INTERNATIONAL JOURNAL OF ENVIRONMENT
Volume-4, Issue-1, Dec-Feb 2014/15 ISSN 2091-2854
Received:8 February *Revised:16 February* *Accepted:19 February*

TRACTOR EFFECTS ON SOIL PROPERTIES AND THE CONSEQUENCES ON CASSAVA (*Manihot esculenta* Crantz) YIELD IN ULTISOL

I. D. Edem[1*], U.C. Udoinyang[2] and P.I. Udounang[3]
[1,2] Department of Soil Science and Land Resources Management, Faculty of Agriculture, University of Uyo, P.M. B.1017, Uyo, Akwa Ibom State, Nigeria
[3]Department of Crop, Faculty of Agriculture, Akwa Ibom State University
*Corresponding author: dennis.edem@gmail.com

Abstract

Physical degradation of the soil could be said to mean the loss of soil's structural quality. It is observed both on the surface where thin crust may be seen and also below th e surface in or below the ploughed horizon where compacted layers may be formed, particularly in conditions of excess moisture. The experiment assessed the influence of the weight of tractor passage on soil failure and compaction. The study of resistance to penetration is produced on three worked soils; unploughed, single ploughed and double ploughed at 0-30 and 30-60 cm depths. This study showed that the number of passage of the tractor affects resistance to penetration by 44 % compared to the initial state (passage 0) and the second pass makes accentuation of 11% relative to the first pass; which shows that the first pass performs compaction most important and most severe. Thus, after sometimes, it was noticed that there's a decrease compaction at 30-60cm depth which shows that the ground based of the ploughed soil experienced a decreasing compaction function.

Key words: *Manihot esculenta*, penetrometer, plough, resistance, soil compaction, soil properties

Introduction

Cassava (*Manihot esculenta* Crantz) is cultivated mainly in the tropic and sub-tropic regions of the world, over a wide range of environmental and soil conditions. It is very tolerant of drought and heat stress and produces well on marginal soils (Ekwere *et al.*, 2014). It is an important dietary staple in many countries within the tropical regions of the world (Perez and Villamayor, 1984), where it provides food for more than 800 million people (FAO, 2007). As a subsistence crop, *M. esculenta* is the third most important carbohydrate food source in the tropics after rice and maize, providing more than 60% of the daily calorific needs of the populations in tropical Africa and Central America (Nartey, 1978). According to Alexandratos (1995), *M. esculenta* plays an important role in alleviating food problems, because it thrives and produces stable yields under conditions in which other crops fail.

Soil ploughing is carried out with the objective of changing the soil physical properties and to enable plants to show full potential. This act of mechanization of agricultural activities often leads to soil compaction. It implies passages of more and heavier machines during agricultural operations. Thus, the practicability of a soil reflects its ability to accept the passage of machines (Vitlox and Loyen, 2002). Overuse of these machineries and improper management led to soils compaction. For many years, the trend in agriculture has been for increasing tractor size and weight, which increases the risk of severe soil compaction. The increasing engine size of the tractors also amplifies the demands on transferring power from the engine to draught force, i.e. using tyre equipment or tracks that can utilise the increasing engine power (Pagliai, 2003).

Soil penetration resistance is an important mechanical property that can be used as an indicator of soil compaction and it is important in determining the least limiting water range (Vitlox, 1998). Different types of penetrometer have been developed to measure soil penetrability (Lowery and Morrison, 2002). In this study, the dynamic soil penetrometer was used to measure soil mechanical resistance in the field. Soil resistance to penetration of a point is an indicator of the state of compaction and its evolution over time (Herrick and Jones, 2002). It is a complex function of parameters characterizing the state of a ground such as cohesion, angle of internal friction and friction metal underground (Batey, 2009). These parameters are dependent on water content and soil texture. Measures of the state of soil compaction using the penetrometer must be accompanied by measures of its water content near the points of measurement (Billot *et al.*, 1993).

Soil compaction by wheeled agricultural vehicles has a negative severe impact on the structural stability of arable soils; it affects crop production in both the short term and long term (Soane and Van Ouwerkerk, 1994). Abou-Zied *et al.* (2004) averred that the vehicles, and the magnitude and distribution of their contact pressures at the soil surface directly affect the topsoil and its substrata. Soil compaction due to field machinery traffic is observed at the depth, which is the cumulative effect of deformation beneath the surface. Accordingly, it is important to control the mechanical impact of the farm machinery on the structure of arable soil, in order to reduce soil degradation (Padam *et al.*, 2014).

