. The mechanical harvesting implement hitched to the tractor in transport position and the tractor was allowed to move within the 40 m distance at normal ploughing speed whilst recording the number of revolutions and the time taken to cover that distance (i.e. no-load distance). 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 for each harvesting implement 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 (Figure 21) was vertically pushed with minimal force through the soil until it hits a hard surface making it difficult to push the probe again. 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 implement and cassava variety. The process was also carried out after manual harvesting to determine the depth for manual harvesting.

Figure 21: The Depth measuring probe in use at Anwomaso field

Implement Draught Measurement

Implement draught was determined for each mechanical harvesting implement using the 10 tonne RON 2125 Dynamometer (Figure 22). 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 draught forces were obtained for each implement in working and transport positions respectively.

Figure 22: The RON 2125 Dynamometer

Figure 23 shows the implement draught measurement procedure with one tractor pulling the other with the harvester hitched to it and the force required for the pulling being logged onto the RON 2125 Dynamometer.

Figure 23: The draught measurement procedure

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-milliliter graduated measuring cylinder, the fuel used was 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. How much fuel was used for the top-up was then recorded as the fuel consumed by the tractor to work that known area (litres/ha) as was employed by AlHashem *et al*, (2000).

Heart Rate Measurements

Polar heart rate sensing devices (RS 800 CX) 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 later onto a computer for analysis. Figure 24 shows the Polar heart rate (RS 800 CX) 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 ten (10) minutes 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. Heart rate recordings were obtained for labourers during coppicing of the cassava prior to mechanical and manual harvesting of cassava, detachment of cassava tubers and gathering after harvesting.

Figure 24: The Polar (RS 800 CX) watch and chest strap as worn by a person

Knowledge of how much energy is used for carrying out a particular physical work is useful in determining the rest period (min/hr) required by a person after work using Equation 3.

$$Tr = 60 \times \left(1 - \frac{250}{P}\right) \qquad \text{Equation 3}$$

Where, Tr = Total rest period (min/hr)
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*, the Gross energy consumption (Watts) was determined.

Root Tuber Damage Assessment

Cassava root tuber damage attributed to 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. According to farmers and processors, cassava root damage was when the roots do not come out whole after harvesting but with cuts and bruises that could render them unsuitable for storage and processing. Cassava deteriorates within 2-3 days after harvesting (Bayoumi *et al*, 2008) and is even shorter for those roots with bruises or cuts on them. Market women on the other hand, described cassava root damage as those parts of the cassava roots that were broken from the whole tuber after harvest.

Conclusions drawn from the enquiries made from these major cassava stakeholders led to the description of damage as any part of the harvested cassava which did not come out with or is broken from the whole tuber after harvest. Size of the broken piece was also taken into consideration. Cassava size that is small enough and could totally go bad within a relatively shorter period of time was considered damaged, whilst those that could stay relatively longer before processing without totally going bad were considered undamaged. Damaged root tubers after harvesting were separated and then weighed using a spring balance to determine their mass in kilograms as shown in Figure 25. The total cassava yields (kg) were also determined. The cassava percentage root tuber damage for each harvester and harvesting method was calculated using Equation 4.

$$\text{Percentage Damage} = \frac{\text{Mass of damaged roots (kg)}}{\text{Total root yield (kg)}} \times 100 \qquad \text{Equation 4}$$

Figure 25: Cassava root tuber damage assessment on Anwomaso field

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 was 1 m, a distance of 40 metres covered during the harvesting process between two fixed ranging poles meant that an area of 40 m^2 (40m × 1m) has been covered. Using Equation 5, the field capacity in hours/hectare (h/ha) is then calculated.

$$C = \frac{10000 \times t}{A \times 3600} \text{ (hours/hectare)} \qquad \text{Equation 5}$$

Where C = Field capacity (h/ha)

t = Total time recorded during harvest (seconds)

A = Area harvested (m^2)

3.3.4 Manual Cassava Harvesting

Manual harvesting was carried out using tools like the cutlass, hoe or mattock. The plants were first coppiced to a level of about 20-30 cm before harvesting. Manual labourers were then tasked to uproot ten (10) cassava plants each on the ridge and flat landforms for different cassava varieties and the time used recorded whilst checking their heart rates using the Polar heart rate sensors (RS 800 CX).

The capacity of the manual labourers doing the harvesting (man-hours/ha) was also determined knowing the total time (seconds) taken to harvest the 10 plants using Equation 6 below:

$$T = \frac{10000 \times t}{n \times 3600} \text{ (man - hours/ha)} \qquad \text{Equation 6}$$

Where T = Total harvesting capacity (man-hours/ha)

t = Total time spent in harvesting (seconds)

n = Number of plants harvested

3.4 Machinery and Equipment Costing

Farm machinery costs can be divided into two categories: Fixed (annual ownership) costs, which occur regardless of machine use, and variable (operating) costs, which vary directly with the amount of machine use. Ownership costs include depreciation, interest, taxes, insurance, and shelter. Operating costs on the other hand, include repairs and maintenance, fuel, lubrication and operator. Total cost of farm machinery or equipment is the sum of its total fixed costs and total variable costs (Iowa State University Extension, 2009).

3.4.1 Fixed (Ownership) Costs

$$\text{Depreciation} = \frac{Purchase\ price - Salvage value}{Economic\ life} \qquad \text{Equation 7}$$

$$\text{Interest} = Rate\left(\frac{Purchase\ price + Salvage value}{2}\right) \qquad \text{Equation 8}$$

Taxes, insurance and shelter are usually 1.0 % of purchase price. Where 0.5% each of purchase price is allocated to insurance and shelter and 0% of purchase price for taxes.

3.4.2 Variable (Operating) Costs

Fuel cost depends on tractor’s fuel consumption (l/ha), cost of fuel (GH¢/litre), field capacity (ha/hr) and working hours per year. Lubricant cost is usually calculated as 15% of fuel cost unless lubricant consumption (l/ha) is otherwise stated. Repairs and Maintenance (R&M) cost is usually 5% of machinery purchase cost while Labour cost depends on the number of farm hands required to complete a specific work/task and the rate charged per hectare.

3.5 Statistical Analysis

Descriptive statistics i.e. means (at least 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. Statistical significance was carried out using Tukey and Fisher’s approach at $p<0.05$.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Soil Mechanical Properties

4.1.1 Soil Bulk Density

Figure 26 presents the mean soil bulk density before ploughing (BP), after ploughing (AP) and at harvest (AH) for Anwomaso, Mampong and Akatsi trial sites.

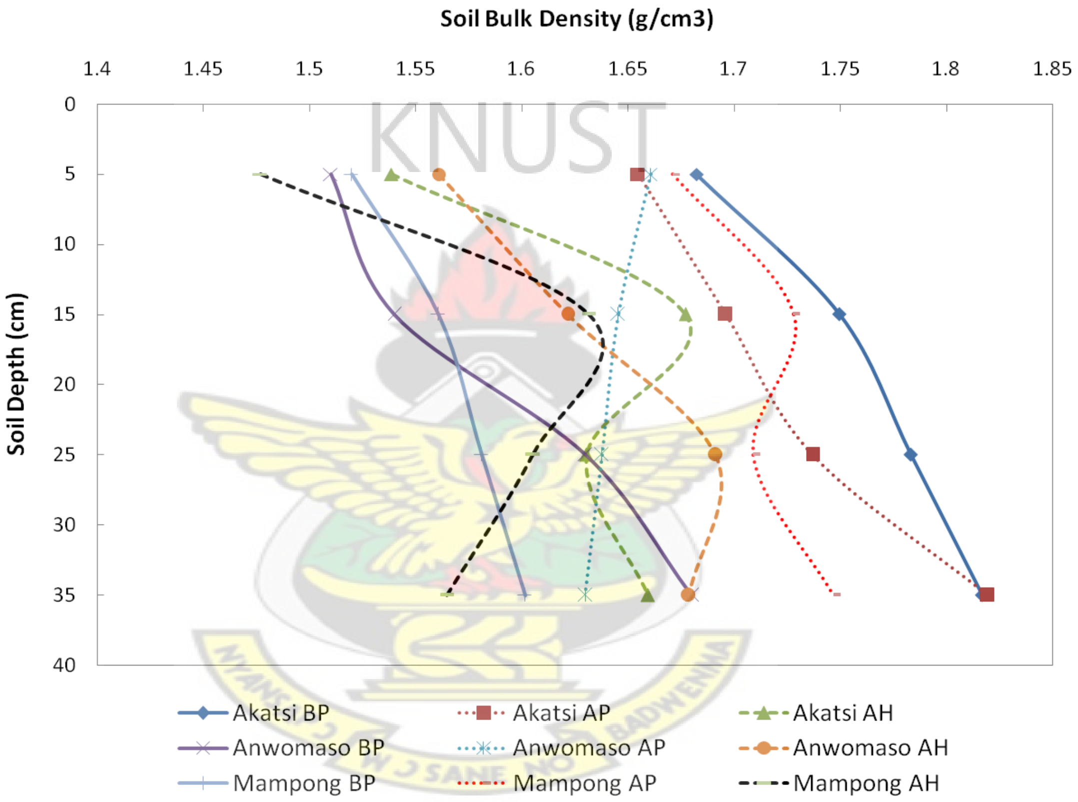


Figure 26: Mean Bulk Density (g/cm^3) before ploughing (BP), after ploughing (AP) and at harvest (AH) versus soil depth for the three (3) study sites.

The graph shows a general increase in bulk density with depth for all the trial sites before ploughing, after ploughing 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. Except for Akatsi, bulk density before ploughing for the other sites generally was lower than that after ploughing. This could be attributed to the fact that the process of ploughing breaks the soil into smaller clods causing these clods to be easily compacted when the tractor wheels pass over the soil during the ploughing process. Again, soil samples were taken after some days after ploughing when the soil had achieved some degree of compaction. Report by USDA, (1999) considered that compacted soil layers have high 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 harvesters with soil having bulk density in the range of 1.48 - 1.69 g/cm^3.

4.1.2 Soil Penetration Resistance

Figure 27 presents the mean soil penetration resistance before ploughing (BP), after ploughing (AP) and at harvest (AH) for Anwomaso, Mampong, Akatsi and trial sites.

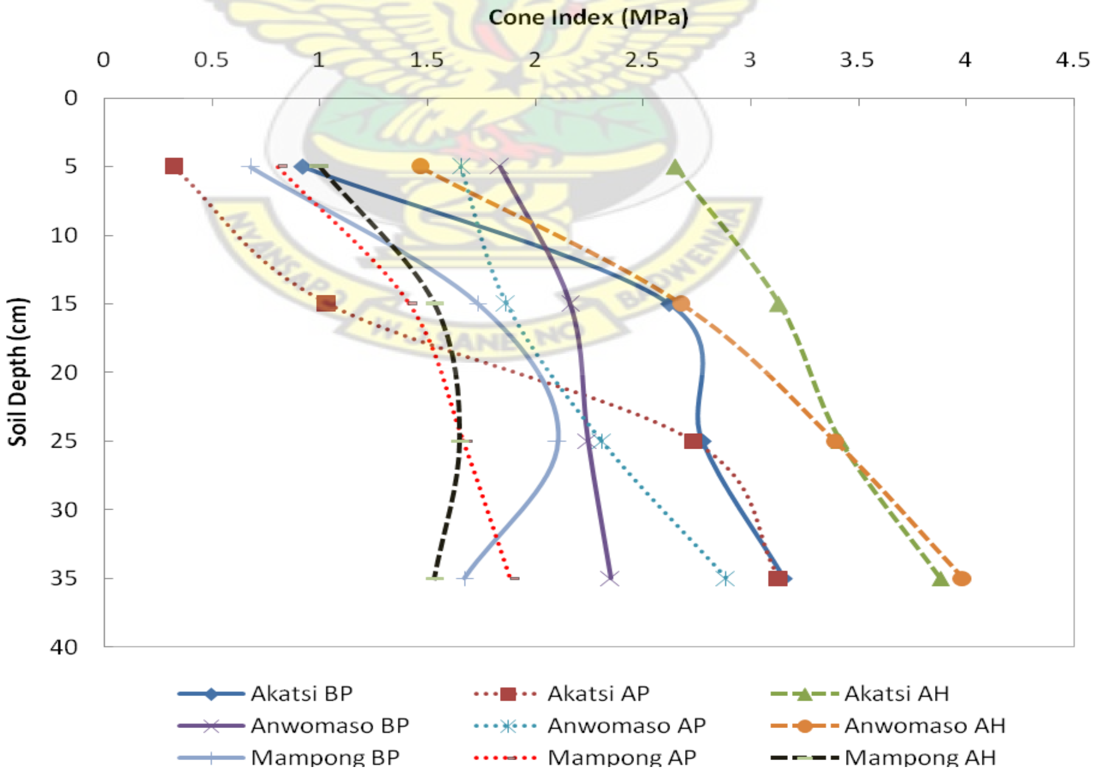


Figure 27: Soil Penetration Resistance (MPa) before ploughing (BP), after ploughing (AP) and at harvest (AH) for the three (3) study sites.

Correlation results presented in Appendix 5 shows that soil penetration resistance generally increased with increasing depth and moisture content for all trial sites. At harvest penetration resistance ranged from 1.47 – 3.99 MPa at Anwomaso, 1.0 – 1.53 MPa at Mampong and 2.65 – 3.88 MPa at Akatsi with increasing soil depth of 0-10, 10-20, 20-30 and 30-40 cm and increasing moisture content respectively. It could also be deduced from Appendix 5 that soil penetration resistance generally increased with increasing bulk density. Ploughing the soil generally reduced the penetration resistance as observed up to soil depth of 25 cm which agrees with what was reported by Reichert *et al.,* (2004).

4.1.3 Soil Moisture Content

Figure 28 presents a graph of the mean soil moisture content before ploughing, after ploughing and at harvest for Anwomaso, Mampong and Akatsi trial sites. Soil moisture generally increased with increasing depth at all the trial sites before and after ploughing and at harvest. At harvest, soil moisture ranged from 12.1 – 15.7 % d.b. at Anwomaso, 15.8 – 21.4 % d.b. at Mampong and 1.0 – 3.7 % d.b. at Akatsi 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. The soil moisture content for Akatsi before and after ploughing was however decreasing with increasing soil depth. This change could be attributed to the fact that it had rained slightly the day before the samples were taken and the water had not infiltrated completely into the soil, hence the topsoil became wetter than soils further down the profile.

