International Journal of Research Studies in Science, Engineering and Technology
Volume 7, Issue 2, 2020, PP 7-22
ISSN : 2349-476X

Determination of Zinc Requirement of Cassava (*Manihot Esculenta* Crantz) in Soils Derived from Coastal Plain Sands of South Eastern Nigeria

UGWU, C. C.[1], Asawalam, D. O.[1], Eteng, E. U.[1*], Ano, A. O.[2]

[1]*Department of Soil Science and Meteorology, Michael Okpara University of Agriculture, Umudike, Nigeria*
[2]*National Root Crops Research Institute, Umudike, Nigeria*

***Corresponding Author:** Eteng, E. U., Department of Soil Science and Meteorology, Michael Okpara University of Agriculture, Umudike, Nigeria, Email: eteng_em@yahoo.com*

ABSTRACT

The zinc requirement of Manihot esculenta in soils derived from coastal plain sands in South Eastern Nigeria was investigated in Abia, Akwa Ibom and Imo States. A portion of the soils were processed for laboratory routine analysis to establish the physical and chemical properties of the soils. Available content of extractable Zn in the soils were evaluated using five different extract ants (Coca-Cola solution, 0.5M EDTA, 0.5M EDTA+ 1.0 N NH40Ac, 0.1N HCl and 1.0 N NH40Ac). The other portion of the soils collected were used to set up pot experiment in the greenhouse in which different rates of zinc (0, 2.0, 4.0, 6.0, and 8.0 kg Zn ha-1) formed the treatments. Zn uptake was correlated with extractable Zn. Based on the calibration curves obtained from the pot experiment, field experiment was established in each of the three States to calibrate the greenhouse study. The experimental treatments were levels of Zn fertilizer (0, 4.0, 8.0, 12.0 and 16.0 kg ha-1). Root yield of cassava tubers were determined among other parameters. Results showed that mean cassava root yields obtained for first- and second-year planting seasons were 12.3 t ha-1 when optimum rate of Zn fertilizer (10.58 kg Zn ha-1) was applied. This study showed that Zn was limiting to cassava production in soils derived from coastal plain sands of South Eastern Nigeria and 10.58 kg ha-1 was required to meet the needs of cassava adequately.

Keywords: *Cassava,*

INTRODUCTION

Of all root and tuber crops, Cassava (*Manihot esculenta* Crantz) is the most important and ranks 4th after rice, sugarcane and maize as a source of calorie for human needs (CIAT, 1992). Nigeria is the world's leading producer of cassava with over 54.8 metric tonnes (FAO, 2015; IITA, 2016).

Although farmers in South Eastern Nigeria grow both local and various genetically improved cassava varieties with high yielding potential, crop yields have been observed to be very low, rarely exceeding 20 t ha^{-1} in an average farmer's field (Chude *et al.*, 2004; CBN, 2003; FFDD, 2002). The low root crops yield gave rise to the suspicion of possible deficiencies of other important essential nutrients. Chude et al., (2004) attributed the low cassava root yield obtained on farmer's field to deficiencies of micronutrients such as Zn, Fe, Cu and Mn in Coastal Plain Sands soils of South Eastern Nigeria.

Enwezor *et al*., (1990) working on coastal plain sands of south eastern Nigeria obtained positive responses of cassava to micronutrient fertilizer on soils having about 4 mg kg^{-1} Zn, 12 – 14 mg kg^{-1} Fe and 5 – 15 mg kg^{-1} Mn. Also, Eteng, (2006) while working on soils of contrasting parent materials in SE Nigeria, obtained low to moderate responses of maize plant to micronutrient fertilizer applications.

I Investigations carried out so far have revealed that there is micronutrients deficiency in some coastal plain sand's soils of South Eastern Nigeria (NFC, 1990; Chude *et al;* 2004; FFDD, 2002; Eteng *et al.*,2014). Though a large percent of food crops (maize, cassava, yam, potato, etc), tree crops (cocoa, oil palm, citrus, pineapple, etc) and assorted vegetable crops consumed in Nigeria, are produced in South Eastern Nigeria, yields of these food crops have been below optimal due in part to soil infertility.