When a soil is compacted, the soil properties are altered, and a reduction in soil water and roots can occur (Batey, 2009). In Tunisia, the agriculture sector has resorted to crop intensification through irrigation systems, whereas these systems offer the possibility of greater diversification and intensification which is consistent with the use of machinery (FAO, 2001). It can increase yield and land productivity, especially when it is well suited to local conditions. But application of machines on the intensively cultivated land over two growing seasons when the soil is moist, may results in higher sensitivity to soil compaction (Hakansson *et al*, 1988), and this may greatly affect the yield of *M. esculenta* growth on marginal soil, especially in humic tropics.

Therefore, this work was designed to study the effect of the tractor weight and the influence of number of passage during ploughing on the physical and mechanical properties of soil as well as growth and yield of cassava (*M. esculenta)*.

Materiels and methods

Experimental site and soil

The study was conducted at the Faculty of Agriculture Teaching and Research Farm of the University of Uyo. Uyo is located between latitudes 4^0 30^1 and 5^0 3^1N and longitudes 7^0 31^1 and 8^0 20^1 E (Ogban and Ekerette 2001). The state has an estimated area of 8, 412 km^2. It is characterized by two seasons; a wet season that last for seven (7) months (April – October) and a five (5) months dry season (November-March). The annual rainfall ranges from 2000-3000 mm, while annual temperature varies between 26 ^oC and 28 ^oC. Relative humidity is high varying from 75-95% with the highest and lowest values in July and January respectively. Soil textures ranged between loamy sand and sandy loam.

Field experiment

Land Preparation sample collections

The research was conducted in two field with different land use system: the first was under continous cassava cultivation while the other was under four years of fallow. Both lands were manually cleared with machete and ploughed at 15% soil moisture content. The fields were treated to conventional tillage using moldboard plough (30 cm depth), and disc harrow (about 10 cm depth) for a long period of time. Soil samples were extracted from 30 cm soil depth interval using an auger. Hundred and twenty diffrent soil samples were collected within 60 × 60 m^2 grid for soil moisture determinations (gravimetric method) after oven-drying at 105 ^oC. In the laboratory, collected soil samples for the determination of physical characteristics were air dried, ground and passed through 2.0 mm sieve.

Measurement of penetration resistance

In this study, an assessment of the impact of the change in weight of the tractor and the multiplication of passages was performed using the penetrometer. The initial state of the soil moisture was characterized by measuring the water content in soil followed by the parameter measurements made to characterize the state of compaction on the ground just before and after each passage of the machine. Moreover, this operation of penetrometer test was repeated same day after 5-6 hours to characterize the evolution of soil compaction over time. The experimental devices have been adopted for the two treatments, with three replications at the two (2) depths.

Soil resistance data were collected at the vertexes of regular squared grids. In the undisturbed, single and double tractor runs (passages) in a 10 × 12 m^2 field. This unit is composed of cone connected to a piston (rod). A handle on the upper end is used to force the cone into the soil slowly against its body so that the low side reads zero after removing the red protective cap. Penetrometer resistance measurements were made by pushing vertically the penetrometer to the soil. This piston insertion continue until the engraved mark is leveled with soil. Also index was defined from the insertion force over the cross sectional area of the base of the cone.

During the experimental period, penetration resistance of the soil under the wheel tracks, between the wheels tracks in the ploughed area after each traffic tractor, as well as on an adjacent un-ploughed area were measured.

Analyses and determinations of soils' characteristics

Laboratory methods of analyses were carried out on soil samples for particle size distribution, pH (soil reaction), organic matter contents, total nitrogen, available phosphorus and exchangeable cations (K, Ca, Mg and Na).

Particle size analysis:

Particle-size distribution of a soil sample sieved through 2 mm mesh was determined in using Day's hydrometer method (Udo *et al* 2009) after oxidation of the organic matter with hydrogen peroxide (H_2O_2).This was followed by particle dispersion with sodium hexametaphosphate solution $(NaPO_3)_6$ (Gee and Or, 2002). Air dried sample was measured 50 g into stirring cup and 10 ml of sodium hexametaphosphate and 250 ml of water was added and stirred in the mechanical stirrer for 5 mins. The suspension was then poured into a 1000 ml cylinder through 210 µm sieve; water was then added up to the 1000 ml mark on the cylinder. The residues (sand fractions) in the sieve were transferred into a moisture Can and oven dried for percent sand determination as shown in equation (1) below. The filtrate was used to determine silt and clay through sedimentation principle.