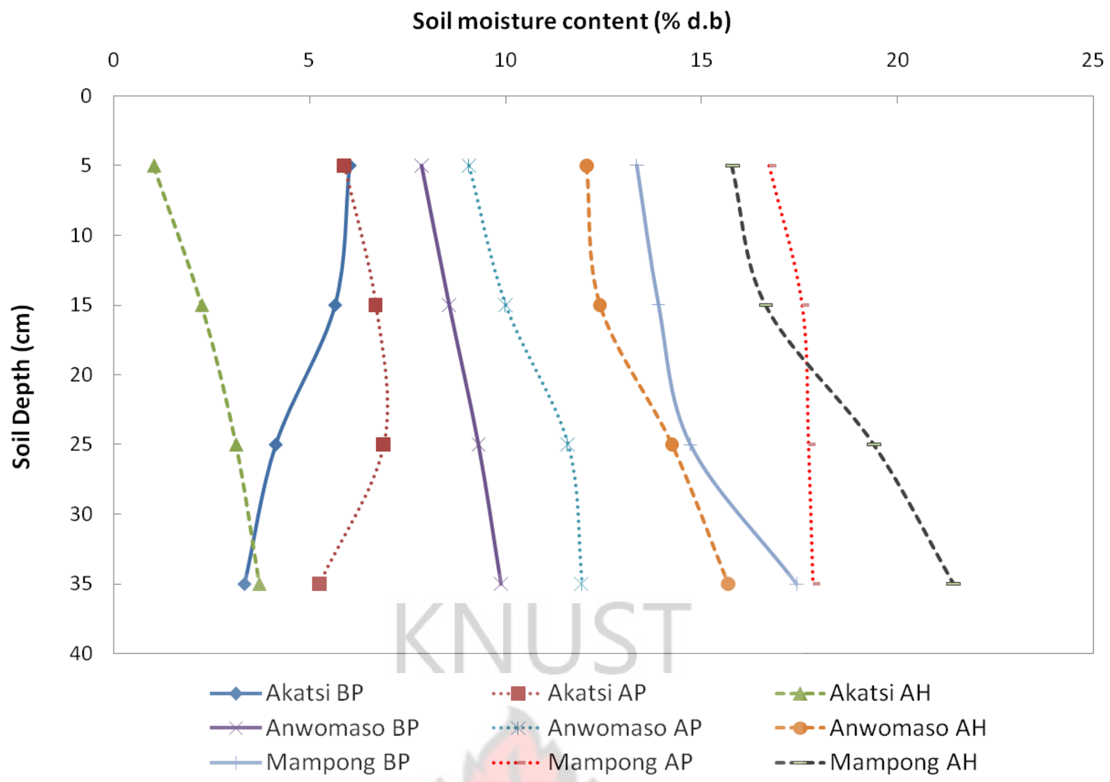


Figure 28: Graph of mean moisture content (% d.b.) before ploughing (BP), after ploughing (AP) and at harvest (AH) for the three (3) study sites.

.

4.2 Soil Physico-Chemical Analysis

Table 6 shows the chemical analysis of soils at Akatsi, Anwomaso and Mampong to determine soil pH, O.C., C.E.C. and N after ploughing and at harvest.

4.2.1 Soil pH

Anwomaso and Mampong soils had very strongly acidic to strongly acidic conditions after ploughing and at harvest in the soil depth range of 0-60 cm. At such pH levels, important soil nutrients such as Potassium and Phosphorus will not be easily available for plant growth. Thus the pH was not suitable for crop growth though the cassava yield was not affected at both locations. Akatsi soils on the other hand, had moderately acidic soil conditions after ploughing and at harvest. This means that cassava can be cultivate in soils with pH ranging from 4.4 – 6.0 without any problem and agrees with reports by O'Hair (1995), Philippine Root Crops Information Service (2005) and Okigbo (1980) that cassava can survive in poor soils with pH ranging from 4 to 9.

Table 6: The chemical analysis results (pH, O.C., C.E.C. and N) carried out on the soils at Akatsi, Anwomaso and Mampong after ploughing (AP) and at harvest (AH)

Location (Soil depth)	**pH (1:1 H_2O)**		**O.C. (%)**		**C.E.C (me/100g)**		**N (%)**	
	AP	AH	AP	AH	AP	AH	AP	AH
Akatsi								
0-20cm	5.70	6.12	0.22	0.34	2.45	5.16	0.16	0.03
20-40cm	6.00	6.12	0.18	0.27	1.60	4.43	0.13	0.02
40-60cm	5.60	5.91	0.15	0.17	1.94	4.17	0.11	0.02
Anwomaso								
0-20cm	5.50	4.83	0.96	0.87	3.64	6.61	0.23	0.11
20-40cm	5.00	4.78	0.52	0.47	3.72	7.02	0.13	0.05
40-60cm	5.00	4.60	0.43	0.23	3.53	6.87	0.10	0.02
Mampong								
0-20cm	4.80	4.77	1.11	1.11	5.38	6.72	0.23	0.09
20-40cm	4.60	4.36	0.89	0.83	5.23	5.70	0.18	0.07
40-60cm	4.50	4.45	0.61	0.52	4.01	5.71	0.13	0.04

4.2.2 Organic Carbon (O.C)

Organic Carbon was generally low (<2%) at all sites, but was relatively higher at Mampong with values of approx. 1% after ploughing and at harvest for the topsoil (0-20 cm). Soils at Akatsi however, had extremely low organic Carbon (%) at ploughing and at harvest (Baldock and Skjemstad, 1999).

4.2.3 Cation Exchange Capacity (C.E.C)

Low C.E.C (6 - 12 me/100g) and very low (<6 me/100g) indicate low to very low exchangeable cations respectively (Metson, 1961). All the study sites generally fell within the range of very low to low C.E.C and thus were suitable for plant growth after ploughing.

4.2.4 Soil Nitrogen (N)

After ploughing, Nitrogen contents were low to medium. At harvest, Nitrogen was very low (<0.1) for all sites (Metson, 1961). . This meant that after ploughing, the soils had enough Nitrogen but at harvest, much of it is utilized by the cassava crop, weed and also lost to the environment.

4.2.5 Soil Texture

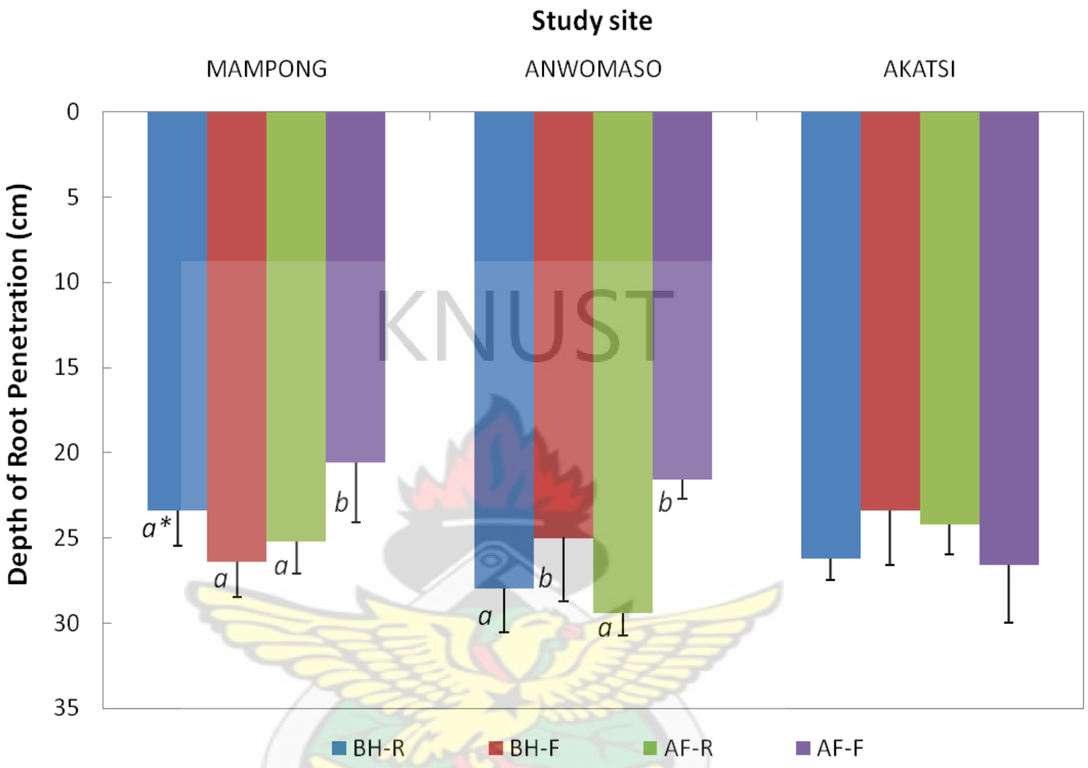
Soils at Anwomaso and Mampong are predominantly sandy loam at 0-20cm and sandy clay to sandy clay loam at 20-60cm soil depth. Soils at Akatsi are mainly loamy sand from 0-60 cm soil depth. Soils at the Anwomaso and Mampong sites had better nutrient and water holding capacity compared to that at Akatsi (FAO, 1998).

4.3 Cassava Root tuber Orientation and Bulking

4.3.1 Depth of Root Tuber Penetration

Figure 29 shows the mean root tuber depth of penetration for Bankyehemaa and Afisiafi on both ridge and flat landforms at 15 MAP for Akatsi, Mampong and Anwomaso before harvesting. The mean root tuber penetration depth for

Bankyehemaa and Afisiafi at Akatsi, Mampong and Anwomaso ranged from 20.6 – 29.4 cm. Afisiafi on ridge at Anwomaso had the highest mean root tuber penetration depth of 29.4 cm whiles Afisiafi on flat at Mampong had the lowest mean root tuber penetration depth of 20.6 cm.



*Values followed by the same letter in the same group are not significantly different at p<0.05

Figure 29: 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 respectively) at Akatsi, Mampong and Anwomaso at 15 MAP.

At 5% significance level, the mean depth of root tuber penetration for Afisiafi and Bankyehemaa on ridge at Anwomaso was significantly different from that on flat. At Akatsi there was no significant difference among the two cassava varieties or landforms at p<0.05. At Mampong, Afisiafi on flat was significantly different (p<0.05) from Afisiafi on ridge and Bankyehemaa on both landforms.

4.3.2 Total Root tuber Length across row

Table 7 presents the mean total root tuber length across row for Afisiafi and Bankyehemaa at all three (3) study sites, and Esambankye, Dokuduade and Nkabom at Anwomaso on both ridged and flat landforms before harvest at 15 MAP. Afisiafi on ridge at Anwomaso had the highest mean total root tuber length across row of 80.8 cm, whilst Bankyehemaa on flat at Akatsi had the least (31.2 cm).

Table 7: Mean total Root tuber length across row (cm) for Bankyehemaa on ridge and on flat (BH-R and BH-F), Afisiafi on ridge and on flat (AF-R and AF-F), Esambankye on ridge and on flat (ES-R and ES-F), Dokuduade on ridge and on flat (DK-R and DK-F) for Mampong, Anwomaso and Akatsi at 15 MAP.

Cassava variety-Landform	Akatsi	Anwomaso	Mampong
BH-R	66.2^{a*}	69.0	52.6^{ab}
BH-F	31.2^{b}	61.0	69.4^{a}
AF-R	60.8^{a}	80.8	47.8^{b}
AF-F	45.0^{ab}	59.2	67.0^{ab}
ES-R	-	61.0	-
ES-F	-	47.8	-
DK-R	-	73.4	-
DK-F	-	73.0	-
NK-R	-	60.0	-
NK-F	-	50.4	-
LSD	**26.95**	**ns**	**19.93**

*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 row recorded for the various study sites, cassava varieties and landforms did not exceed the standard working width (100 cm) of the TEK mechanical harvester. Thus harvesting will cause less root tuber damage as Bobobee *et al* (1994) reported, that cassava root spread beyond 1m (100 cm) makes it difficult to readily mechanize. Though there was no statistical difference between the mean total root tuber length across row for both Afisiafi and Bankyehemaa on either flat or ridge landforms at Anwomaso but at Mampong and Akatsi, there was differences ($p<0.05$). The reason for the relatively higher root tuber length on ridges than flat landform at Akatsi and the opposite at Mampong for Afisiafi and Bankyehemaa could be due to differences in soil characteristics at both locations. *Nkabom* on the average had the least root tuber spread across the row at Anwomaso with values of 50.4 cm and 60 cm for flat and ridged landform respectively.

4.3.3 Total Root tuber Length along row

Table 8 presents the mean total root tuber length along row for Afisiafi and Bankyehemaa at all three (3) study sites and Esambankye, Dokuduade and Nkabom at Anwomaso on both ridged and flat landforms before harvest at 15 MAP.

Dokuduade on ridge at Anwomaso had the highest mean total root tuber length along row of 99.2 cm, whilst Bankyehemaa on ridge at Akatsi had the least (44.2 cm). Afisiafi cassava variety on the average had longer lengths along row at all three (3) sites than Bankyehemaa variety. Root spread along row for Afisiafi and Bankyehemaa at all three (3) study sites on ridge on the average, was lower than flat landform though showed no significant difference ($p<0.05$). This agrees with reports by Odigboh and Moreira (2002) and Sam and Dapaah (2009) about the advantage ridges have in controlling the spread of cassava roots to suitable lengths both across and along row. At Anwomaso, *Nkabom* cassava variety averagely had the lowest mean total root spread along and across row of all the cassava varieties, though there was no statistical difference at 5% significance level.

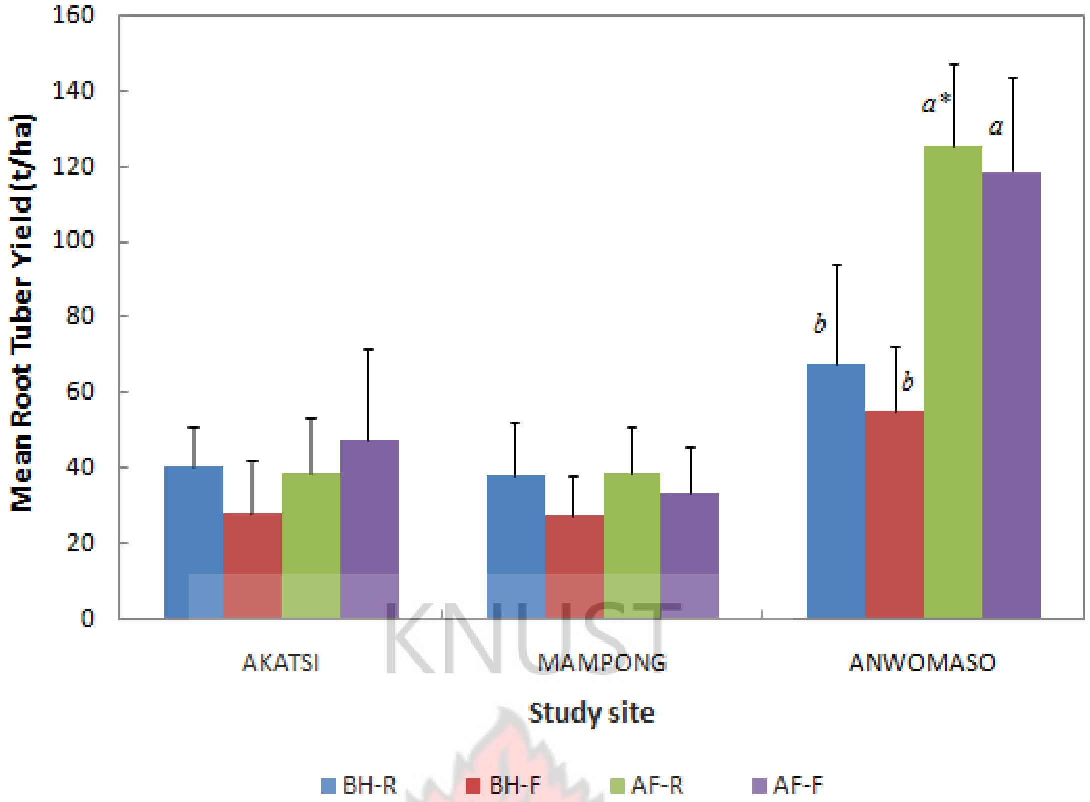
Table 8: Mean total Root tuber length along row (cm) for Bankyehemaa on ridge and on flat (BH-R and BH-F), Afisiafi on ridge and on flat (AF-R and AF-F), Esambankye on ridge and on flat (ES-R and ES-F), Dokuduade on ridge and on flat (DK-R and DK-F) for Mampong, Anwomaso and Akatsi at 15 MAP.