Manihot esculenta has been adjudged as one of the most important root crops in the world, and has contributed greatly to the economic growth (FAO, 2013). Cassava is a high-value root crop consumed in many households in different parts of Nigeria as staple food and it constitutes important ingredient and raw material in animal feed production, brewing industry, bakery industry and as starch in textile industry (FAO, 2008; IITA, 2013). However, sustained cultivation of cassava has been marred by decreased land productivity that is linked to soil infertility. Soil infertility has been identified as one of the major factors militating against food production, including cassava production in South Eastern Nigeria (Anikwe and Eze, 2010; Gichuru *et al.*, 2003).As crop nutrient removal increased with high yields of improved crop varieties, soil reserves of plant nutrients, particularly micronutrients that are not part of common fertilizers become depleted, resulting in nutrient deficiencies and lower yield. Consequently, there is need to determine the requirements of micronutrients particularly Zn, for cassava production popularly grown in soils derived from Coastal Plain sands in South Eastern Nigeria.

Materials and Methods

Study Area and Soil Sample Collection

Soil samples were collected from fallow plots of between 2-5 years at a depth of 0-20 cm.

Soils were collected from ten sampling locations reflecting 10 local government areas in each of Akwa Ibom, Abia, and Imo States (Table 1). A total of 30 composite samples were collected from the study area with each sample weighing about 15 kg for the laboratory and greenhouse studies.

The soil samples were air-dried and sieved through a 2.0mm sieve and a portion of it was collected for physical and chemical analyses.

Table1. *Sampling locations by state in the coastal plain sands soils of southeastern Nigeria*

ABIA STATE		AKWA IBOM STATE		IMO STATE	
Sampling point	**L.G.A**	**Sampling point**	**L.G.A.**	**Sampling point**	**L.G.A.**
Ariam	Ikwuano	NEPA Line	Uyo	Umulogho,	Obowo
Ihie Olokoro,	Um. South	Ndon Itak	Ikono	Mbeke,	Isiala Mbano
Nsulu	Isialangwa N.	Obot	Ikot Ekpene	Ogbaku,	Mbaitoli/Ikeduru
Ntigha	Isialangwa N.	Nong Udo	Ibesikpo	Obinze,	Owerri East
Obehie Asa	Ukwa West	Ndon Ebom	Oron	Umuagwo,	Ohaji/Egbema
Umuawa Alaocha	Um. North	Essiet Iboko	Etoi	Nkwerre,	Nkwerre
Umudike	Ikwuano	Ikot Akpan	Essien Udim	Umuezugwu,	Ihitte Uboma
Umuoba	Isialangwa S.	Mbang	Uruan	Nguru	Aboh Mbaise
Umuocham Abayi	Aba North	Abak Ikpo	Abak	Umuebela Okporo	Orlu
Umuosu Ubakala	Um. South	Ikot Ewang	Itu	Airport Rd	Ngor Okpuala

Laboratory Analyses

The laboratory analyses of soil physical and chemical properties was conducted at the soil science laboratory of the National Root Crops Research Institute, Umudike.

Particle size analysis was determined by the Hydrometer method as reported in Gee and Or (2002).

- Soil Reaction (pH) was carried out using the electronic method which determines the soil pH in water and 0.1 N KCl suspension of 1:2.5 soil-water solution using an electrode pH meter.
- Organic Carbon (OC) was determined by the chromic acid wet oxidation method as modified and described by Nelson and Sommers (1982). It involves the oxidation of organic carbon by potassium dichromate in the presence of sulphuric acid - (H_2SO_4) and then titrated with ferrous ammonium sulphate – $Fe(NH_4)_2SO_4$. The values for organic matter (OM) was obtained by multiplying the organic carbon values by Van Bremelen factor of 1.724 based on the assumption that soil organic matter contains 58% carbon.
- Total nitrogen (TN) was determined by the semi-micro Kjeldahl method. Nitrogen in the soil sample was converted to ammonium sulphate by digesting the sample with concentrated sulphuric acid in the presence of a sodium-copper-sulphate catalyst mixture (Bremner and Yeomans, 1988). The ammonia liberated by distillation of the digest with 40% sodium hydroxide was titrated with standard dilute hydrochloric acid.
- Carbon/Nitrogen (C/N) Ratio was determined by computation of carbon and nitrogen values (Brady and Weil, 1999).
- Available phosphorus (P) was extracted by Bray-2 solution method. (Olsen and Sommers, 1982).