Sand % = = Ovd_{wt}/ Wt of soil x 100 (1)

Where,

Ovd_{wt} = weight of oven dried sand sample and

Wt of soil = weight of air dried soil sample used

Bulk density was estimated by dividing the oven dry mass of the soil by volume of the soil as described by Grossman and Reinsch (2002).

$$BD\ (g\ cm^{-3}) = \frac{Ms}{Vs} \quad (2)$$

Where: BD = Bulk Density (g cm^{-3})

Ms = mass of oven-dried soil samples (g)

Vs = total volume of soil (cm^3), (solid + pores)

The total volume of the soil was calculated from the internal diameter of the core cylinder. Total porosity was calculated from bulk density assuming particle density of 2.65g cm^{-3} as described by (Gee. and Or, 2002).

Soil moisture determination

The variation of the penetration depends on soil moisture (Kai, 2008). To this end, measures the resistance to penetration were carried out with monitoring of depths of water content by weight at each treatment by the following method: Samples were taken every 15 cm to a depth of 130 cm, the sampling was performed using a hand auger; The wet sample was weighed, and after oven drying at a temperature of 105 °C for 24 hours, the dry weight was also measured. Determination of the water content was achieved by the weighing difference (before and after drying). Water content as shown in the following expression:

$$MC(\%) = \frac{MWS - MDS_s}{MDS} \times 100 \quad (3)$$

Where,
MC = moisture content, MWS = mass of wet soil sample;
MDS = mass of dry soil sample.

Saturated hydraulic conductivity was determined using constant head parameter method according to Darcy's procedures (Klute, 1986). The saturated core samples were placed in funnel, resting on a tripod stand after the constant head cylinder was placed on top of it and fastened together using marking tape: A constant head of water was maintained throughout the period of the experiment. The flux of water passing through the soil column was collected in a measuring cylinder and readings were attended in each of the samples and expressed as follows:

$$U = -K\frac{dh}{dz}, \quad (4)$$

Where, U is Darcy's velocity (or the average velocity of the soil fluid through a geometric cross-sectional area within the soil), h is the hydraulic head, and z is the vertical distance in the soil. The coefficient of proportionality, K is the hydraulic conductivity (Ksat)

Water stable aggregates (WSA) were determined using wet sieving methods described by Nimmo and Perkins (2002) and Hubbert (2006). Also 100 g of moist soil sample at 0-15 cm and 15-30 cm depths were placed on a nest of sieves (2, 1, 0.5 and 0.25 mm). The nests of sieves were cycled through a column of water for 10 minutes (10 cycles per mm). The percentage of water stable aggregate (WSA) and means weight diameter (MWD) fraction of the total sample were calculated, a statistical index of aggregation was calculated from aggregate size distribution data after correction had been made for sand fractions by dispersion with sodium hexametaphosphate using this formula:

$$MWD = \sum_{i=1}^{n} XiWi \quad (5)$$

Where, MWD = mean weight diameter of each size fraction (mm) and w1 the proportion of total sample in the corresponding size fraction after deducting the mass of stones (upon dispersing and passing through the 210 µm sieve)

Soil colour determination

The colour of the soil was determined insitu using Munsell colour chart. The colour of the soil is dark brown on the top, changing to light brown in the subsoil. The dark colour on topsoil could be related to high content of plant debris and root of different stages of decomposition.

Planting of cassava cuttings

Improved cassava *M. esculenta* cultivar used was TMS 30572 obtained from National Root Crop Research Institute at Umudike, where viable cuttings of 20 cm length were planted at 1 x 1 m on the different degree of ploughed land.

Weed Control

Weeding were carried out manually using weeding hoe and machete at 4, 8 and 16 weeks after planting and followed up routinely to maintained weed free farm through the growing period.

Measurements of growth and yield parameters of cassava

During growth seasons and at the time of harvesting, different parameters such as plant height, stem diameter, number of leaves per plant, leaf area index, number of tubers per strip, average tuber diameter, average weight of each tuber and the tuber yield of plant within plots were recorded.

Statistical Analysis

Laboratory and field data collected from the treatment sets were subjected to statistical analyses. ANOVA was performed using MegaStat computer software 9.1 for Windows. Means were subjected to Duncan Multiple Range Test (DMRT). Significant difference among the parameters was concluded when the probability has a difference by 0.05.

Results and Discussion

The objective set by this work was to study the compaction of soil by repeated tractor traffic. Table 1 shows the mean difference of soils' physical parameters in unploughed, single and double ploughed fields.