Cassava variety-Landform	**Akatsi**	**Anwomaso**	**Mampong**
BH-R	44.2	82.6	60.4
BH-F	45.2	78.8	80.4
AF-R	45.8	68.4	70.2
AF-F	57.4	95.8	69.0
ES-R	-	69.4	-
ES-F	-	79.8	-
DK-R	-	99.2	-
DK-F	-	94.2	-
NK-R	-	62.0	-
NK-F	-	59.6	-
LSD	**ns**	**ns**	**ns**

4.3.4 Mean Cassava Root Tuber Yield

Figure 30 shows the mean cassava root tuber yield for Bankyehemaa and Afisiafi at 15 months after planting (MAP) on both ridged and flat landforms at Akatsi, Mampong and Anwomaso.

Afisiafi and Bankyehemaa on both ridged and flat landforms at Anwomaso was significantly ($p<0.05$) higher in terms of root tuber yields compared to those obtained at Akatsi and Mampong. Root tuber yield at Anwomaso for Afisiafi on both landforms was significantly ($p<0.05$) higher than the yield for Bankyehemaa and also for Afisiafi and Bankyehemaa at Mampong and Akatsi on the two landforms.



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

Figure 30: Mean Root tuber yield (t/ha) for Bankyehemaa on ridge and flat (BH-R and BH-F respectively) and Afisiafi on ridge and flat (AF-R and AF-F respectively) for Akatsi, Mampong and Anwomaso at 15 MAP.

The root tuber yield was higher, though not significantly different on ridged compared to the flat landform for Afisiafi and Bankyehemaa at all sites except for Afisiafi at Akatsi. This is in agreement with Ennin *et al* (2009) report 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.

4.4 Harvesting Performance Evaluation

Results presented under the performance evaluation include the following parameters: harvester working depth, percentage root tuber damage, field capacity (both mechanical and manual harvesting), fuel consumption, harvester working speed, percentage wheel slip, draught force and tractor power requirement, energy consumption and economic analysis (for both manual and mechanical harvesting).

4.4.1 Harvester Working Depth

Depth of Harvester Penetration at Anwomaso

Table 9 presents the mean depth of harvester penetration for the six (6) mechanical cassava harvesters during performance evaluation on the ridged landform at Anwomaso.

Table 9: Depth of harvester penetration (cm) on ridge for TEK MCH 1-6 at Anwomaso

TEK MCH No.	Depth (cm)
MCH 1	24.8^{a*}
MCH 2	26.3^{a}
MCH 3	27.6^{a}
MCH 4	28.4^{a}
MCH 5	25.6^{a}
MCH 6	24.0^{b}
LSD	**3.45**

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

From the table, it could be seen that TEK MCH 4 harvester went deepest into the soil during the harvesting process, having a mean value of 28.4 cm, which was not significantly different from MCH 1, 2, 3 and 5 but MCH 6. This implies that statistically MCH 1, 2, 3, 4 and 5 are the same in terms of depths of harvester penetration when harvesting on ridge at Anwomaso. TEK MCH 6 had the least mean depth of penetration of 24.0 cm.

With reference to Figure 29, the mean depth of root penetration for Afisiafi on ridge at Anwomaso for instance, was higher than the mean depth of harvester penetration; which meant that damage to the roots at harvest, was eminent. Except for TEK MCH 6, the mean depth of harvester penetration for the other five (5) mechanical harvesters were found to be statistically not significant at $p<0.05$.

Depth of Harvester Penetration at Akatsi and Mampong

Table 10 presents the depth of harvester penetration depth for TEK MCH 2 at Akatsi and Mampong after harvesting Afisiafi and Bankyehemaa on both flat and ridged landforms.

Table 10: Mean depths of TEK MCH 2 harvester penetration (cm) for Afisiafi and Bankyehemaa on both ridged and flat landforms (AF-R, AF-F, BH-R and BH-F respectively) at Akatsi and Mampong.

Cassava variety-Landform	Akatsi	Mampong
AF-R	30.1^{a*}	27.5^{a}
AF-F	20.7^{b}	24.9^{a}
BH-R	27.0^{a}	21.7^{b}
BH-F	22.1^{b}	24.3^{a}
LSD	**2.12**	**3.95**

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

The harvester went deepest when harvesting both Afisiafi and Bankyehemaa on ridge than on the flat landform at Akatsi. Similar observation was made after harvesting Afisiafi at Mampong on both landforms. However, the depth of penetration during harvesting on the ridge was significantly less compared to the flat for Bankyehemaa at Mampong.

Harvesting Afisiafi on the flat at both locations gave relatively higher penetration depth than what was recorded after harvesting Bankyehemaa on flat and on ridged landform. The reason being that the roots of Afisiafi cassava variety went deeper into the soil than the Bankyehemaa variety and to be able to harvest mechanically with little or no damage, the harvester would have to go deeper beyond the depth of root penetration. Odigboh and Moreira (2002) and Sam and Dapaah, (2009) reported that ridges are able to control cassava root tuber development to reasonable depths to allow for optimum mechanical harvesting.

Another reason may be due to the ease with which ridges were easily pulverized. That is, with little effort the harvester blade goes deeper into the ridges during harvesting and shatters the soil with ease on the ridged than on the flat landform.

4.4.2 Root Tuber Damage Assessment

Percentage Root Tuber Damage at Anwomaso

Figure 31 shows the mean percentage root tuber damage for Afisiafi and Nkabom on ridge after harvesting with different mechanical cassava harvesters at Anwomaso. TEK MCH 1 had the highest mean percentage tuber damage of 19.1 % for harvesting Afisiafi on the ridge.

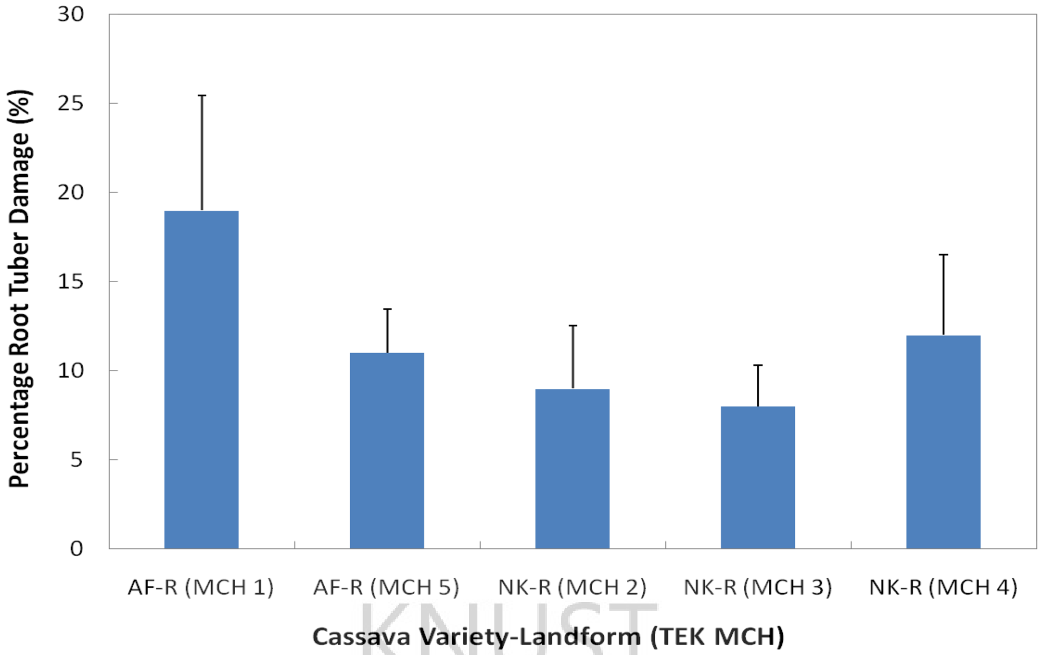


Figure 31: Percentage root tuber damage for Afisiafi on ridge (AF-R) and Nkabom on ridge (NK-R) after harvesting with different Mechanical Cassava Harvesters (MCH) at Anwomaso.

TEK MCH 3 had the lowest mean percentage tuber damage of 7.7 % after harvesting Nkabom on ridge. From the graph, it could be seen that the Nkabom cassava variety on ridge easily lends itself to mechanical harvesting with mean percentage root tuber damage ranging from 7.7 – 12.1 % compared to harvesting Afisiafi on ridge (10.8 – 19.1 %). This could be due to its relatively shorter root spread both along and across the row and the bunchy nature of its roots compared to other cassava varieties. 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 another mechanical harvester.

However, at 5% significance level, the percentage root tuber damage obtained for Afisiafi and Nkabom after harvesting with their respective mechanical cassava harvesters (MCH 1 – 5) was significantly not different.

Percentage Root Tuber Damage at Mampong

Figure 32 is a graph showing the mean percentage tuber damage for Bankyehemaa and Afisiafi on ridged and flat landforms after harvesting with TEK MCH 2 at Mampong.

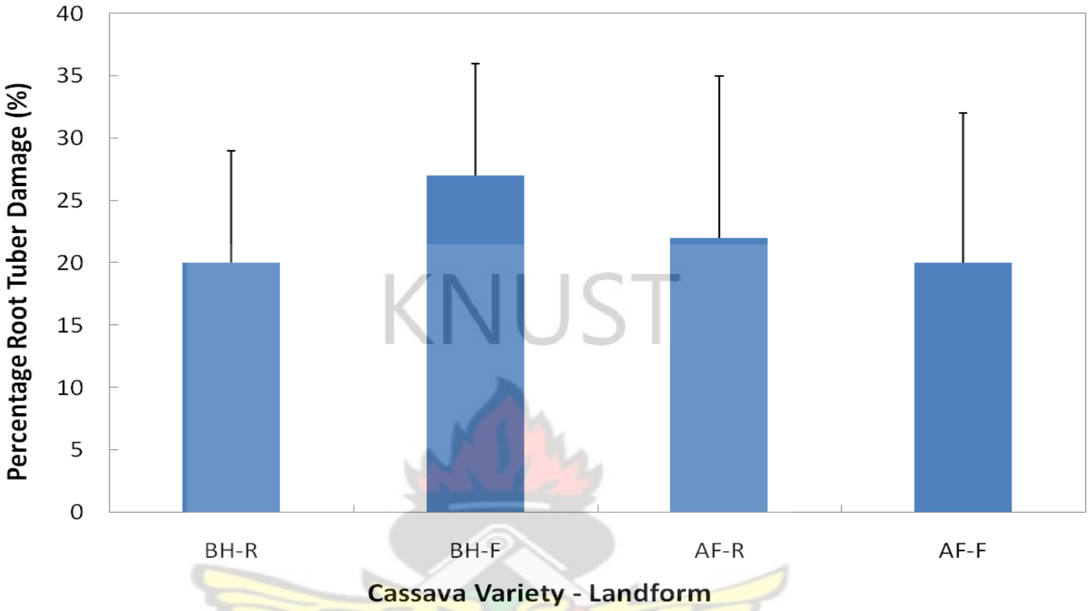


Figure 32: Percentage root tuber damage for Bankyehemaa on ridge (BH-R), Bankyehemaa on flat (BH-F), Afisiafi on ridge (AF-R) and Afisiafi on flat (AF-F) after harvesting with TEK MCH 2 at Mampong.

Bankyehemaa on flat had the highest mean percentage root tuber damage of 26.9% whilst Afisiafi on flat had the least percentage root tuber damage of 19.6%. There was no statistical difference between mean percentage tuber damage for Afisiafi or Bankyehemaa on the ridged or flat landforms at 5% significance level after harvesting with TEK MCH 2 at Mampong. Generally, the percentage root tuber damage for Mampong compared to Anwomaso and Akatsi was highest. This may be attributed to the relatively higher soil moisture content observed during harvest at Mampong. The shakers of the harvester as a result, are blocked by the wet soil resulting in an increase in draught on the tractor. This makes it difficult for the harvester to achieve the required harvesting depth which subsequently results in high percentage root tuber damage.

Percentage Root Tuber Damage at Akatsi

Table 11 presents the percentage root tuber damage after mechanical and manual harvesting of Afisiafi on both ridged and flat landforms and after manual harvesting of Bankyehemaa on ridged and flat landforms at Akatsi.

Afisiafi on flat harvested mechanically had the highest percentage root tuber damage of 18.9 %. In general, manual cassava harvesting gave significantly lower ($p<0.05$) percentage root tuber damage than mechanical harvesting. Manual harvesting of Bankyehemaa on both ridged and flat landforms gave the lowest mean percentage root tuber damage of 8.0 % and 8.7 % respectively compared to manual harvesting of Afisiafi (10.1 % and 10.5 %) for ridged and flat landforms respectively.

Table 11: Percentage root tuber damage after using TEK MCH 2 to harvest Afisiafi on ridge (AF-R (mech)), Afisiafi on flat (AF-F (mech)) and after manual harvesting of Bankyehemaa on ridge (BH-R (man)), Bankyehemaa on flat (BH-F (man)), Afisiafi on ridge (AF-R (man)), Afisiafi on flat (AF-F (man)) at Akatsi.

Cassava variety (Harvesting method)	**Tuber Damage (%)**
AF-R (mechanical)	12.3^{a*}
AF-F (mechanical)	18.9^{a}
AF-R (manual)	10.1^{b}
AF-F (manual)	10.5^{b}
BH-R (manual)	8.0^{b}
BH-R (manual)	8.7^{b}
LSD	**7.24**

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

The reason could be due to the wide root tuber spread and depth of Afisiafi compared to Bankyehemaa, posing difficulty to manual harvesting.

4.4.3 Field Capacity

Mechanical Harvesting at Akatsi and Mampong

Table 12 depicts the mean field capacity for TEK MCH 2 and 6 on both ridged and flat landforms at Akatsi and ridged landform only at Mampong. TEK MCH 6 at Akatsi, after harvesting on flat recorded the highest mean field capacity of 2.96 h/ha at Akatsi whilst harvesting at Mampong with TEK MCH 2 on the ridge gave the least mean field capacity of 1.55 h/ha.

Table 12: Mean field capacity (h/ha) for TEK MCH 2 on ridge (MCH2-R), TEK MCH 2 on flat (MCH2-F), TEK MCH 6 on ridge (MCH6-R) and TEK MCH 6 on flat (MCH6-F) at Akatsi and Mampong.