- Exchangeable Cations (Ca, Mg, K and Na) in the soil was extracted by displacement with 1.0N NH_4OAc at pH 7.0, using the saturation method, while the exchangeable Ca and Mg were determined by EDTA complexometric titration method by Thomas (1982); K and Na was measured photometrically using EEL flame photometer.
- The Exchangeable Acidity (EA) was determined by extracting 5g of soil with 1.0N KCl and titrated with 0.5N NaOH using phenolphthalein indicator (Mc Clean, 1982).
- Effective Cation Exchange Capacity (E C E C) was determined as the sum of the basic cations (Ca^{2+}, Mg^{2+}, k^+ and Na^+) and the exchangeable acidity.
- Percentage base saturation was calculated as follows:
  - % base saturation (% BS) = (Ca^{2+}+ Mg^{2+}+ k^+ + Na^+)/ ECEC x 100
- Extraction of Available Micronutrients (Zn, Fe and Mn). Available Zn, Fe and Mn contents of the soil samples were extracted with the following extractants.
  - Coca-Cola solution (Schnug et al., 2001).
  - 0.5M EDTA (Bloomfield and McGrath, 1982);
  - 0.5M EDTA + 1.0N NH4OAc (Lekanem and Ervio, 1971);
  - O.1N HCl (Sorensen et al., 1971); and
  - 1.0N NH4OAc (Lekanem and Ervio, 1971).

Greenhouse Study

The greenhouse experiment was conducted at Michael Okpara University of Agriculture, Umudike greenhouse. The experimental design was Completely Randomised Design (CRD), replicated five times. There were 30 composite samples taken from thirty sampling locations across the study area. Two kilogramme (2.0 kg) of soil was weighed into an experimental pot for the planting of cassava stem (cuttings) with approximately 20 cm length containing about 5 – 7 nodes ensuring that at least 2 - 3 nodes were embedded in the soil. There were 150 pots in all. The cassava variety used for the experiment was TME 419, known to be high yielding, early maturing and disease resistant. Five Zn fertilizer levels (0, 2.0, 4.0, 6.0, and 8.0 kg ha^{-1}) as $ZnSO_4.7H_2O$ were applied as treatments. A basal NPK fertilizer application of 180.0kg N ha^{-1}, 90.0kg $P_2O_5ha^{-1}$, 90.0kg K_2O ha^{-1} as Urea, SSP and MOP was applied uniformly to all the pots at three (3) weeks after planting (WAP). The cassava were grown for 90 days and the following measurements were made on the plants.

- Number of leaves was counted at 4, 8 and 12 weeks after planting (WAP).
- Plant Height (cm) was measured from the plant base to the tip of the plant using a meter rule at 4, 8, 12 weeks after planting (WAP)
- Stem Girth (mm) was measured using Venier Calippers at 4, 8 and 12 weeks after planting (WAP).
- Inter node Length (cm) was measured using a meter rule At 4, 8 and 12 weeks after planting (WAP).
- Leaf Area (LA) was determined by measuring the longest tip from stalk base line (Length) and broadest section of the leaf (width) using a meter rule and rationalizing the product i.e. A = L x W (Ekanayeke 1976; Nwafor *et al.*, 2010).
- Leaf Area Index (LAI) was measured (Ekanayeke, 1976; Nwafor *et al.*, 2010), while number of leaves/plants were measured by counting.
- Number of nodes was counted while inter-node length and petiole length were determined with a meter rule.
- Dry matter yield (g $plant^{-1}$) was determined by weighing the oven-dry plant samples (g) using an electronic weighing balance.
- Leaf nutrient content was determined by wet digestion process. The nutrient content was measured using Atomic Absorption Spectrophotometer (AAS).
- Nutrient uptake (mg $plant^{-1}$) was determined by multiplying total dry matter (shoot and roots) with nutrient contents values of Zn of the plant.