Particle size distribution

Particle size distribution in the experimental plot followed a particular trend of dominant clay in the sub-surface soil of the three treatments while sand fraction decreased with depth.

Moisture content

The characterization of soil compaction has been determinate by water retention characteristics and soil resistance to penetration. The initial state of the field before passing the tractor was characterized by an initial series of measurements. First, measurement of the average water content over a depth of 0-30 and 30-60 cm that characterizes the initial state of soil was done (Table 1). The results of the measured moisture content at 0-30 and 30-60 cm showed that the moisture decreased with the depth. Moisture decreased from 10.98 to 6.84%, between 30 to 60 cm depths in the unploughed plots, from 10.11 to 6.64 and 13.23 to 7.00% in single and double ploughed plots of the same depths respectively.

Bulk density

Bulk density in the field varied from treatment to treatments. In the unploughed field, it ranged from 1.40 to 1.57 g cm^{-3} and from 1.65 to 1.68 g cm^{-3} and , 1.73 to 1.85 g cm^{-3} in the single and double ploughed respectively for 0-30 and 30-60 cm depths. Generally, bulk density increased down the depth. Beyond 30 cm depth double passage of the tractor increased the bulk density above the threshold value for sandy soils (El-Haris, 1987). This indicates that double pass increased the bulk density of the soil and this negative severe impact on the structural stability of arable soils as it affects cassava production (Soane and Van Ouwerkerk, 1994).

Aggregate stability and soil water movement

It was also evident from Table 1 that, after the passage of tractor, there was alteration and increase in aggregate stability (Arvidsson et al., 2011) which could lead to increasing stability against erosion, but with attendance compaction observed, soil water movement via saturated hydraulic conductivity was impeded (especially on the area with double pass), hence increased surface runoff. Therefore, to improving this soils' fertility, organic materials and mulching practices are imminent.

Table 1.Particle size analysis, bulk density and moisture properties of soils in the study site.

Treatments (No. of Ploughing)	Depths	Sand	Silt	Clay	Texture	Bulk density	MC	MWD	Ksat
	(cm)	←	%	→		g cm^{-3}	%	mm	Ksat (cm/hr)
Control	0-30	88.40	3.20	8.40	LS	1.40	15.98	0.60	9.86
	30-60	86.40	3.20	10.40	LS	1.57	6.84	0.40	3.36
Single ploughed	0-30	86.40	7.20	6.40	LS	1.65	10.11	0.91	1.76
	30-60	84.40	7.20	8.40	LS	1.68	6.64	1.02	0.62
Double ploughed	0-30	80.40	7.20	12.40	LS	1.73	13.23	1.11	0.23
	30-60	78.40	11.20	10.40	SL	1.85	7.00	1.35	0.11

LS = loamy sand, SL = sandy loam, MC = moisture content, MWD = mean weight diameter, Ksat = saturated hydraulic conductivity.

Characterization of the penetration resistance

After each passage of the tractor, a series of measured resistance to penetration at the tracks of wheels was carried out to characterize the soil conditions. At the surface soil of 0–30 cm, the penetration resistance increased gradually after the initial state (unploughed). Passage of tractor for single and double ploughs which shows the compaction of soil with the weight of the tractor. The compaction increases from 76% at the transition of the first tractor to 85% at the second tractor (Fig. 1).