TEK MCH-Landform	Akatsi	Mampong
MCH 6-F	2.96^{a}	-
MCH 6-R	1.78^{b}	1.89^{b}
MCH 2-F	2.04^{b}	-
MCH 2-R	2.03^{b}	1.55^{a}
LSD	**0.25**	**0.04**

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

Harvesting with TEK MCH 2 at Akatsi gave similar field capacity for both landforms. On the other hand, the field capacity obtained for TEK MCH 6 on flat was significantly ($p<0.05$) higher than that on ridge at Akatsi. This part of the results is similar to findings by Sam and Dapaah (2009), Ennin *et al.*, (2009) and Ekanayake *et al.*, (1997) that ridges lend themselves easily to mechanisation in terms of harvesting compared to the flat landform. This could be due to the fact that setting the depth of cut and pulverising the soil was easily achieved on the ridge than on the flat landform.

Mechanical Harvesting at Anwomaso

Figure 33 shows a graph of the field capacity using TEK MCH 1 – 5 for harvesting cassava on the ridged landform at Anwomaso.

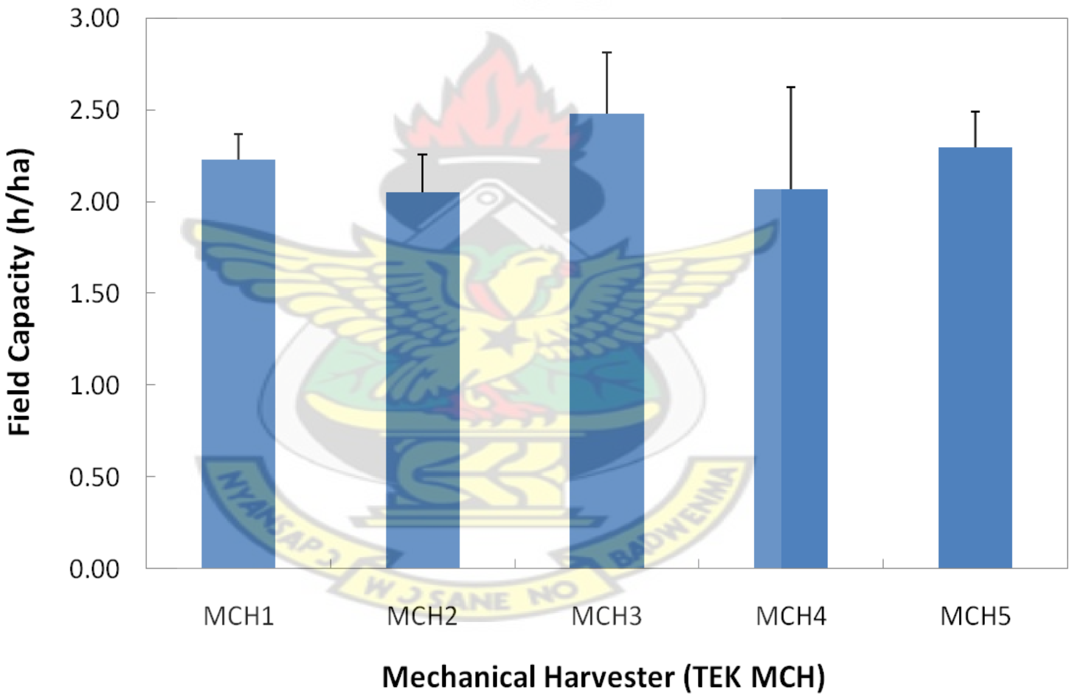


Figure 33: Field capacity for TEK MCH 1 - 5 after harvesting at Anwomaso

TEK MCH 3 had the highest field capacity of 2.48 h/ha whilst TEK MCH 2 had the least (2.05 h/ha). However, the differences was not significant (($p<0.05$).

Generally, the field capacity for the different TEK MCH's at all three (3) study sites ranged from 1.55 h/ha to 2.96 h/ha. Bobobee *et al.*, (1994) reported a range of 2.63 – 4.0 h/ha for the Leipzig. Ospino *et al.*, (2007) also, reported a mean field capacity range of 1.0 – 1.6 h/ha for the CLAYUCA Cassava Harvester Model P600 and Oni (2005) reported a range of 0.83 – 1.25 h/ha for the NCAM harvester.

Manual Harvesting Capacity

Table 13 shows manual cassava harvesting capacities (man-days/hectare) obtained for Afisiafi and Bankyehemaa on ridged and flat landforms at Akatsi, Anwomaso and Mampong.

Table 13: Manual cassava harvesting capacity (man-days/ha) for Afisiafi on Ridge (AF), Afisiafi on Flat (AF-F), Bankyehemaa on Ridge (BH-R) and Bankyehemaa on Flat (BH-F) at Akatsi, Anwomaso and Mampong.

Cassava variety-Landform	Akatsi	Anwomaso	Mampong
AF-R	28.5	11.4	13.2
AF-F	29.9	16.0	17.7
BH-R	31.9	11.1	12.5
BH-F	29.2	13.9	16.0
LSD	**ns**	**ns**	**ns**

High values of manual harvesting capacity were obtained at Akatsi for both Afisiafi and Bankyehemaa on ridged and flat landform compared to the values obtained at Mampong and Anwomaso. The reason could be due to the very low soil moisture levels recorded during harvest at Akatsi as compared to Mampong or Anwomaso, making it more difficult to harvest both on the ridge and on the flat landforms. This emphasizes the ease of manual harvesting during the wet season and therefore the preferred choice at this time of year as reported by Bobobee *et al.,* (1994) and Ospino *et al.,* (2007). Also, the labour requirements (capacities) for Bankyehemaa and

Afisiafi on both ridged and flat landforms at Akatsi were higher than those obtained at Mampong and Anwomaso.

Moreover, except of Bankyehemaa at Akatsi, harvesting on the ridge required much lower capacities than on the flat landform irrespective of the cassava variety being harvested which agrees with what was reported by Sam and Dapaah (2009) and Ennin *et al.*, (2009).

Manual harvesting labour requirements for Bankyehemaa and Afisiafi at Mampong, Akatsi and Anwomaso ranged from 11.1 – 31.9 man-days/ha which is comparable with Nweke *et al.*, (2002) report of 22-63 man-days per hectare labour requirement. Comparing the capacities obtained for mechanical and manual harvesting methods, it could generally be deduced that manual cassava harvesting requires longer periods of time than mechanical harvesting.

IITA Harvester Prototype versus Cutlass

Table 14 presents the percentage root tuber damage and working capacity obtained after using the IITA manual harvester prototype and a cutlass to harvest the "*Nkabom"* cassava variety at the Anwomaso field. At 5% significance level, the mean percentage root tuber damage obtained after harvesting with the IITA harvester prototype and cutlass was statistically different. Bobobee *et al,* (2000) reported 5.2 - 40% root tuber damage when using fork/hoe.

The IITA harvester prototype and cutlass harvesting gave comparable field capacity that was statistically not different at $p<0.05$. This was however lower than Nweke *et al.*, (2002) observation with labour requirement of 22-63 man-days/ha when harvesting cassava manually.

Table 14: Mean Percentage Root tuber Damage and Capacity for two manual harvesting tools

Manual Harvesting Tool	Mean Root Tuber Damage (%)	Capacity (man-day/ha)
Cutlass	8.9^{a*}	18.5
IITA Harvester prototype	3.4^{b}	18.3
LSD	**2.56**	**ns**

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

4.4.4 Average Fuel Consumption

Fuel consumption at Anwomaso

Table 15 depicts the mean fuel consumption for TEK MCH 1-5 after harvesting cassava on ridged landform. TEK MCH 2 recorded the highest mean fuel consumption of 24.7 l/ha whilst TEK MCH 5 had the lowest (16.9 l/ha). TEK MCH 1-3 had similar mean fuel consumption that was significantly ($p<0.05$) higher than TEK MCH 4 which is also higher than TEK MCH 5.

Table 15: Mean fuel consumption (l/ha) for TEK MCH 1-5 at Anwomaso

TEK MCH No.	Mean
MCH 1	22.5^{a*}
MCH 2	24.7^{a}
MCH 3	22.5^{a}
MCH 4	21.0^{b}
MCH 5	16.9^{c}
LSD	**2.22**

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

Fuel consumption at Akatsi and Mampong

Table 16 presents the mean fuel consumption recorded for TEK MCH 2 on both the ridged and flat landforms at Akatsi and for TEK MCH 2 and TEK MCH 6 on the ridged landform at Mampong after harvesting both Bankyehemaa and Afisiafi cassava varieties. A mean fuel consumption of 42.1 l/ha was recorded after harvesting on the ridge while 43.6 l/ha was recorded after harvesting on the flat landform at Akatsi. It could be said that harvesting on the flat has higher fuel consumption than harvesting on the ridged landform though statistically, not significantly different ($p<0.05$).

Table 16: Mean fuel consumption (l/ha) for TEK MCH 2 on both ridged and flat landforms at Akatsi and for TEK MCH 2 and TEK MCH 6 on ridged landform at Mampong.

TEK MCH-Landform	Akatsi	Mampong
MCH 2-R	42.1	15.0
MCH 6-R	-	16.2
MCH 2-F	43.6	-
LSD	**ns**	**ns**

At Mampong TEK MCH 6 recorded a higher mean fuel consumption (16.2 l/ha) compared to TEK MCH 2 (15.0 l/ha) though statistically not significant. Several factors such as wheel slip, moisture content, operator experience etc. could have caused this difference in mean fuel consumption for these two harvesters during harvest.

It was also worth noting that TEK MCH 2 recorded far lower fuel consumption at Mampong (15.0 l/ha) as compared to that obtained at Akatsi (42.1 l/ha). This was because at harvest at Akatsi, the soil was relatively dryer, giving rise to a higher penetration resistance than the soil at Mampong.

4.4.5 Harvester Working Speed

Harvesting speed at Anwomaso

Figure 34 shows the mean working speed recorded for TEK MCH 1 -5 at Anwomaso for harvesting various cassava varieties on the ridged landform. TEK MCH 2 recorded the highest mean working speed of 4.69 km/h whilst TEK MCH 4 recorded the least mean working speed of 4.18 km/h. However, no statistical difference existed among the mean working speeds recorded for all the harvesters (TEK MCH 1 – 5) at $p<0.05$.

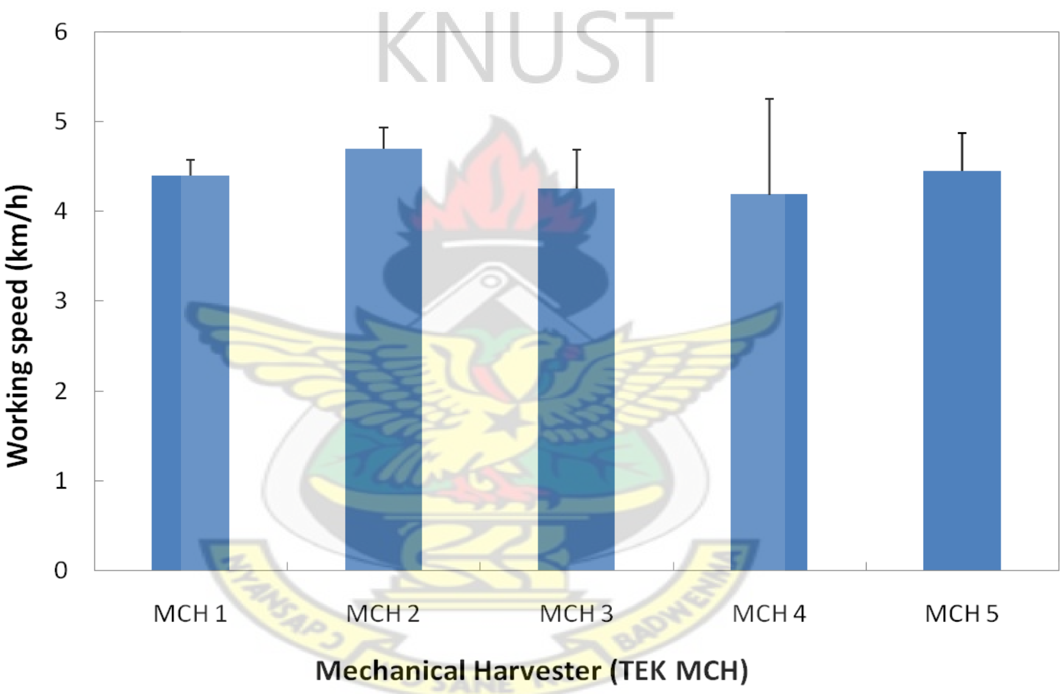


Figure 34: Mean working speed for TEK MCH 1-5 during harvest at Anwomaso

Harvesting speed at Mampong and Akatsi

Table 17 depicts the mean working speed recorded for TEK MCH 2 and TEK MCH 6 during harvesting for both Afisiafi and Bankyehemaa on the ridged landform and for TEK MCH 2 only for harvesting Afisiafi or Bankyehemaa on the ridged landform at Akatsi.

TEK MCH 2 at Mampong recorded a significantly ($p<0.05$) higher mean working speed of 6.46 km/h than TEK MCH 6 (5.30 km/h) during harvesting of both Bankyehemaa and Afisiafi cassava varieties. At Akatsi, harvesting Bankyehemaa recorded a higher mean working speed of 4.85 km/h than Afisiafi which recorded 4.16 km/h, but there was no statistical difference.

Harvesting with TEK MCH 2 at Mampong generally recorded a significantly ($p<0.05$) higher working speed than harvesting at Akatsi with LSD of 0.18. The reason could be due to the soil penetration resistances recorded at Mampong study site just before harvesting. Thus with less effort from the tractor, the harvester is able to move faster in the Mampong.

Table 17: Mean working speed (km/h) for TEK MCH 2 and TEK MCH 6 during harvesting on the ridged landform and for only TEK MCH 2 during harvesting of Afisiafi and Bankyehemaa both on the ridged landform (AF-R and BH-R respectively) at Akatsi.

TEK MCH-Landform	Mampong	Akatsi
MCH 2-R	6.46^{a*}	-
MCH 6-R	5.30^{b}	-
MCH 2 (AF-R)	-	4.16^{b}
MCH 2 (BH-R)	-	4.85^{b}
LSD	**0.18**	**ns**

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

A working speed range of 3.13 - 6.64 km/h was recorded for all the TEK mechanical cassava harvesters. This is higher than what Bobobee *et al.*, (1994) reported for the Leipzig mechanical harvester with a working speed range of 2.4 – 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.

4.4.6 Percentage Tractor Wheel-slip

Wheel-slip at Akatsi, Anwomaso and Mampong

Table 18 depicts the mean tractor wheel-slip recorded for TEK MCH 2 and TEK MCH 6 during harvesting of various cassava varieties at Akatsi, Anwomaso and Mampong. Harvesting with TEK MCH 2 at Akatsi recorded the highest mean wheel-slip whilst the lowest was recorded at Mampong. For TEK MCH 6, the highest was recorded at Anwomaso and the lowest at Mampong. On the average however, irrespective of the harvester (TEK MCH 2 and TEK MCH 6), Akatsi recorded the highest mean tractor wheel-slip compared to Anwomaso and Mampong.