Plant Sample Preparation and Micronutrients Determination

Cassava stem, roots and leaf samples were harvested 90 days after planting. The samples were rinsed in distilled water, air-dried, under the greenhouse shade for some days after which the plant materials were placed in large envelopes, and dried in a forced -air oven at 60^0C until constant weight for dry matter yield (DMY) determination.

A sub-sample of the oven-dried plant samples was weighed, ground and digested using sulphuric acid, nitric acid and perchloric acid in equal ratio (H_2SO_4: HNO_3: $HClO_4$) digestion method (Shuman, 1985) in Teflon crucible, and heated on a hot plate for about 10 minutes.

The extracted digest was analyzed by Atomic Absorption Spectrophotometer to determine the concentration of Zn in the plant samples.

Nutrient uptake (mg plant $^{-1}$) of cassava plant was determined by the product of dry matter yield (g plant $^{-1}$ DM) and Zn concentrations in plant.

The Zn uptake by cassava was correlated with the extractable Zn of each of the five extractants to assess the relationship between extractable Zn and cassava uptake of Zn in soils formed from coastal Plain Sands. Also, regression analysis was conducted on the Zn uptake with extractable Zn by each of the extracting solutions. The best relationship between Zn uptake and extractable Zn based on the coefficient of regression was obtained with ammonium acetate solution. This formed the basis of the calibration studies conducted at three locations for two planting seasons.

Field Experiments

The field studies were conducted in three different locations in 2012/2013 and 2013/2014 planting seasons. The experimental sites were located at Uyo (National Cereals Research Institute Oworo Ita outstation farm, Nung Udo, Uyo); (National Root Crops Research Institute west farm, Umudike); and Federal University of Technology Owerri (FUTO) demonstration farm Owerri. The experimental locations at Uyo, Umudike, and Owerri were so chosen because they belong to the same coastal plain sands parent material and are subject to similar climatic and environmental conditions. Rates of Zn fertilization (0, 4.0, 8.0, 12.0 and 16.0 kg ha $^{-1}$) for the field studies were determined from the calibration values from greenhouse study.

Land Preparation

The plots were previously under multivariate grass fallow for two years or more in each occasion before establishing the experiments. The varieties of grasses found in the environment include the following: *Seteria barbata, Chryssopogon acciculatus, Panicum maxima, Sorghastrum bipennatum, Eleusin indica, Axonopus compressus, Cynodon dactalon, Dactylocterium aegyptium, Pernnisetum purperum, Axonopus affinis, and Eragrostis tennella* among others. The vegetation was slashed and the farm ploughed, harrowed and ridged.

The ridges were spaced 1m apart. The plots were marked out into experimental units of 5 m x 5 m. The plots were separated by 1 m spacing while the blocks were separated by 2 m spacing. Cross bars and bonds were constructed to check erosion and to demarcate the plots. The same field experiment was set up in each of the three locations.

Each experiment was laid out in a randomized complete block design (RCBD) with four (4) replications. The plot size measured 5 x 5 m^2 each. Planting was done at 1 x 1 m^2 interval spacing. Treatment consisted of five (5) Zn fertilizer levels of 0, 4.0, 8.0, 12.0 and 16.0 kg ha-^{1} as $ZnSO_4.7H_2O$. A basal NPK fertilizer application of (180.0kg N ha^{-1}, 90.0 kg P_2O_5 ha^{-1}, and 90.0 kg K_2O ha^{-1}), of ammonia (Urea), single super phosphate, (SSP), and Muriate of Potash (MOP) was applied six (6) weeks after planting (WAP) by side dressing, as recommended for Southeast region of Nigeria (Enwezor *et al.,* 1990).

One cassava stem cutting (30cm length) of improved variety with about 7-9 nodes was planted in each ridge at a spacing of 1m x 1m. The farms were maintained following proper agronomic practices for cassava production. The cassava was harvested after 12 calendar months.