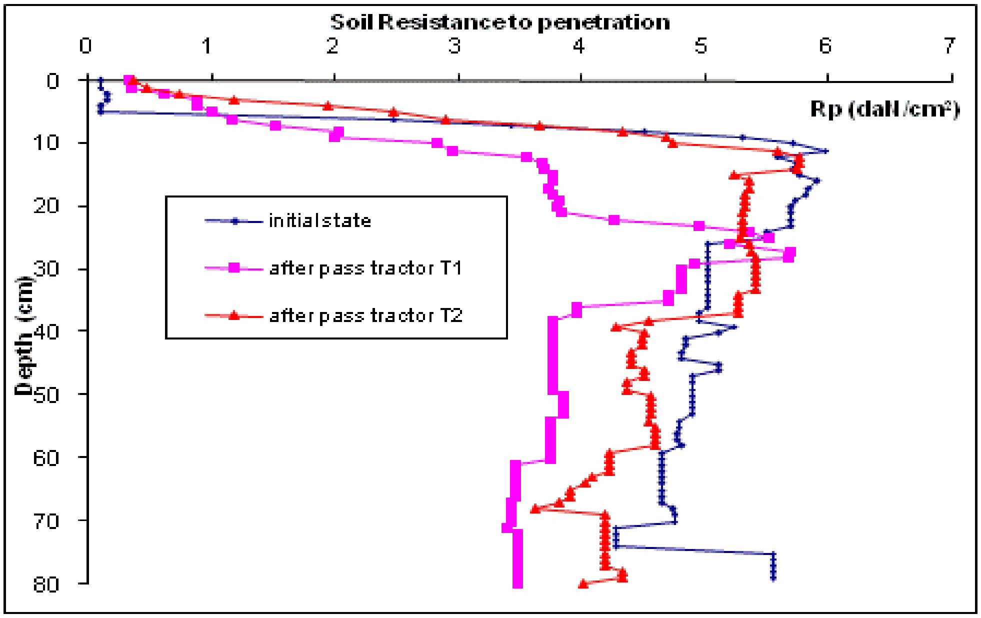

Figure 1. **Measure of soil resistance to penetration in unploughed, following first and second tractor passages.**

The analysis of this result shows that the resistance increases as a result of the passage of multiple tractors. Measurements taken at 30 cm depth show that after a passage of tractor in single plough, there was increasing resistance to penetration that exceeds 70% compared to the initial state. Also the second passage shows an increase of 44% compared to the first passage. This agrees with the results of Elaoud and Chehaibi (2011) that tractor passage increases the penetrometer resistance of the soils. Examining the results of the penetration resistance (Figure 2) shows that resistance decreases with time.

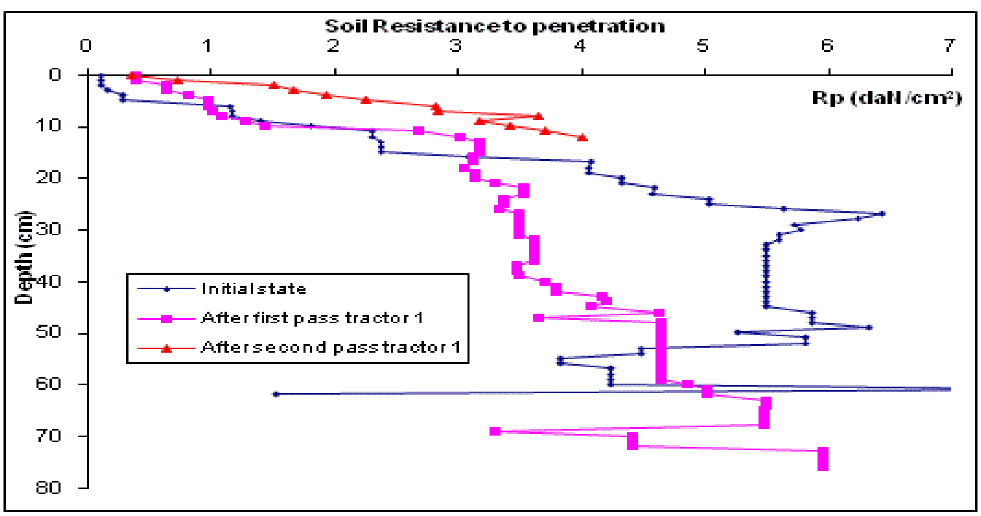

Figure 2. **Measure of soil resistance to penetration as a function of time.**

When comparing the results of the penetration resistance to the initial state of the soil, a regression and reduction of the resistance were observed. This indicates a decreased compaction with time (decompaction by natural aeration with time). At a depth of 0-30 cm, the penetration resistance (Rp) was 1.61 MPa at initial state, and after 8 hours period, Rp decreased to 0.94 MPa. This shows a decrease of 53% in the space of 8 hours. Also, it was noticed that in some areas, over time the resistance to penetration increased. In 30-60 cm, Rp value increased from 1.56 to 2.02 MPa.

According to Lindstrom and Voorhees (1994), the pressure of the wheels of the tractor (from the weight of the tractor) imposed pressure on the soil, hence caused the soil pores to be tortuous and thereby causing soil compaction. These showed that when the moisture content is less than 15%, the penetration resistance increases with it. As shown in Table 1, the average moisture content decreased compared to baseline and remained below 15.98 %.

The report of Miyoshi (1972) noted that the penetration resistance of soil to 10 daN/cm^2 was defined in Japan as the threshold for very severe constraint to rooting for a variety of cultures and on different soil types. As different authors have stated different extreme values for soil compaction, this research used 2 MPa as a threshold for separating compaction from uncompacted soil because the soil's porosity is within the satisfactory scale for tropical agricultural soil (Kachinskii, 1970).