Table 18: Mean tractor wheel-slip (%) for TEK MCH 2 and TEK MCH 6 at Akatsi, Anwomaso and Mampong.

TEK MCH 2 No.	**Akatsi**	**Anwomaso**	**Mampong**
MCH 2	14.93	8.19	6.99
MCH 6	12.92	14.80	10.56
LSD	**ns**	**ns**	**ns**

The reason could be due to the fact that at Akatsi, the soil had relatively lower moisture at time of harvest compared to Anwomaso and Mampong which prevented the tractor wheels from easy movement because the soil had become highly friable. Also, the tyre logs for the tractor used for harvesting at Akatsi were worn and that made it difficult for the wheels to easily grip on the dry soils. However, for all three (3) study sites, no statistical difference was observed for the wheel-slip recorded between TEK MCH 2 and 6 at 5% significance level ($p<0.05$). The range of tractor wheel slip observed during mechanical harvesting was from (7 ± 2) % to (15 ± 8) % for all three (3) study sites (Akatsi, Anwomaso and Mampong).

4.4.7 Draught Force and Tractor Power Requirement

Mechanical Harvesting at Anwomaso and Mampong

Table 19 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 1-6 at Anwomaso and Mampong during harvest. The draught values ranged between 6.51 kN for TEK MCH 3 and 12.33 kN for TEK MCH 4 at Anwomaso. TEK MCH 2 recorded an average draught force of 4.90 kN while TEK MCH 6 recorded 8.60 kN at Mampong. Equations 8 and 9 were useful in calculating for the Tractor Power requirement.

$$\text{Drawbar Power (kW)} = \text{Draught Force (kN)} \times \text{Average Speed (m/s)} \qquad \text{Equation 8}$$

$$\text{Brake Horse Power (kW)} = \frac{\text{Drawbar Power}}{0.19} \qquad \text{Equation 9}$$

Table 19: Draught Force of TEK MCH 1 – 6 as used to calculate the tractor engine power requirement at Anwomaso and Mampong.

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 1	11.85	1.22	0.25	47.85	14.47	76.16
MCH 2	8.23	1.30	0.26	31.32	10.73	56.47
MCH 3	6.51	1.18	0.28	23.59	7.68	40.44
MCH 4	12.33	1.16	0.28	43.43	14.33	75.43
MCH 5	7.15	1.24	0.26	27.93	8.83	46.46
MCH 6	11.03	1.32	0.24	46.03	14.55	76.55
			Mampong			
MCH 2	4.90	1.79	0.28	17.80	8.79	46.26
MCH 6	8.60	1.47	0.25	34.55	12.66	66.64

The range of draught force obtained is lower than what was reported for the Leipzig harvester (11.94 – 16.2 kN) by Bobobee *et al.,* (1994). The range of Brake Horse Power (Tractor Engine Power) requirement for TEK MCH 1-6 at Anwomaso was 40.44 kW – 76.55 kW (54 – 103 hp). This means that any tractor within the power range of 54 – 103 hp can work with the TEK mechanical harvesters. Again, at Mampong, the minimum tractor engine power requirement was within the range of 46.26 – 66.64 kW (62 – 89 hp) for TEK MCH 2 and MCH 6. Bobobee *et al.*, (1994) reported a tractor power requirement of 55 – 80 kW (69 - 107 hp) for the Leipzig harvester prototype while 90 hp was reported for the CLAYUCA Cassava Harvester Prototype by Ospino *et al.,* (2007). It could therefore be deduced that the tractor power requirements for the TEK mechanical cassava harvesters is less or within the range of the Leipzig harvester prototype and the CLAYUCA Cassava harvester prototype.

4.4.8 Mean Heart Rate, Gross Energy Consumption and Total Rest Period

Table 20 presents the mean Heart rate (bpm), Gross energy consumption (Watt) and Total rest period (min/h) obtained for three (3) labourers and a tractor operator at Anwomaso, Akatsi and Mampong during cassava harvesting.

The table generally depicts a higher mean heart rate when harvesting cassava manually compared to harvesting mechanically except for Mampong which registered a higher heart rate for the tractor operator. The reason why the tractor operator had a higher heart rate than the manual harvesting labourers could be due to the fact that the soil moisture content in Mampong at time of harvest was highest (15.8 – 21.4 % d.b.) compared to Anwomaso and Akatsi, thus making it difficult to harvest mechanically because of the non-scouring nature of the soil on the harvester blade. In effect, the operator would have to exert a great deal of effort in order to control the tractor so as to harvest the cassava as expected.

Table 20: Mean Heart Rate, Gross Energy Consumption and Total Rest Period for three (3) Labourers and a Tractor Operator at Anwomaso, Akatsi and Mampong during cassava harvesting.

Study site	**Mean Heart Rate (bpm)**		**Energy Consumption (Watt)**		**Rest Period (min/h)**	
	Labourer	Tractor operator	Labourer	Tractor operator	Labourer	Tractor operator
Anwomaso	119.65	91.58	746.27	426.65	39.90	24.84
Akatsi	112.42	96.86	664.91	487.90	37.44	29.26
Mampong	94.41	101.95	464.21	545.78	27.69	32.52
LSD	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**

On the other hand, it was much easier for the manual labourers to uproot the cassava roots which resulted in the relatively lower heart rates being recorded compared to the tractor operator. However, the gross energy consumption for the manual harvesting labourers for Anwomaso, Akatsi and Mampong was not statistically different at 5% significance level.

Though there was also no statistical difference between the gross energy consumption obtained for the manual harvesting labourers and the tractor operators at Anwomaso, Akatsi and Mampong at $p<0.05$. The results in emphasizes the fact that manual harvesting was generally easier in terms of energy expenditure compared to mechanical harvesting during the wet season as reported by Bobobee *et al.*, (1994) and Ospino *et al.*, (2007).

Knowledge of the total rest period required after every harvesting activity is important in order to determine the effective working hours for a field worker.

Assuming that there is eight (8) hours allocated for work each day, a tractor operator at Anwomaso for instance, would have an effective working time of 4 hours 38 minutes. This means that out of the total working time of eight (8) hours, the operator is required to rest for a period of three (3) hours and twenty-one (21) minutes.

It is could be seen from Appendix 5 that the energy consumption was directly proportional to the total rest period required. This means that the more the energy consumed during an activity, the longer the rest (recovery) period required to compensate for the lost energy. Crouter *et al.,* (2004), Freedson and Miller (2000) and Ericsson *et al.*, (2006) reported that heart rate is directly proportional to the gross energy consumption as observed from correlation results presented in Appendix 5.

4.4.9 Economic Analysis

Table 21 depicts the cost per ha of manual and mechanical cassava harvesting using the TEK mechanical harvester (TEK MCH) for the study sites (Anwomaso, Akatsi and Mampong) in the year 2010.

Using CALTECH commercial cassava farm for the case study, it could be deduced from the table that harvesting with the TEK mechanical harvester allows a reduction of 50% labour cost for harvesting resulting in a further reduction of 31% of the cost in harvesting manually. Harvest cost after using the TEK mechanical cassava harvester was 18.3% of the total production cost while that after using manual harvesting techniques was 26.5% of total production cost. This is similar to Ospino *et al.*, (2007) report that the use of a mechanical cassava harvester (CLAYUCA harvester prototype) helped to substantially reduce the total cost of cassava production.

Table 21: Cost per ha for cassava production (locally) and for manual and mechanical harvesting (using TEK MCH) at Mampong, Anwomaso and Akatsi in the year 2010 using CALTECH Commercial Cassava farm as a Case Study.

Cost of Cassava Production

(Using local rates and charges)

Activity	***per hectare***	***No. of times***	***Total cost/ha***
Cost of ploughing (GH¢)	125	2	250
Cost of harrowing (GH¢)	75	1	75
Cost of ridging (GH¢)	75	1	75
Cost of planting (GH¢)	87.5	1	87.5
Cost of weeding (GH¢)	62.5	3	187.5
Cost of manual harvesting (GH¢)*	87.5	1	87.5
Miscellaneous** (GH¢)	125	-	125
Total Cost of Production (GH¢)			**887.5**

* This was the average value after enquiries from local cassava farmers at the three (3) study areas

** This covers the cost of planting materials

Cost of Cassava Harvesting per ha

Using CALTECH Commercial Cassava Farm (Ho, V/R) as Case Study

Manual Harvesting

	Unit	***Amount***	***Unit Value (GH¢)***	***Total Value (GH¢)***
Labour (Harvesters)	Man-days	32	6	192
Miscellaneous***				20
Total Harvest cost				**212**
Harvest cost as percentage of total production cost				**26.5%**

Mechanical Harvesting (TEK MCH)

Labour (gathering and detaching)		16	6	96
Fixed variable cost of tractor (per ha)				22
Labour (tractor operator)				8

Miscellaneous**	20
Total Harvest cost	**146**
Harvest cost as percentage of total production cost	**18.3%**

*** This could cover the cost of loading harvested produce

An added advantage in using mechanical cassava harvesting apart from the fact that the farm is harvested within a shorter period of time and an appreciable reduction on labour cost compared to manual harvesting is that the field is also ploughed in advance; hence the cost involved in ploughing is removed for the next planting season. This makes it easier for the farmer to start cultivation at the right time consequently increasing timeliness of field work.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Mechanical cassava harvesting was possible with soil having bulk density in the range of 1.48 - 1.69 g/cm^3, a soil moisture content of 1.02 – 21.43 % d.b and soil penetration resistance of 1.0 – 3.99 MPa. The best performance for mechanical cassava harvesting using the TEK mechanical harvesters was achieved on the ridged landform with minimum trash with bulk density of 1.56 - 1.68 g/cm^3, soil moisture content of 1.0 – 16.0 % d.b and soil penetration resistance of 1.0 – 3.99 MPa.

The average depth of cassava root tuber penetration at 15 MAP was in the range of 23.4 cm to 28.0 cm and 20.6cm and 29.4 cm for *Bankyehemaa* and *Afisiafi* respectively. The mean root tuber length across row ranged from 31.2 cm to 69.4 cm for *Bankyehemaa,* 45.0 cm to 80.8 cm for *Afisiafi*, 47.8 cm to 61.0 cm for *Esambankye*, 73.0 cm -73.4 cm for *Dokuduade* and from 50.4 – 60.0 cm for *Nkabom* cassava variety on both ridged and flat landforms.

The highest mean root tuber yield was recorded at the Anwomaso study site with mean root tuber yield of 114.0 ton/ha to 120.5 ton/ha for *Afisiafi* cassava variety and from 57.5 ton/ha to 64.6 ton/ha for *Bankyehemaa* variety on both ridged and flat landforms. However, the mean root tuber yield was higher on ridged than the flat landform for *Bankyehemaa* and Afisiafi at all sites except Afisiafi on flat.

Harvesting with TEK mechanical cassava harvesters resulted in a percentage root tuber damage ranging from 7.7 % to 26.8 % for *Afisiafi*, *Bankyehemaa* and *Nkabom* cassava varieties. However, *Nkabom* cassava variety planted on ridges at Anwomaso proved to lend itself easily to mechanical harvesting with the lowest percentage root tuber damage (7.7 – 12.1 %) and due to its bunchy nature arising from its relatively shorter root tuber spread across and along row.

Cassava root tuber damage during mechanical harvesting increased with increasing soil moisture content. Also, harvesting mechanically on the ridged landform on the average, gave lower percentage root tuber damage than harvesting on the flat though no statistically significant difference was observed at $p<0.05$. Furthermore, there was no statistically significant difference between percentage root tuber damage during manual harvesting and mechanical harvesting at $p<0.05$.

The depth of harvester penetration for the TEK mechanical cassava harvesters ranged from 20.7 cm to 30.1 cm. Percentage root tuber damage generally increased with decreasing depth of harvester penetration and increasing depth of root tuber penetration and total length across row.

Manual harvesting of cassava with the IITA harvester prototype recorded a relatively lower percentage root tuber damage compared to the use of a cutlass. At 5% significance level, the IITA harvester prototype gave less tuber damage compared to cutlass as a harvesting aid.

Field capacity of the TEK mechanical cassava harvesters ranged from 1.55 h/ha to 2.96 h/ha during harvesting. However, field capacity was generally higher on the flat than on the ridged landform and was statistically different at 5% level of significance.

On the average, fuel consumption for the TEK mechanical cassava harvesters ranged from 15.0 l/ha to 43.6 l/ha and increased with increasing wheel slip (from 7% to

15%) with a working speed range of 4.2 km/h to 6.5 km/h. Moreover, tractor fuel consumption when harvesting with the TEK mechanical harvester generally increased with high soil penetration resistance whilst harvester working speeds on the other hand, increased with low soil penetration resistance.

The TEK mechanical harvesters recorded draught forces ranging from 4.9 - 12.3 kN requiring tractor engine power in the range of 40.4 kW (54 hp) to 76.6 kW (103 hp).

Manual harvesting capacity ranged from 11.4 man-days/ha to 31.9 man-days/ha and also increased with decreasing soil moisture. Moreover, manual harvesting of cassava generally required longer periods of time and high energy consumption compared to mechanical harvesting.

Cost of harvesting per ha was lower for mechanical harvesting compared to manual harvesting while reducing labour cost by 50% and a further reduction of 31% in the cost of manual harvesting. Additionally, the harvested field is ploughed in advance with saving on time, fuel and money.

5.2 Recommendations

1. Further testing of the TEK mechanical cassava harvesters should be carried out in all cassava growing agro-ecological zones on different soil types and soil moisture regimes in Ghana to promote nationwide adoption.
2. Due to the increasing popularity and awareness of the industrial importance of cassava products, the government should intervene by providing funds for small-scale cassava farmers to go into commercialized cassava cultivation with the

availability of the mechanical harvester. This will result in an increase in total land acreage under cultivation.

3. Design considerations on modification of the mechanical cassava harvesters should involve the incorporation of a rake mechanism to take trash off the field during the harvesting process as this is a serious constraint to mechanical harvesting.
4. Detailed research should be carried out concerning the economic viability of mechanical cassava harvesting.
5. Further testing of the IITA manual harvester prototype is recommended for different cassava varieties, landforms and soil conditions at several agro-ecological zones in Ghana.

REFERENCES

AATF - African Agricultural Technology Foundation (2007). *Annual Report 2006*: Delivering the Promise: Impacting Lives with New Technologies. English Press, Kenya. pp. 18. Available online: *http://aatf-africa.org/userfiles/annual2006.pdf.* Date accessed: 24-06-2011

Addy., P. S., Kashaija, I. N., Moyo, M. T., Quynh, N. K., Singh, S. and Walekhwa, P. N. (2004). Constraints and Opportunities for Small And Medium Scale Processing of Cassava in the Ashanti and Brong Ahafo Regions of Ghana, *Working document series 117*, pp. 60-69.

Adekunle, A.A., Dixon, A., Ojurongbe, J., Ilona, P., Muthada, L. and Adisa, S. (2004). Growing Cassava Commercially in Nigeria - An Illustrated Guide. USAID, ICS-Nigeria and IITA. 22 pp. Available online: *http://www.cassavabiz.org/agroenterprise/ent%20images/casava%20illust%20guid%20book.pdf*. Date Accessed: 22-06-2011

Agbetoye, L. A. S., Dyson, J. and Kilgour, J. (2000). Prediction of the Lifting Forces for Cassava Harvesting. *J. agric. Engng Res*. 75: 39-48. Silsoe Research Institute.