Cassava growth parameters were collected at 3, 6 and 9 months after planting (MAP). At the end of each experiment, the cassava was harvested and the following data collected according to standard procedure:

- Leaf weight (kg) was done by physically detaching the number of developed leaves along the leaf stalk using a weighing balance
- Stalk (stem) weight (kg) was measured from each plot at ground level to the point of stem attachment with the aid of weighing balance.
- Root Dry matter yield (DMY) (g $plant^{-1}$) was determined by harvesting whole plants in net-plot, oven dried root samples and weighed using an electronic weighing balance and then converted into tonnes per hectare (t ha^{-1}).
- Average weight of tuber (kg), average length of tuber (cm), and number of tubers per plant was measured.

- Crop yield (t ha-1) was determined by harvesting tubers from net-plot and then converted to tonnes per hectare (t ha-1).

Statistical Analysis

Growth and yield data was analyzed using two-way analysis of variance (2-way ANOVA). This was accomplished using Genstat (3rd edition) and SPSS 15 statistical software package. Significant means was separated using Fisher's LSD at 0.05 probability level. A simple correlation and regression analysis was performed to show the relationship among the variables (Gomez and Gomez, 1984).

Results and Discussion

Soil Physical and Chemical Properties

Results of the physical properties are presented in Table 4.1. Sand particles ranged from 573-874 g kg^{-1} with a mean of 736 g kg^{-1}. Silt fractions varied between 14 g kg^{-1} and 358 g kg^{-1} with a mean of 136 g kg^{-1} while, the clay fractions ranged from 18-371 g kg^{-1} with a mean of 138 g kg^{-1}. Generally, the soils are coarse textured with high content of sand. The texture of the soils ranged from loamy sands, sandy loams and sandy clay; the dominant textural class being sandy loam. The coarse nature of the soil textures implies poor nutrient content and low structural stability with characteristic low water retention capacity. The result is moderate to high infiltration which may be favorable to high erodibility and hence make the soils of the study area vulnerable to degradation (Ogban *et al.*, 2011). Coarse texture is characteristic of the soils developed on acid sands of the South eastern Nigeria (Udoh *et al.*, 2013; Eteng *et al.*, 2014).

Table4.1. *Some physical properties of soils formed over coastal plain sands*

Sampling location	Particle size distribution			Textural class
	Sand	Silt	Clay	
	→	g kg^{-1}	←	
Abak	673	82	245	SCL
Abayi	675	14	311	SCL
Alaocha	675	269	56	SL
Ariam	669	98	233	SCL
Essien Udom	696	64	240	SCL
Etoi	713	26	261	SCL
Ibesi Ikpo	771	46	183	SCL
Ikono	874	93	33	SL
Ikot Ekpene	754	174	72	LS
Ikot Ewang	574	85	341	SCL
Mbaise	775	152	73	LS
Mbeke Mbano	669	259	72	SL
Ngor Okpoala	874	63	63	LS
Nkwere	872	95	31	SL
Nsulu	761	149	90	SL
Ntigha	771	171	58	SL
Obehie	873	93	34	SL
Obinze	674	271	55	SL
Obowo	669	313	18	SL
Ogbaku	574	358	68	SL
Olokoro	774	28	198	SCL
Orlu	574	351	351	SL
Oron	775	76	149	SL
Ubakala	869	83	48	SL
Umuagwo	671	278	51	SL
Umudike	869	28	103	LS
Umuezeugwu	874	45	81	LS
Umuoba	573	56	371	SCL
Uruan	775	34	191	SL
Uyo	738	218	44	LS
Min	**573**	**14**	**18**	**-**
Max	**874**	**358**	**371**	**-**
Mean	**736**	**136**	**138**	**SL**

Legend

SCL – Sandy clay loam

LS - Loamy sand

SL - Sandy loam

The results of the soil chemical properties are presented in Table 4.2. Soil pH in H_2O and KCl ranged from 4.30 - 5.90 and from 3.10-3.90 with a mean of 4.87 and 3.40 respectively, indicating that the soils are strongly acidic in reaction irrespective of the location. Acidic condition encourages the availability of micronutrients in soil (Chude *et al.*, 2004; Eteng *et al.*, 2014). The acidic conditions might be due to the acidic nature of the parent materials, high rainfall that exceeds 2000 mm yearly, the sandy nature of the soils, the erosion losses, and high leaching of bases and depletion of organic matter (Enwezor *et al*., 1990; Effiong and Ibia, 2009).