Therefore, increase in the number of passes increased soil compaction, although, the first passage density was less than the second. Statistical analysis of measurements and separation of significant means were done according to Duncan test at 0.05 level of probability as shown in Table 2.

Table 2. ANOVA results for soil resistance to penetration data.

Source of variation	D.F.	M.S.
Tractor passage	1	14.90**
Depth	29	17.66**
Error	96	0.005

**: significant at the 0.01 level.

Statistical analysis of soil resistance to penetration data show highly significant ($P < 0.01$) effects of the tractor passage number and the depth on soil resistance (Table 2.). The higher resistance corresponds to the second passage whereas the lowest occurs after the first passage of the tractor.

Table 3. Means comparisons of soil resistance to penetration as a function of the tractor passage number

Passage number	Soil resistance to penetration (MPa)
0 (initial state without tractor passage)	4.27^c
1	2.40^a
2	2.82^b

Statistical comparison performed at this level of penetration resistance in the number of passing parameter shows that the lowest intensity was performed after the first pass (Table 3). At 60 cm depth, statistical analysis of soil resistance to penetration data show highly significant effects (P <0.01) of the higher resistance corresponds to the first passage whereas the lowest occurs after the second passage of the tractor (Table 4).

Table 4. ANOVA results for soil resistance to penetration data at 60 cm depth

Source of variation	D.F.	M.S.
Tractor Passage	1	2.52**
Depth	59	9.33**
Error	90	0.016

**: significant at the 0.01 level.

The statistical comparison performed at 60 cm level of penetration resistance in the number of passing parameter shows that the lowest intensity was performed after initial state and after the first pass (Table 5). Considering the statistical analysis, it is clear that the results are highly significant mainly for the first tractor passage weight and further number of passes is variable depending on the track work and of depth not exceeding 30 cm.

Table 5. Means comparisons of soil resistance to penetration as a function of the tractor passage number at 60 cm depth

Passage number	Soil resistance to penetration (MPa)
0 (initial state without tractor passage)	1.56^{a}
1	1.61^{b}
2	2.02^{c}

Morphological characteristics of cassava

The cassava in the three treatments was evaluated for morphological characteristics. Stand establishment was very good for the ploughed plots (experimental plots). There were no visible signs of pests and diseases on the leaf, stem or root parts in any of the treatments during the period of this experiment. There was loss of foliage mostly in the ploughed plots during the short dry spell from November 2012 to February 2013, but this had no effect on the tuber yields (Fig. 3), except that there were more broken and damaged tubers during harvesting in the unploughed plot and that contributed to lesser yield observed in the unploughed plots.

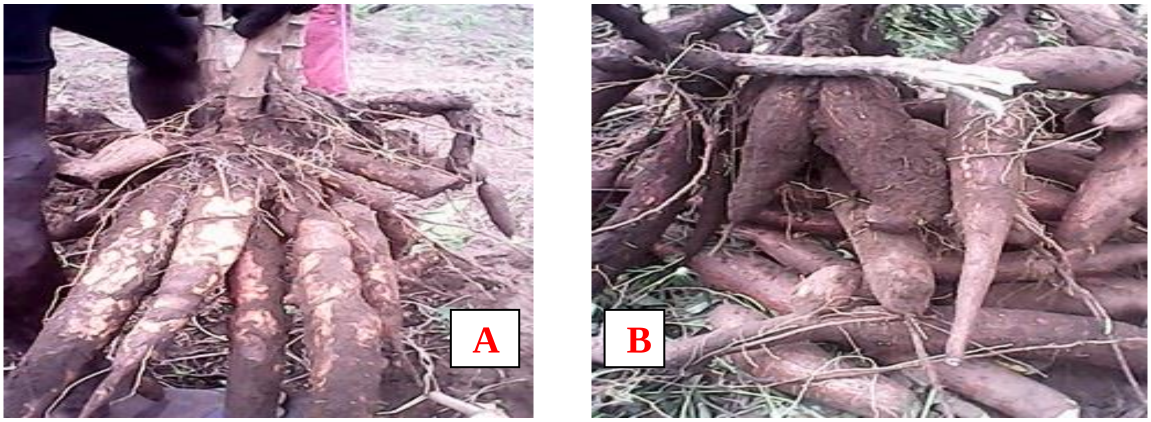

Fig. 3. Freshly harvested cassava *M. esculenta* tubers from plouged (A) and Unploughed (B) plots

The analysis of variance test performed tuber yield revealed significant differences between the three worked soils for all root yield responses measured. Analysis of data (Table 6) showed a statistical significance of 0.01 level of confidence for the root measurements.