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 (Lagelu 2003), Ibadan, Nigeria, 8–12 December 2003; pp. 80-86.

Agodzo, S.K. and Adama, I. (2003). Bulk Density, Cone Index and Water Content Relations for Some Ghanaian Soils. Kwame Nkrumah University of Science and Technology, Kumasi-Ghana. Available online:

AlHashem, H. A., Abbouda S. K., and 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

Alves, A. A. C. (2002). Cassava Botany and Physiology. In: Hillocks, R. J., Thresh, J. M. and Bellotti A. (eds) Cassava: Biology, Production and Utilization. *CABI Publishing*, UK, pp. 67-83.

Anderson, J.V., Delseny, M., Fregene, M. A., Jorge, V., Mba, C., Lopez, C., Restrepo, S., Soto, M., Piegu, B., Verdier, V., Cooke, R., Tohme, J. and Horvath, D. P. (2004). An EST Resource for Cassava and other Species of Euphorbiaceae. *Plant Molecular Biology* 56: 527–539, Kluwer Academic Publishers, Netherlands.

Apea Bah, F. B., Oduro, I., Ellis, W.O. and Safo-Kantanka, O. (2007). Time of Harvest and its Effect on Quality of flour from four Cassava Varieties. *Proceedings of the 13th ISTRC Symposium*, pp 248-259.

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

Arzai, A.H. and Aliyu, B.S., (2010). The Relationship between Canopy Width, Height and Trunk Size in Some Tree Species Growing in the Savannah Zone of Nigeria. *Bayero Journal of Pure and Applied Sciences*, Nigeria. 3(1): 260 – 263

Asare, D. K., Ayeh, E. O. and Amenorpe, G. (2009). Response of Rainfed Cassava to Methods of Application of Fertilizer-Nitrogen in a Coastal Savannah Environment of Ghana. *World J. Agric. Sci., 5 (3): 323-327*5. (3): 323-327. ISSN 1817-3047, IDOSI Publications.

Ayoola, O. T. and Makinde, E. A., (2007). Fertilizer Treatment Effects on Performance of Cassava under two Planting Patterns in a Cassava-based Cropping System in South West Nigeria. *Research Journal of Agriculture and Biological Sciences*, 3(1): 13-20.

Baldock, J. A. and Skjemstad, J. O. (1999). Soil Organic Carbon/Soil Organic Matter, in Soil Analysis: an Interpretation Manual, Eds. Peverill, KI, Sparrow, LA and Reuter, DJ, CSIRO Publishing, Melbourne, pp 159-70.

Baryeh, H. I., (1997). Land Management and Tenure Systems in Peri-Urban Areas of Kumasi, Ghana *in:* Kumasi Natural Resource Management Research Project, Inception Report, Vol. 2 (3), pp.1-25

Bayoumi, S.A.L., Rowan, M.G., Blagbrough, I.S., Beeching, J.R., (2008). Biosynthesis of Scopoletin and Scopolin in Cassava Roots during Post-Harvest Physiological Deterioration: The E-Z-Isomerisation Stage. *Journal of Phytochemistry*, 69 : 2928–2936

Bill and Melinda Gates Foundation (2010). Ghana: Profiles of Progress. *Global Development Program*. Available online: *http://www.gatesfoundation.org/agriculturaldevelopment/Documents/profiles-of-progress-ghana-agricultural-development.pdf*. Date accessed: 28-06-2011

Bobobee, E.Y.H., Okyere, J. B. and Asare, E. (2000). Mechanical Cassava Harvesting Technique: Final Report. National Agricultural Research Project (NARP)- Council for Industrial and Scientific Research (CSIR).

Bobobee, E.Y.H., Okyere, J.B., Twum, A., Neumann, R. H and 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.

Bolfrey-Arku, G. E.-K., Onokpise, O. U., Carson, A. G. Shilling, D. G. and Coultas, C. C. (2007). The Speargrass (*Imperata cylindrica* (L) Beauv.) Menace in Ghana: Incidence, Farmer Perceptions and Control Practices in the Forest and Forest-Savanna Transition Agro-ecological Zones of Ghana. Available Online: *http://www.ajol.info/index.php/wajae/article/viewFile/45713/29191*. Date Accessed: 24-06-2011

Brammer, H. (1962). Soils: In Agriculture and Landuse in Ghana. J. B. Wills ed., Oxford University Press London, Accra, New York. Pp 88-126.

Cadavid, L. F., El-Sharkawy, M. A., Acosta, A. and Sanchez, T. (1998). Long term Effects of Mulch, Fertilization and Tillage on Cassava grown in Sandy soil in Northern Columbia. *Field Crops Research*, 57: 45-56.

CIA (2010). The World Factbook: Ghana. Available online: *http://www.cia.gov/cia/publications/factbook/*. Date Accessed: 09-06-2010.

Crouter, S. E., Albright, C. and Bassett, D. R. (2004). Accuracy of Polar S410 Heart Rate Monitor to Estimate Energy Cost of Exercise. *Med. Sci. Sports Exercise.* Vol. 36, No. 8, pp. 1433–1439

DeAngelis K. M., (2007). Measurement of Soil Moisture Content by Gravimetric Method. Available online: *http://www.cnr.berkeley.edu/soilmicro/methods/Soil%20moisture%20content.pdf.* Date accessed: 28th October, 2010.

EAC - East African Community (2010). Bitter cassava: Specification and Grading. East African Standard. pp 11-13. Available online: *http://www.eac-quality.net/fileadmin/eac_quality/user_documents/3_pdf/CD-K-106-2010__Bitter_cassava_-_Specification_and_grading.pdf*. Date accessed: 28-06-2011

Ekanayake, I. J., Osiru, D. S. O. and Porto, M. C. M. (1997). Agronomy of Cassava. IITA Research Guide 60. Available online: *http://betuco.be/manioc/Agronomy%20of%20cassava%20IITA%20nr%2060.pdf*. Date Accessed: 22-06-2011

El-Sharkawy, M. A. and Cadavid, L. F. (2000). Genetic Variation within Cassava Germplasm in Response to Potassium. *Expl Agric*, 36, pp. 323-334. Cambridge University Press, UK.

El-Sharkawy, M.A. (1993). Drought-tolerant Cassava for Africa, Asia and Latin America. – *BioScience* 43: 441-451.

Ennin, S. A., Otoo, E. and Tetteh, F. M. (2009). Ridging, a Mechanized Alternative to Mounding for Yam and Cassava Production. *West African Journal of Applied Ecology*, vol. 15, pp 1-8

Ericsson, F., Dalarna, U. and Björklund, G. (2006). The Relationship between Heart rate and Power output during cycling competitions. Available online: *http://www.toppfysik.nu/userfiles/file/The%20relationship%20between%20heart%20rate%20and%20power%20output%20during%20road%20cycling%20competitions.pdf*. Date accessed: 12-08-2011

External Market Task Force (2004). Report on Cassava: Analysis of Cassava as a target Product for the Development and Export from Mozambique and in particular to South Africa. External Market Study No. 3 (1). Maputo, Mozambique. Available Online: *http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.169.6100&rep=rep1&type=p*. Date accessed: 22-06-2011

FAO (2000). The State Of Food Insecurity in the World. Rome, Italy. Available online: *http://www.fao.org/FOCUS/E/SOFI00/img/sofirep-e.pdf*. Date accessed: 22-06-2011

FAO (2002). *Agricultural Statistics*. Rome, Italy

FAO (2009). Cassava. *Food Outlook – Global Market Analysis*. Available online: *http://www.fao.org/docrep/012/ak341e/ak341e06.htm.* Date accessed: 28-06-2011

FAO and IFAD (2000). The Global Cassava Development Strategy and Implementation Plan. *Proceedings of the validation forum on the global cassava development strategy, Volume 1*, Rome, pp 14-59

FAO and IFAD (2001). Strategic Environmental Assessment-An assessment of the Impact of Cassava Production and Processing on the Environment and Biodiversity. Proceeding of the Validation Forum on the Global Cassava Development *Strategy. Volume 5*. Rome, Italy.

FAO. (1998). World Reference Base for Soil Resources. World Soil Resources Report 84, FAO, Rome.

FAOSTAT (2006). FAO Statistics Division 2006.

Freedson, P. S. and Miller. K. (2000). Objective Monitoring of Physical Activity using Motion sensors and Heart rate. *Res Q Exerc Sport*. Vol 71, S21-S29

Ghana Districts, (2010). Available online: *http://www.ghanadistricts.com/districts/.* Date accessed: 28th October, 2010.

Graffham, A., Kleih, U., Jagwe, J., Nabawanuka, J., Wanda, K., Kalunda, P., Ntibarikure, G. and Ferris, S. (2003). A Market Opportunities Survey for Value Added Utilization of Cassava-based Products in Uganda. Part I: Demand Analysis for Industrial Utilization, *ASARECA/IITA Monograph 3* IITA, Ibadan, Nigeria.

Grisso, R., Perumpral, J. V., Vaughan, D., Roberson, G. T. and Pitman, R. (2010). Predicting Tractor Diesel Fuel Consumption. *Communications and Marketing, College of Agriculture and Life Sciences, Virginia Polytechnic Institute and State University,* Publication 442-073, pp 1-10

GTZ and Stumpf, E. (1998). Post-harvest loss due to pests in dried cassava chips and comparative methods for its assessment - A case study on small-scale farm households in Ghana. *Humboldt University*, Berlin, Germany. Available online: *http://www.fao.org/wairdocs/x5426E/x5426e02.htm#1. introduction*. Date Accessed: 24-06-2011

Gutteridge, R.C. and Shelton, H. M. (1994). The role of forage tree legumes in cropping and grazing systems. In Gutteridge R.C. and Shelton HM (eds.) Forage Tree Legumes in Tropical Agriculture. CAB International, United Kingdom.

Hanna, M. (2001). Estimating Field Capacity of Field Machines. Cooperative Extension Service, Iowa State University of Science and Technology, PM 696, pp 1-4

Hillocks, R. J. (2002). Cassava in Africa. In: Hillocks, R. J., Thresh, J. M., Bellotti, A. C., (eds). Cassava: Biology, Production and Utilization. *CABI Publishing, Wallingford, UK*. pp. 41–54.

Howeler, R. H. (1991). Long-term effects of cassava cultivation on soil productivity. *Field Crops Res.*, 26: 1-18.

Howeler, R. H., Watananonta, W. and Ngoan, T. N. (2008). Improving the Sustainability of Cassava-Based Cropping Systems in Asia: A Farmer Participatory Approach to Technology Development and Dissemination. pp 1-19. Available online: *http://ciat-library.ciat.cgiar.org/Articulos_Ciat/0208_Improving_Sustainability.pdf*. Date Accessed: 24-06-2011

http://users.ictp.it/~pub_off/lectures/lns018/02Agodzo2.pdf. Date accessed: 30-06-2011

IFAD and FAO (2005). A Review of Cassava in Africa with Country Case Studies on Nigeria, Ghana, the United Republic of Tanzania, Uganda and Benin. *Proceedings of the validation forum on the global cassava development strategy, Volume 2*, Rome.

IFAD, AU and NEPAD (2008). Working together to enable Smallholders to Influence Rural Development Policies in Africa. Rome, Italy. Available Online: *http://www.ifad.org/pub/factsheet/nepad/nepad.pdf*. Date accessed: 22-06-2011.

IITA- International Institute of Tropical Agriculture (1992). Cassava as Livestock Feed in Africa. Hahn, S.K., Reynolds, L and Egbunike, G.N. (*Eds)*: In: *Proceedings of the IITA/ILCA/University of Ibadan Workshop on the Potential Utilization of Cassava as Livestock Feed in Africa*. 14-18 November 1988. Ibadan, Nigeria. Available online: *http://pdf.usaid.gov/pdf_docs/PNABQ291.pdf.* Date accessed: 29-06-2011

International Institute of Tropical Agricultural – IITA. (2003). Growing Cassava in Nigeria, *Information and Communication Support for Agricultural Growth in Nigeria*, Nigeria, pp. 2-10

International Institute of Tropical Agriculture - 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. *IITA*, Ibadan, Nigeria. 79 pp.

International Starch Institute (2002). Cassava Plantation, *Science Park Aarhus*, Denmark. Available online: *http://www.starch.dk/isi/papers/TM29%20Cassava%20Plantation%20EB.pdf.* Date Accessed: 23-06-2011

Iowa State University Extension. (2009). Estimating Farm Machinery Costs. *Ag Decision Maker*, PM-710, pp. 1-8. Available online: *http://www.extension.iastate.edu/publications/pm710.pdf*. Date accessed: 08-08-2011

Jahn, B. R., and Hamburg, D. S. (2002). A Tractor-Mounted Device for Measurement of In-situ Soil Strength Properties. *An ASAE/CSAE Meeting Presentation*, Paper No: MBSK 02-308, Niles Road, St. Joseph, MI 49085-9659 USA.

Jones, W.O. (1959). Manioc in Africa. *Stanford Univ. Press*, Stanford, California, USA. 355 pages.

Keim, N. L., Blanton, C. A. and Kretsch, M. J. (2004). America's Obesity Epidemic: Measuring Physical Activity to Promote an Active Lifestyle. *J. of the Amer. Diet. Assoc.* 104: 9, pp 1398-1409.

Kolawole, P. O., Agbetoye, L. and Ogunlowo, S. A. (2010). Sustaining World Food Security with Improved Cassava Processing Technology: The Nigeria Experience. *Sustainability*, *2*, 3681-3694.

Kuiper, L., Ekmekci, B., Hamelinck, C., Hettinga, W., Meyer, S. and Koop, K. (2007). Bio-ethanol from Cassava. Ecofys Netherlands BV, pp 1 – 38. Netherlands.

Available online: *http://www.probos.net/biomassa-upstream/pdf/FinalmeetingEcofys.pdf*. Date Accessed: 24-06-2011.

Macmillan, R. H., (2002). The Mechanics of Tractor - Implement Performance: Theory and Worked Examples. *Agricultural Engineering International Development Technologies Centre,* University of Melbourne.

Melifonwu, A., Braima, J., Aïhou, K. Weise, S., Awah, E. and Gbaguidi B. (2000). Weed Control in Cassava Farms - IPM Field Guide for Extension Agents, IITA. *Wordsmithes Printers*, Lagos, Nigeria.

Metson, A. J., (1961). Methods of chemical analysis for soil survey samples. New Zealand DSIR Soil Bur. Bull. 12. Govt. printer. Wellington. New Zealand.

MINITAB Inc. (2007). MINITAB Statistical Software, Release 15 for Windows. Minitab Inc. State College, Pennsylvania.

Molina, J.L and El-Sharkawy, M.A (1995). Increasing crop productivity in cassava by fertilizing production of planting material, *Field Crop Research*, 44:151-157.

Montoye, H. J. (1996). Measuring Physical Activity and Energy Expenditure. *Champaign, IL*: Human Kinetics.