The values of organic carbon contents of the study area were generally rated very low in most of the soils being below 15gkg^{-1} in almost all the soils, and these ranged from 6.7 – 15.6gkg-^{1} with a mean of 11.9gkg^{-1}. The low organic carbon value may be as a result of increased rate of mineralization due to intense cultivation (Aruleba and Ogunkunle, 2006). Intensive cultivation is known to favour a rapid mineralization of organic matter.

Total nitrogen varied between 0.03 and 0.84 % with a mean value of 0.13 %, this range of value is rated low for most soils when compared with the range 0.2-0.5% for productive soils Eteng *et al.* (2014). Generally, the nitrogen content of the soils is critically low, with most of the soils having values below 1.0 %, indicating serious deficiency problem. This may be attributed to the low organic carbon content in the soils. The probable reasons for low values of total N in most of the soils are rapid decomposition of organic matter, high rate of leaching of cations and to a lesser extent, soil erosion.

Available P fluctuated irregularly within the locations and varied from 3.70 to 16.30 mg kg$^{−1}$ with a mean of 8.30 mg kg$^{−1}$. This range of values is low as almost all the soils had values of available P less than 15 mg kg$^{−1}$ regarded as the critical limit for productive soils. According to Landon (1991) soils with P values below 10 mg kg^{-1} are generally considered marginal while soils with P values greater than 20 mg kg^{-1} are considered high. The values agree with values reported by Ibia and Udo (2009); Udo *et al.* (2011); Udom *et al.* (2004) for other soils in southeastern Nigeria.

The level of exchangeable Ca in the soils investigated ranged from 1.60 to 8.80Cmol kg^{-1} with a mean of 3.65 Cmol kg^{-1}. About 40% of the soils samples have values of Ca above the range of 4.0 Cmolkg^{-1} regarded as the lower limit for fertile soils (Kyuma *et al.*, 1986; Enwezor *et al.*, 1981; Chude *et al.*, 2004).

The values of exchangeable Mg ranged from 0.40 to 6.40 Cmol kg^{-1}. These values are above 0.5 Cmol kg^{-1} regarded as critical value for productive soils (Landon, 1991; Chude *et al.*, 2004) and could be rated high when compared with the acceptable limits of individual basic cations for crop production in the southeastern agro-ecological zone.

Potassium,is noted to be a key element in the fertilization of agricultural crops. However, the values of K in the study area ranged between 0.01 Cmol kg^{-1} and 0.14 Cmol kg^{-1}, with a mean of 0.07 Cmolkg^{-1} which are less than 0.2 Cmol kg^{-1} given as the critical levels of exchangeable K (Chude *et al.*, 2004). However, based on fertility rating, these values are low to medium (Vanlanwe *et al.*, 2002).

Total exchangeable bases (Ca, Mg, K and Na) content of the study area ranged from 3.32 to 12.75 Cmolkg^{-1} with an average of 6.55 Cmolkg^{-1}. These values are low to moderate when compared with the acceptable limits of individual basic cations for crop production in soils of the Southeastern agro-ecological zone. The low values of exchangeable bases in most of these soils may be attributed to the nature of underlying rocks (parent materials), high rainfall intensity, intensity of weathering, leaching and lateral translocation of bases (Eshiett, 1992).

Exchangeable acidity values varied widely from 1.50 to 5.20 Cmol kg^{-1} with an average of 3.08 Cmol kg^{-1}. These values are low for productive soils compared, to other soils of southeastern Nigeria as established by FPDD (1990) and Eteng *et al.*, (2015).

ECEC values ranged between 10 and 20 Cmol kg^{-1}andare considered marginally adequate and high for crop production. Based on the values reported for Nigeria soils (Fasina, 2005), the soils of the study area have low ECEC values. The low values of ECEC indicate that the soils are prone to leaching, poor potential for retaining plant nutrients and have low activity clay characteristic of Kaolinite (Enwezor *et al.*, 1981). Generally base saturation of the soils is >50%, indicating that the soils can sustain crop production for some time before deficiency sets in.