Table 6. ANOVA for root yield response measurement for three tractor ploughed soils

		Significance level				
Source of variation	df	Total tuber wt plant^{-1} (kg)	Total No. of tubers plant^{-1}	Tuber length (cm)	Marketable wt plant^{-1}	Unmarketable wt plant^{-1}
Treatments (No of tractor passage)	2	**	**	**	**	**
Error	119	2.3	1.5	1.2	0.3	1.6

** denote statistical difference at 0.01 level of confidence.

Root yields were determined by the length, weight and number of storage tubers produced per plant. The tubers were separated into marketable and unmarketable tubers, depending upon size and weight. Total tuber yield of the ploughed soils ranged from 7.81 kg per plant for double tractor passage to 2.96 kg per plant for the unploughed soil. Of these three levels of tractor passages, double tractor passage had the highest number of marketable tuber per plant and marketable weight per plant. Single plough produced the highest number of tubers, though with far less tuber length and unmarketable tuber per plant (Table 7). This result supports the data of Hayford (2009), whose research showed that a negative correlation existed between number of tubers per plant and tuber mean weight of cassava. The result of competition between the roots during root filling could be responsible for lower tuber mean weight of cassava when the number of cassava tubers per plant increases.

Table 7. Means of root yield responses assessed 10 months after planting cassava (*M. esculenta*) in three different worked soils.

Tractor passages	Total tuber wt plant^{-1} (kg)	Total No. of tubers plant^{-1}	Tuber length (cm)	Marketable wt plant^{-1}	Unmarketable wt plant^{-1}
Initial state	2.96^{c}	11.25^{a}	25.58^{c}	2.63^{b}	9.24^{a}
1	5.64^{b}	7.78^{b}	40.65^{a}	7.69^{a}	2.31^{b}
2	7.81^{a}	5.99^{c}	38.47^{b}	8.12^{a}	1.85^{c}

1 = after first phase of tractor passage, 2 = after second phase of tractor passage

Conclusion

The study of the effect of ploughing on the physical and mechanical properties of soil revealed that passage number influence the weight and the degree of soil compaction. Increase in weight on the ground transmits a steeper pressure that leads to a higher compaction that affects the yield. Therefore, to minimize the compaction of the soil is to use a small tractor, or tractor with wider tires that can change and distribute more of the force of weight inorder to reduce compaction and increase yield. The average penetrometer profiles were closely related to the number of passage and it was observed that the first passage was most important especially at the impact of the settlement; it is for this reason that it is necessary to choose the best condition in the first passage (water content, weight of vehicle, tire wheels). The time parameter measured in this work shows that over time (few days after compaction) soil decompact by natural effect (air absorption). Thus, as a solution to decrease soil compaction, integration of organic matter is necessary. Also, reduced number of passes is the best solution to avoid soil compaction. It has also shown in this study that, differences in total tuber weight per plant (kg), total number of tubers per plant, tuber length (cm), marketable and unmarketable weight per plant depended on the level of tractor passages.

References

Alexandratos, N., 1995. World Agriculture: Towards 2010. An FAO Study, New York: Food and Agriculture Organization of the United Nations; John Willey and Sons.

Arvidsson, J., Westlin, H. T., Keller, M., Keller, G., 2011. Rubber track systems for conventional tractors – Effects on soil compaction and traction. Soil & Tillage Research 117, 103-107.

Batey, T., 2009. Soil compaction and soil management. Soil Use and Management, 25: 335–345.

Billot, J.F., Aubineau M. and Autelet R., 1993. Les matériels de travail du sol, semis et plantation. Paris: CEMAGREF/ITCF/TEC & DOC, 384p.

Elaoud A., Chehaibi S., 2011. Soil compaction due to tractor traffic. Journal of Failure Analysis and Prevention JFAP - DOI 10.1007/s11668-011-9479-3, p539-545.

El-Haris, M. K., 1987. Soil spatial variability: Areal interpolation of physical and chemical properties. Ph. D. dissertation. Univ. of Arizona, Tucson.

Ekwere, G. E, I. D. Edem, Agbasi, O. E., 2014. Adoption of Root and Tuber Technologies among Farmers (Agricultural Development Programme. International Journal of Environment. 3 (4): 117-132.

FAO (Food and Agriculture Organization of the United Nations) Yearbook, (2007). Website: www.fao.org.

FAO. 2001. Systèmes de production et pauvreté. Améliorer les moyens d'existence des agriculteurs dans un monde en changement. Moyen-Orient et Afrique du Nord, 4 p.