Muma, A.K. (2000). Animal Power for Weed Control in Kaoma District, Zambia. *In:* Animal Power for Weed Control. A resource book of the Animal Traction Network for Eastern and Southern Africa, edited by P. Starkey and T. Simalenga. Technical Center for Agricultural and Rural Cooperation (CTA), The Netherlands.

Naderi, M., Alimardani, R., Abbaszadeh, R and Ahmadi, H., (2008). Assessment of Dynamic Load Equations through Drive Wheel Slip Measurement, *Am-Euras. J. Agric. & Environ. Sci., 3 (5): 778-784*, ISSN 1818-6769, IDOSI Publications, Iran.

Nweke, F. I. (2004). New Challenges in the Cassava Transformation in Nigeria and Ghana. *International Food Policy Research Institute, EPTD discussion paper No. 118*, Washington D.C, U.S.A. pp 10-67

Nweke, F. I., Dunstan S. C. S. and Lynam J. K. (2002). The Cassava Transformation: Africa's Best Kept Secret. *Lansing, Mich., USA: Michigan State University Press*.

Odigboh, E. U. and Moreira, C. A. (2002). Development of a Complete Cassava Harvester 1 – Conceptualisation. *Journal of Agricultural Mechanisation in Asia, Africa and Latin America* 4 (33), pp 1-7

O'Hair, S. K. (1995). New Crop Factsheet: Cassava. *Tropical Research and Education Center*, University of Florida. Available online: *http://www.hort.purdue.edu/newcrop/cropfactsheets/cassava.html*. Date accessed: 24-06-2011

Okigbo, B. N. (1980). Nutritional Implications of Projects giving High Priority to the Production of Staples of Low Nutritive Quality: The Case for Cassava (Manihot esculenta, Crantz) in the Humid Tropics of West Africa. *International Institute of Tropical Agriculture (IITA)*, Ibadan, Nigeria. *In*: Food and Nutrition Bulletin (UNU) , 2(4) p. 1-10

Oni, F.C and Eneh, M.C.C. (2004). Strategies for reducing the cost of Production and Processing of Cassava, *Paper presented at the facilitation and sensitization workshop for cassava producing States under the Presidential Initiatives on Cassava Production and Export*, 8th – 12th November, 2004. Federal Ministry of Agriculture and Rural Development, Abuja.

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. And 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

Peipp, L. and Maehnert, E. (1992). The Development of a Technical Solution to Cassava Harvesting Problem. *Agric. Mech. Asia Afr. Lat. Amer.* 1992, *23*, 33-36.

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

Phillips, T. P. (2009). The Market for Cassava in the World. *dTp Studies Inc*. pp 1-6. Available online:

http://www.cerat.unesp.br/xiiicbm/palestras/Rodolfo/16/palestra15.pdf. Date accessed: 23-06-2011

Plucknett, D. L., Phillips, T. P. and Kagbo, R. B. (1998). A Global Development Strategy for Cassava: Transforming a Traditional Tropical Root Crop. *Spurring Rural Industrial Development and Raising Incomes for the Rural Poor.* Available online: *http://www.fao.org/docrep/006/y0169e/y0169e04.htm.* Date accessed: 24-06-2011

Rañola, R. F., Demafelis, R. B., Del Rosario, E. and Bataller, B. G. (2009). Enhancing the Viability of Cassava Feedstock for Bio-ethanol in the Philippines, *J. ISSAAS* (15) 2:147 -158

Reichert, J. M., da Silva V.R. and 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. Available online: *www.tucson.ars.ag.gov/isco/isco13/PAPERS%20R.../REICHERT.pdf.* Date accessed: 15-07-2011.

RTIMP (2010). Root and Tuber Improvement and Marketing Programme - MOFA, Personal communication.

Sam, J. and Dapaah, H. (2009). Baseline Survey Report, *West African Agricultural Productivity Programme (WAAPP)*, Ghana. pp. 13-18. Available online: *http://waapp.coraf.org/documents/WAAPP/Rapports/Final%20WAAPP%20Baseline%20Survey%20Report%20Ghana.pdf.* Date accessed: 23-06-2011

Scott, G.J., Rosegrant, M. W. and Ringler, M. W. (2000). Roots and tubers for the 21st century: trends, projections and policy options. *Food, Agriculture and Environment Discussion Paper 31*, International Food Policy Research Institute. pp 10-29

Seini, A. W. (2002). Agricultural Growth and Competitiveness under Policy Reforms in Ghana. Institute of Statistical, Social & Economic Research (ISSER), *Technical Publication Series No. 61*, ISBN: 9964-75-044-7, University of Ghana, Legon, pp. 28-35.

Siemens, J. C., and W. W. Bowers. (1999). Machinery Management: How to Select Machinery to Fit the Real Needs of Farm Managers. *Farm Business Management Series.* Davenport, Iowa: John Deere Publishing.

Sims B. G. and Kienzle J. (2006). Farm power and Mechanization for small farms in sub-Saharan *Africa, Agricultural and Food Engineering Technical Report for FAO*, Rome.

United Nations (2008). South-South Trade in Asia: the Role of Regional Trade Agreements. UNCTAD/DITC/TAB/MISC/2008/2, Switzerland.

USDA - United States Department of Agriculture (1999). Soil Quality Test Kit Guide. Section II, pp. 57-58. Available online: *http://ocw.tufts.edu/data/32/383298.pdf*. Date 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. Available online: *http://plants.usda.gov/plantguide/pdf/cs_maes.pdf*. Date accessed: 24-06-2011

Vaz, C. M. P., Bassoi, L. H. and Hopmans, J. W. (2001). Contribution of Water content and Bulk density to field Penetration Resistance as measured by a Combined Cone penetrometer – TDR Probe. *Soil and Tillage Research,* 60: 35-42.

APPENDICES

APPENDIX 1: Mean Experimental Results

Soil Moisture Content (% d.b)

Site	0-10cm	10-20cm	20-30cm	30-40cm
Anwomaso BP	7.85	8.56	9.31	9.89
Anwomaso AP	9.06	9.99	11.59	11.95
Anwomaso AH	12.06	12.41	14.25	15.69
Mampong BP	13.35	13.91	14.72	17.43
Mampong AP	16.73	17.57	17.73	17.85
Mampong AH	15.78	16.64	19.40	21.43
Akatsi BP	6.015	5.65	4.139	3.35
Akatsi AP	5.89	6.69	6.89	5.26
Akatsi AH	1.02	2.25	3.12	3.72

Soil Bulk Density (g/cm^3)

Site	0-10cm	10-20cm	20-30cm	30-40cm
Anwomaso BP	1.51	1.54	1.63	1.68
Anwomaso AP	1.66	1.65	1.64	1.63
Anwomaso AH	1.56	1.62	1.69	1.68
Mampong BP	1.52	1.56	1.58	1.60
Mampong AP	1.67	1.731	1.71	1.75
Mampong AH	1.48	1.63	1.61	1.57
Akatsi BP	1.68	1.75	1.78	1.82
Akatsi AP	1.66	1.70	1.74	1.82
Akatsi AH	1.54	1.68	1.63	1.66

Soil Penetration Resistance (MPa)

Site	0-10cm	10-20cm	20-30cm	30-40cm
Akatsi BP	0.921	2.620	2.775	3.152
Akatsi AP	0.321	1.032	2.731	3.130
Akatsi AH	2.650	3.131	3.415	3.880
Anwomaso BP	1.838	2.163	2.243	2.350
Anwomaso AP	1.654	1.865	2.309	2.886
Anwomaso AH	1.465	2.675	3.390	3.985
Mampong BP	0.679	1.732	2.105	1.672
Mampong AP	0.806	1.412	1.665	1.885
Mampong AH	1.000	1.532	1.650	1.531

Depth of Root Tuber Penetration (cm) at 15 MAP

	Mampong	Anwomaso	Akatsi
Bankyehemaa-R	23.4 ± 2.07	28.0 ± 2.55	26.2 ± 1.30
Bankyehemaa-F	26.4 ± 2.07	25.0 ± 3.74	23.4 ± 3.21
Afisiafi-R	25.2 ± 1.92	29.4 ± 1.34	24.2 ± 1.79
Afisiafi-F	20.6 ± 3.51	21.6 ± 1.14	26.6 ± 3.36

Total Root Tuber Length across row (cm) at 15 MAP

	Mampong	Anwomaso	Akatsi
Bankyehemaa-R	52.6 ± 20.30	69.0 ± 22.02	66.2 ± 17.11
Bankyehemaa-F	69.4 ± 20.62	61.0 ± 28.94	31.2 ± 8.79
Afisiafi-R	47.8 ± 20.13	80.8 ± 36.01	60.8 ± 20.14
Afisiafi-F	67.0 ± 19.36	59.2 ± 30.65	45.0 ± 10.42

Depth of Harvester Penetration (cm) for TEK MCH's

Anwomaso

Sample	MCH 1	MCH 2	MCH 3	MCH4	MCH 5	MCH 6
1	26.40	30.65	26.35	26.25	27.20	24.35
2	26.45	29.80	25.15	27.75	25.70	23.40
3	24.7	24.29	27.45	31.05	24.95	24.30
4	23.07	23.90	28.05	28.70	25.85	23.85
5	23.25	22.81	30.90	28.18	24.20	23.90
Grand Mean	24.77	26.29	27.58	28.39	25.58	23.96
StDv	1.63	3.65	2.16	1.75	1.12	0.39

Mampong (TEK MCH 2)

Sample	Afisiafi-R	Afisiafi-F	Bankyehemaa-R	Bankyehemaa-F
1	27.20	27.45	19.10	19.00
2	28.10	26.60	23.35	21.85
3	27.40	18.00	20.85	27.70
4	27.90	24.30	22.50	27.65
5	27.10	28.15	22.70	25.35
Grand Mean	27.54	24.90	21.70	24.31
StDv	0.44	4.12	1.72	3.81

Akatsi

Sample	BH-R (MCH 2)	BH-F (MCH 2)	AF-R (MCH 2)	AF-F (MCH 2)	AF-F (manual)	BH-R (manual)
1	28.00	22.55	29.00	22.00	22.00	28.00
2	25.15	19.25	31.00	21.40	21.40	25.15
3	26.30	21.00	28.30	20.40	20.40	26.30
4	29.00	22.90	32.10	19.20	19.20	29.00
5	26.75	24.65	30.00	20.30	17.00	23.60
Grand Mean	27.04	22.07	30.08	20.66	20.00	26.41
StDv	1.50	2.041	1.52	1.08	1.98	2.16

APPENDIX 2: Soil Physico-Chemical Analysis Results

After Ploughing

Site Description	Horizon (cm)	Mechanical Analysis			Texture
		Sand	Silt	Clay	
Akatsi	0-20	83.02	14.98	2.00	Loamy sand
	20-40	81.70	14.30	4.00	Loamy sand
	40-60	80.46	15.54	4.00	Loamy sand
Anwomaso	0-20	64.94	25.06	10.00	Sandy loam
	20-40	50.70	21.30	28.00	Sandy clay loam
	40-60	43.10	26.90	30.00	Clay loam
Mampong	0-20	65.54	26.46	8.00	Sandy loam
	20-40	61.40	24.60	14.00	Sandy loam
	40-60	51.66	26.34	22.00	Sandy clay loam
		At Harvest			
Akatsi	0-20	81.24	14.71	4.05	Loamy sand
	20-40	83.74	10.18	6.08	Loamy sand
	40-60	81.08	12.88	6.04	Loamy sand
Anwomaso	0-20	68.92	21.06	10.02	Sandy loam
	20-40	57.98	19.98	22.04	Sandy clay loam
	40-60	49.70	20.29	30.01	Sandy clay loam
Mampong	0-20	64.24	21.71	14.05	sandy loam
	20-40	55.16	24.81	20.03	Sandy clay loam
	40-60	47.40	20.54	32.06	Sandy clay loam

Location	FAO Classification
Akatsi	Cambisol
Anwomaso	Acrisol
Mampong	Lixisol

Soil Chemical analysis Description

Study site	**pH**		**Organic Carbon (O.C)**		**Cation Exchange Capacity (C.E.C)**		**Percentage Nitrogen (N)**	
	AP	AH	AP	AH	AP	AH	AP	AH
Akatsi	Moderately acidic	Moderately acidic	Very low (<2%)	Very low (<2%)	Very low (<6)	Very low (<6)	Low (<0.2)	Very low (<0.1)
Anwomaso	Strongly acidic	Very strongly acidic	Very low (<2%)	Very low (<2%)	Very low (<6)	low	Medium (0.2-0.5)	Very low (<0.1)
Mampong	Very strongly acidic	Very strongly acidic	Very low (<2%)	Very low (<2%)	low	low	Medium (0.2-0.5)	Very low (<0.1)

APPENDIX 3: Heart Rate - Energy Conversion Chart

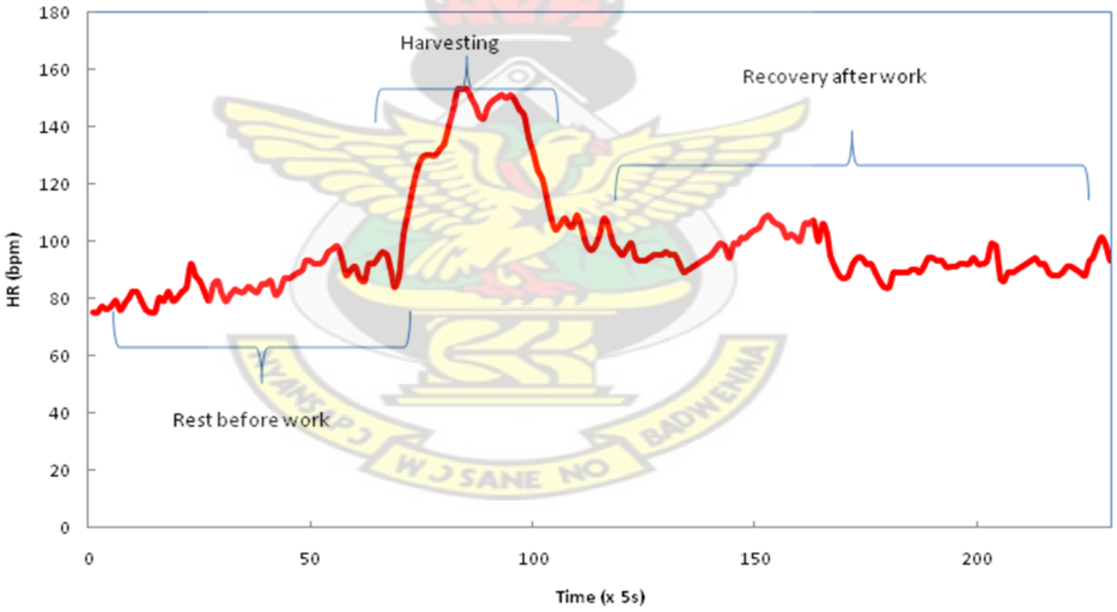
Heart Rate (bpm)	Energy (watt)	Heart Rate (bpm)	Energy (watt)
72	210	120	751.68
76	255	121	763.28
80	300	122	773.72
84	346	123	785.32
88	390	124	796.92
90	408.32	125	808.52
91	419.92	126	820.12
92	431.52	127	831.72
93	443.12	128	843.32
94	454.72	129	854.92
95	466.32	130	866.52
96	477.92	131	875.8
97	489.52	132	886.26
98	501.12	133	895.52
99	512.72	134	905.96
100	523.16	135	922.2
101	534.76	136	915.24
102	546.36	137	926.84
103	557.96	138	937.28
104	569.96	139	948.88
105	580	140	960.48
106	591.6	141	972.08
107	609.2	142	982.52
108	614.8	143	994.12
109	626.4	144	1009.4
110	638	145	1016.16
111	648.44	146	1027.76
112	660.04	147	1038.2
113	671.64	148	1049.8
114	683.24	149	1061.4
115	694.84	150	1071.84
116	706.44	151	1083.44
117	716.88	152	1095.04
118	728.48	153	1105.48
119	740.08	154	1117.08

Rest Period (Tr) calculation:

Using Equation 2, $Tr = 60 \times \left(1 - \frac{250}{P}\right)$ and knowing for instance that the tractor operator at Anwomaso used 426.65 Watts of energy (gross energy consumed), then it means the operator would have to rest for $Tr = 60 \times \left(1 - \frac{250}{426.65}\right)$ minutes every hour

= 60 × (1-0.5859) = 60×0.4206 = **24.84 mins/hour**

The graph below shows a typical heart rate profile during manual harvesting by a labourer recorded using the Polar heart rate watch and sensor (RS 800 CX).