Table4.2. *Some chemical properties of soils formed over coastal plain sands*

Sampling location	pH (1:25)		Org carbon	Org matter	Total N	Av. P	Exchangeable cation				TEB	TEA	ECEC	BS
	H_2O	KCl					Ca	Mg	K	Na				
			→ g kg^{-1} ←		%	$mgkg^{-1}$	→ Cmol kg^{-1} ←							%
Abak	5.2	3.2	10.8	18.6	0.10	16.3	2.8	2.8	0.06	0.06	5.72	3.2	8.92	64.13
Abayi	4.6	3.2	6.7	11.6	0.07	7.7	3.6	3.6	0.07	0.06	7.33	1.9	9.23	79.14
Alaocha	5.1	3.5	13.0	23.4	0.10	4.8	2.4	1.6	0.06	0.07	4.13	3.3	7.43	55.59
Ariam	4.8	3.2	12.4	21.4	0.13	10.7	2.4	2.4	0.06	0.06	4.92	1.9	6.82	72.14
Essien Udom	5.4	3.6	8.0	13.8	0.06	11.2	3.6	3.6	0.06	0.07	7.33	2.6	9.93	73.82
Etoi	5.4	3.4	11.5	19.8	0.84	10.8	6.0	6.0	0.06	0.07	12.13	4.6	16.73	72.50
Ikisi Ikpo	4.6	3.3	12.1	20.9	0.14	8.4	2.4	2.4	0.01	0.07	4.88	3.4	8.28	58.94
Ikono	4.4	3.2	12.2	21.0	0.10	3.9	3.6	3.6	0.07	0.06	7.33	3.2	10.53	69.61
Ikot Ekpene	5.5	3.9	12.7	21.9	0.11	11.1	4.8	4.8	0.06	0.07	9.73	2.0	11.73	82.95
Ikot Ewang	5.0	3.6	13.4	23.4	0.11	12.3	2.8	2.8	0.07	0.07	5.74	3.4	8.78	65.38
Mbaise	5.3	3.2	13.0	22.4	0.13	14.2	5.6	5.6	0.14	0.08	11.42	3.0	14.42	79.20
Mbeke	4.8	3.6	9.6	16.6	0.07	3.7	4.4	1.6	0.07	0.43	6.50	4.5	11.00	59.09
Ngor okporo	5.2	3.8	13.6	23.5	0.14	12.2	2.0	2.0	0.06	0.06	4.12	2.7	6.19	66.56
Nkwere	4.7	3.4	11.1	19.1	0.04	6.5	2.4	1.2	0.07	0.06	3.73	4.7	8.43	44.25
Nsulu	4.5	3.4	12.1	19.3	0.08	6.5	4.0	0.4	0.05	0.07	4.52	5.2	7.72	58.55
Ntigha	4.9	3.2	12.0	20.7	0.11	6.3	8.8	3.8	0.09	0.06	12.75	1.5	14.25	89.47
Obehie	4.5	3.1	14.0	24.1	0.13	4.5	2.4	2.4	0.07	0.05	4.92	2.3	7.22	68.33
Obinze	4.9	3.3	14.6	25.2	0.11	14.9	1.6	1.6	0.07	0.05	3.32	2.6	5.92	56.08
Obowo	4.3	3.8	14.3	26.7	0.11	5.7	3.2	3.2	0.05	0.05	6.50	2.7	9.20	70.65
Ogbaku	4.7	3.4	12.4	21.4	0.10	7.8	2.8	2.0	0.07	0.06	3.93	3.2	7.13	55.12
Olokoro	4.8	3.4	14.3	24.7	0.11	5.7	2.4	1.6	0.06	0.06	4.12	3.4	7.52	54.79
Orlu	4.5	3.3	15.6	26.9	0.13	6.2	3.6	3.6	0.08	0.06	7.34	3.7	10.41	70.51
Oron	4.8	3.5	8.6	14.8	0.08	5.1	4.0	0.4	0.07	0.06	4.53	3.3	7.83	57.85
Ubakala	4.7	3.2	11.1	19.1	0.08	12.6	4.0	4.0	0.05	0.04	8.09	1.7	9.79	82.64
Umuagwa	4.7	3.3	8.0	13.8	0.07	5.0	2.8	1.8	0.05	0.06	4.71	3.1	7.81	60.31
Umudike	4.5	3.3	10.2	17.6	0.11	6.7	2.8	2.8	0.07	0.07	5.74	2.4	8.14	70.52
Umuezeugwu	4.9	3.3	10.2	17.6	0.11	7.8	3.6	3.6	0.06	0.06	7.32	2.6	9.92	73.79
Umuoba	4.6	3.3	13.7	23.6	0.11	4.5	6.4	6.4	0.06	0.05	9.91	4.4	14.31	69.25
Uruan	4.8	3.5	15.3	26.4	0.14	5.9	4.4	4.4	0.05	0.05	8.93	3.4	12.33	72.42
Uyo	5.9	3.7	11.8	20.3	0.03	10.0	4.0	0.8	0.08	0.07	4.95	2.4	7.35	67.35
Min	**4.30**	**3.10**	**6.7**	**11.6**	**0.03**	**3.70**	**1.60**	**0.40**	**0.01**	**0.04**	**3.32**	**1.50**	**5.92**	**44.25**
Max	**5.90**	**3.90**	**15.6**	**26.9**	**0.84**	**16.30**	**8.80**	**6.40**	**0.14**	**0.43**	**12.75**	**5.20**	**16.73**	**89.47**
mean	**4.87**	**3.40**	**11.9**	**20.7**	**0.13**	**8.30**	**3.65**	**2.89**	**0.07**	**0.07**	**6.55**	**3.08**	**9.51**	**67.36**