Gee, G. W. and Or, D., 2002. Particle size analysis. In: J. H. Dane and G. C. Topp (eds.) Methods of soil analysis. Part 4, Physical Methods, SSSA, Incorporated, Madison, 255–294.

Grossman, R. B. and Reinsch, T. G., 2002. Bulk density and linear extensibility: Core method. In: J. H. Dane and G. C. Topp (eds.) Methods of soil analysis. Part 4, Physical Methods, SSSA, Incorporated, Madison, pp 208–228.

Hakansson L., Voorhees W.B. & Riley, H., 1988. Vehicle and wheel factors influencing soil compaction and crop response in different traffic regimes. Soil & Tillage Res. 11, 239- 282.

Hayford, M.A., 2009. Growth, Yield and Quality of Cassava as Influenced by Terramend 21, Poultry Manure and Inorganic Fertilizer. Master of Agronomy Thesis, School of Graduate Studies, Kwame Nkrumah University of Science And Technology (KNUST), Kumasi.

Herrick, J.E., Jones, T.L., 2002. A dynamic cone penetrometer for measuring soil penetration resistance. Soil Science Society of America Journal 66, 1320-1324.

Hillocks, R. J., Thresh, J. M. and Bellotti, A. C., 2002. Cassava; biology, production and utilization. New York: CABI Publishing.

Hubbert, K.R., Preisler, H.K., Wohlgemuth, P.M., Graham, R.G. and Narog, M.G., 2006. Prescribed burning effects on soil physical properties and water repellency in a steep chaparral watershed, Southern California, USA Geoderma.139:284-298.

Kachinskii, N. A. 1970. Soil Physics, P. I. Moscow. Pp 177.

Kai, C., 2008. Vers une approche hydro-mécanique du comportement des sols cultives: Expérimentations et simulations.Thèse de doctorat à l'Institut des Sciences et industries du vivant et de l'environnement-Agro Paris Tech.

Lindstrom, M.J. and Voorhees, W.B., 1994. Responses of Temperate Crops in North America to Soil Compaction. In: Soil Compaction in Crop Production.

Lowery, B., Morrison, J.E., 2002. Soil penetrometers and penetrability. In 'Methods of Soil Analysis, Part 4, Physical Methods'. Eds. JH Dane, GC Topp pp. 363-388. Soil Science Society of America, Inc.: Madison, WI.

Miyoshi, H., 1972. Effective layer for upland field from a view point of suitable soil condition for root development. Soil Sci. Plant Nut., Vol 43, (3) 92-97.

Nartey, F., 1978. *Manihot esculenta* in Africa: Utilization as human food and animal feed. Munksgaard, Copenhagen. pp: 42-43.

Ogban, P.I., Ekerette, I.O., 2001. Physical and Chemical Properties of the Coastal Plain Sand of South Eastern Nigeria Nigerian J. Soil Resources 2:6-16.

Padam, K. D., Lalita, l., Sarina, K., Sazina, P., Bhawana, K., 2014. Environmental Impact Assessment of Kathmandu Terai Fast track. *International Journal of Environment*. 3(4):1-11.

Pagliai, M., Marsili, A., Servadio, P., Vignozzi, N. and Pellegrini, S., 2003. Changes in some physical properties of a clay soil in central Italy following the passage of rubber tracked and wheeled tractors of meduim power.Soil Tillage Res. 73, 119-129.

Perez, R. D. and Villamayor, F. G., 1984. Relationships among specific gravity, dry matter and starch contents of cassava roots. National Science and Technology Authority Technology Journal 9 (2), 18-22.

Soane, B. D. and Van Ouwerkerk, C., 1994. Soil compaction problems in word agriculture. Elsevier, Amsterdam, Netherlands. pp.1-22.

Udo, E. J., Ibia, T. O., Ogunwale, J. A., Ano, A.O. and Esu, I. E., 2009. Manual of Soil, Plant and Water analysis Sibon Books Limited, Lagos. Pp 26.

Vitlox, O., 1998. Répartition de la pression de contact des pneumatiques déterminée par la mesure de déformation du sol.Journée à thème conjointe de Pédologie et de Génie Rural, FUSAGx-Gembloux,pp.65-69.

Vitlox, O. and Loyen, S., 2002. Conséquences de la mécanisation sur la compaction du sol et l'infiltration de l'eau. Compte rendu de la journée d'étude: Erosion hydrique et coulées boueuses en Région Wallonne, pp. 45-58.