APPENDIX 4: Machinery Costing

- **Farm Tractor**

Fixed Costs

$Depreciation = \frac{Purchase\ price - Salvage value}{Economic\ life}$ = GH¢ $\frac{22{,}000 - 2{,}200}{10}$ = GH¢ 1,980/y

$Interest = Rate\left(\frac{Purchase\ price + Salvage value}{2}\right)$ = GH¢ 5% $\left(\frac{22{,}000 + 2{,}200}{2}\right)$ = GH¢ 605/y

Taxes = 0% of Purchase price = GH¢ 0.00/y

I*nsurance* = 0.5% of Purchase price = GH¢ 0.005 × 22,000 = GH¢ 110/y

Shelter = 0.5% of Purchase price = GH¢ 0.005 × 22,000 = GH¢ 110/y

Total Fixed Costs = *Depreciation* + *Interest* + *Taxes* + *Insurance* + *Shelter (GH¢/y)*

= GH¢ 1,980 + GH¢ 605 + GH¢ 0.00 + GH¢ 110 + GH¢ 110

= **GH¢ 2805/y**

Variable Costs

Fuel cost = Cost of fuel (GH¢/l) × fuel consumption (l/ha) × Field capacity (ha/h)

= GH¢ 1.54/l × 20.6 l/ha × 0.49 ha/h = GH¢ 15.54/h

Lubricant cost = Cost of engine oil (GH¢/l) × Engine oil consumption (l/ha) × Field capacity (ha/h) = GH¢ 6.21/l × 0.5 l/ha × 0.49 ha/h = GH¢ 1.52/h

Repairs and Maintenance (R&M) cost = 0.05 × GH¢ 22,000 = (GH¢ 1100/y) = GH¢ 1.10/h

Labour cost (Tractor operator) = 1 operator × (GH¢ 400 ÷ 26 days) ÷ 8 hours = GH¢ 1.92/h

**Labour cost for coppicing, detaching and loading cassava after harvest* = 16 labourers × (GH¢ 144 ÷ 26 days) ÷ 8 hours = GH¢ 0.69/h × 16 = GH¢ 11.08/h

Total Variable Cost = *Fuel + Lubricant + R &M + Labour (GH¢/h)*

= 15.54 + 1.52 + 1.10 + 1.92 = **GH¢ 20.08/h** (excluding*)

Or = 15.54 + 1.52 + 1.10 + 1.92 + 11.08 = **GH¢ 31.16/h** (including*)

Fixed Variable cost = Total Fixed cost + Total Variable cost

= GH¢ 2805/y + (GH¢ 20.089/h × 1000 h)/y

= GH¢ 2805/y + GH¢ 20089/y

= GH¢ 22,894/y (excluding*)

= GH¢ 33,965/y (including*)

- **TEK Mechanical Cassava Harvester**

Fixed Costs

$$Depreciation = \frac{Purchase\ price - Salvage value}{Economic\ life} = \text{GH¢ } \frac{6000 - 660}{6} = \text{GH¢ } 900/\text{y}$$

$$Interest = Rate\left(\frac{Purchase\ price + Salvage value}{2}\right) = \text{GH¢ } 5\%\left(\frac{6000 + 660}{2}\right) = \text{GH¢ } 165/\text{y}$$

Taxes = 0% of Purchase price = GH¢ 0.00/y

I*nsurance* = 0.5% of Purchase price = GH¢ 0.005 × 6000 = GH¢ 30/y

Shelter = 0.5% of Purchase price = GH¢ 0.005 × 22,000 = GH¢ 30/y

Total Fixed Costs = *Depreciation + Interest + Taxes + Insurance + Shelter (GH¢/y)*

= GH¢ 900 + GH¢ 165 + GH¢ 0.00 + GH¢ 30 + GH¢ 30

= GH¢ 1125/y

Variable Costs

Repairs and Maintenance (R&M) cost = 0.05 × GH¢ 6000 = (GH¢ 300/y) = GH¢ 0.3/h

Labour cost for coppicing and loading cassava after harvest = 16 labourers × (GH¢ 144 ÷ 26 days) ÷ 8 hours = GH¢ 0.69/h × 16 = **GH¢ 11.076/h**

Total variable cost = *R&M + Labour*

= GH¢ (0.3 + 11.08)/h = **GH¢ 11.377/h**

Fixed Variable cost = Total Fixed cost + Total Variable cost

= GH¢ 1125/y + (GH¢ 11.377/h × 1000 h)/y

= **GH¢ 1125/y + GH¢ 11,377/y**

= GH¢ 12,502/y

Some Useful Conditions and Assumptions

i. The purchase price of a tractor is GH¢22,000.00 and that of a harvester is GH¢ 6000.00.
ii. Salvage value is 10% of purchase price for both tractor and harvester.
iii. Economic life (life span) for a tractor is 10 years and six years for a harvester.
iv. Fuel consumption of tractor when using harvester is 20.6 l/ha where 1 litre of diesel costs GH¢ 1.54.
v. The tractor consumes 0.5 litres of engine oil per hectare.

vi. Sixteen labourers are needed for coppicing, detaching and loading and from a company's point view each is paid GH¢ 4.00 per day (26 days in a month, excluding 4 Sundays).

vii. The tractor operator of the company is paid GH¢ 400.00 a month and works for approximately 8 hours each day of the month excluding Sundays.

viii. 1000 hours per year is the work frequency for the tractor and implement, 900 hours when working with a hoe/cutlass in the dry season or the IITA harvester, 1000 hours when working with a hoe/cutlass in the wet season.

ix. 32 labourers are required to harvest in the dry season and 16 labourers in the wet season (4 labourers per trailer in wet season and 8 labourers in the dry season with 8 trailers per hectare).

Conditions and Assumptions (Cont'd)	
Salvage	10% of Purchase Price
Interest	5%
Insurance	0.5% of Purchase Price
Tax	0% of Purchase Price
Shelter	0.5% of Purchase Price
Fuel (Diesel) cost	GH¢ 1.54 per litres
Fuel consumption	20.6 l/ha
Lubricant cost	GH¢ 6.21 per litres
Field Capacity of Harvester	0.49 ha/h
Actual working period (manual)	2408 h/yr
Repairs and Maintenance (R&M)	5% of purchase price
Tractor operator pay rate	GH¢ 400 (GH¢ 8 per ha)
Manual harvesters pay rate	GH¢ 6/ha
Using CALTECH Farm Ventures (Ho-V/R) as case study	
Max Manual Harvesting Capacity	31.9 man-days/ha
Cost of Harvesting in Dry season	GH¢ 4.00
Cost of Harvesting in Wet season	GH¢ 4.00
# of Labourers in dry season	8 per trailer
# of Labourers in wet season	4 per trailer
# of trailers per hectare	8
# of working days	26

			Dry Season	*Wet Season*	
	TRACTOR	**TEK MCH**	**Hoe/Cutlass**		**IITA Harvester**
Purchase price (GH¢)	22000	6000	8	8	25
Salvage value (GH¢)	2200	600	0.8	0.8	2.5
Economic life (years)	10	6	2	2	4
Fixed Cost (GH¢/yr)					
Depreciation	1980	900	3.6	3.6	5.625
Interest	605	165	0.22	0.22	0.6875
Insurance	110	30	0.04	0.04	0.125
Tax	0	0	0	0	0
Shelter	110	30	0.04	0.04	0.125
Total Fixed Cost	**2805**	**1125**	**3.9**	**3.9**	6.56

Fuel (Diesel) cost (GH¢ /l)	1.54	-	-	-	-
Fuel Consumption (l/ha)	20.6	-	-	-	-
Field Capacity (ha/h)	0.49	-	-	-	-
Working hours/yr	1000	1000	900	1000	900
Engine oil consumption (l/ha)	0.5	-	-	-	-

Lubricant cost (GH¢ /l)	6.21	-	-	-	-
Worker's salary (GH¢)	400	104	104	104	104
Number of Workers	1	16	64	32	16
Variable cost (GH¢/h)					
Fuel	15.54	-	-	-	-
Lubricant	1.52	-	-	-	-
Repairs & Maintenance	1.10	0.30000	0.00044	0.00040	0.00139
Labour	1.92	8.00	32.00	16.00	8.00
Total Variable Cost (GH¢/h)	**20.09**	**8.30**	**32.00**	**16.00**	**8.00**
Total Variable Cost (GH¢/y)	20089	8300	28800	16000	7201
Fixed Variable Cost (GH¢/y)	22894	9425	35.90	19.90	14.56
Total Cost per hour (GH¢)	**22.89**	**9.43**	**32.00**	**16.00**	**8.01**

APPENDIX 5: Correlation Analysis Results

- **Bulk Density, Cone Index and Moisture Content**

Akatsi

	CI-BP	CI-AP	CI-AH	MC-BP	MC-AP	MC-AH	BD-BP	BD-AP	BD-AH
CI-BP	1								
CI-AP	0.84479	1							
CI-AH	0.877935	0.993784	1						
MC-BP	-0.79164	-0.98609	-0.98693	1					
MC-AP	0.050321	-0.17475	-0.22479	0.335199	1				
MC-AH	0.944172	0.970268	0.986607	-0.94858	-0.14433	1			
BD-BP	0.960664	0.951093	0.974392	-0.92919	-0.14472	0.997533	1		
BD-AP	0.830386	0.928505	0.959648	-0.96209	-0.46008	0.944984	0.942857	1	
BD-AH	0.914901	0.558102	0.617727	-0.49251	0.1701	0.737159	0.778314	0.604839	1

Anwomaso

	CI-BP	CI-AP	CI-AH	MC-BP	MC-AP	MC-AH	BD-BP	BD-AP	BD-AH
CI-BP	1								
CI-AP	0.917867	1							
CI-AH	0.971675	0.973577	1						
MC-BP	0.985367	0.971904	0.991014	1					
MC-AP	0.982346	0.937491	0.954094	0.98535	1				
MC-AH	0.912278	0.992578	0.952851	0.966923	0.951398	1			
BD-BP	0.948199	0.982871	0.96311	0.984308	0.980519	0.99334	1		
BD-AP	-0.99513	-0.92917	-0.98559	-0.98621	-0.96637	-0.91241	-0.94194	1	
BD-AH	0.970905	0.831811	0.890915	0.933597	0.970911	0.849985	0.904983	-0.94337	1

Mampong

	CI-BP	CI-AP	CI-AH	MC-BP	MC-AP	MC-AH	BD-BP	BD-AP	BD-AH
CI-BP	1								
CI-AP	0.852463	1							
CI-AH	0.991562	0.896217	1						
MC-BP	0.415569	0.828492	0.49478	1					
MC-AP	0.923164	0.979348	0.960735	0.710071	1				
MC-AH	0.608701	0.907065	0.652021	0.945094	0.804104	1			
BD-BP	0.814576	0.997321	0.861889	0.865915	0.962256	0.933533	1		
BD-AP	0.695084	0.891312	0.782201	0.778284	0.900453	0.725497	0.885714	1	
BD-AH	0.898944	0.665349	0.906151	0.172229	0.802487	0.293851	0.609854	0.685957	1

- **Heart Rate, Energy Consumption and Rest Period**

	HR-Lab	HR-Tr Op	EC-Lab	EC-Tr	RP-Lab	RP-Tr
HR-Lab	1					
HR-Tr Op	-0.96833	1				
EC-Lab	0.999998	-0.96887	1			
EC-Tr	-0.96688	0.999983	-0.96743	1		
RP-Lab	0.995936	-0.94191	0.995737	-0.93996	1	
RP-Tr	-0.94645	0.997082	-0.94715	0.997505	-0.91352	1

CI – *Cone Index*

MC - *Moisture Content*

BD – *Bulk Density*

AP – *After Ploughing*

BP – *Before Ploughing*

AH – *At Harvest*

EC – *Energy Consumption*

RP – *Rest Period*

Lab – *Manual Labourer*

Tr Op – *Tractor Operator*

APPENDIX 6: Draught Force and Tractor Power Requirement Calculations

Assuming:

Drawbar Power/Brake Horse Power = 19%

Width of cut (TEK mechanical harvester) = 1 m

Now, taking TEK MCH 1 at Anwomaso with a draught force of 11.85 kN and an average depth of harvester penetration of 0.25 m (25 cm) and a working speed of 1.22 m/s,

Soil Specific Resistance = $\frac{Draught\,Force\,(kN)}{\text{width of cut (m)} \times \text{depth of cut (m)}} = \frac{11.85kN}{1\text{m} \times 0.25m} =$ **47.85 kN/m^2**

Drawbar Power = Draught force (kN) × Speed of travel (m/s)

= 11.85 × 1.22 m/s = **14.47 kW**

Brake Horse Power (Tractor Engine Power requirement) = Drawbar Power÷0.19

= 14.47÷0.19

= **76.16 kW**

Therefore, the minimum power required by a tractor in order to pull the TEK MCH 1 would be **76.16 kW (102 hp)**

APPENDIX 7: Some photos from harvesting trials

Figure i: Field being coppiced at Akatsi before harvesting

Figure ii: Harvesting with TEK MCH 6 at Akatsi

Figure iii: TEK MCH 1 (right) and TEK MCH 3 (left)

Figure iv: TEK MCH 2

Figure v: TEK MCH 5

Figure vi: TEK MCH 6

Figure vii: TEK MCH 4 hitched to a tractor in transport position

Figure viii: Shakers of TEK MCH 1 blocked by trash during harvesting

Figure ix: the IITA harvester prototype in operation at Anwomaso

Figure x: Using the probe to record harvester penetration depths at Anwomaso

Figure xi: Collecting soil samples with the soil auger at Mampong study site

Figure xii: The cone penetrometer in use to determine soil penetration resistance