Available Zn in Soils Using Five Different Extractants

The results of extractable Zn content of the soils by different extraction methods are presented in Table 4.3.

Available Zn content extracted by the NH_4OAc extractant varied from 0.98 mg kg^{-1} to 19.01 mg kg^{-1} with a mean value of 7.87 mg kg^{-1}. The use of neutral salt solutions such as 1.0 N NH_4OAc for the extraction of trace elements is an established technique.

Coca-Cola extracted Zn values which varied widely from 0.14 mg kg^{-1} to 3.66 mg kg^{-1} and a mean value of 1.78 mg kg^{-1}. The content of Coca-Cola extractable Zn obtained in most of the soils was higher than the range of critical values obtained in the study reported by Schnug *et al.* (2001).

Similarly, HCl-extractable Zn varied widely from 0.95 mg kg^{-1} to 11.48 mg kg^{-1} with a mean of 5.10 mg kg^{-1}. The EDTA extractable Zn values obtained from the soil, ranged from 0.17 mg $kg^{-1}$to 24.40 mg kg^{-1} with a mean value of 5.04 mg kg^{-1}.

Values for available Zn content extracted with EDTA + NH_4OAc (table 4.3) ranged from 1.46 mg kg^{-1} to 12.11 mg kg^{-1}. However, the EDTA + NH_4OAc extraction method has significantly ($P < 0.05$) higher extractable -Zn relative to Coca-Cola extraction method.

Going by the critical index of 0.8 mg kg^{-1} (Chirwa and Yerokun, 2012) used by many soil analysis laboratories, only the soils extracted by Coca-Cola method were observed to be low in extractable Zn and EDTA + NH_4OAc-extractable Zn of the soils were rated insufficient (1.78 – 3.51 mg kg^{-1}), single EDTA and HCl-extractable Zn of the soils were rated marginal (> 3.98 mg kg^{-1}), while NH_4OAc-extractable Zn of the soils was rated sufficient in availability.

Table4. *Extractable zinc (Zn) content with different extractants*

Location	Extractable Zinc (mg kg^{-1})					Mean
	Coca-Cola	EDTA	NH_4OAc+EDTA	HCl	NH_4OAc	
Abak	1.00	7.20	4.83	2.51	18.25	6.76
Abayi	2.09	0.88	1.49	4.55	3.22	2.45
Alaocha	0.19	1.86	2.37	4.41	12.00	4.17
Ariam	3.40	1.24	1.46	11.37	4.65	4.42
Essien Udom	1.96	5.94	5.02	2.19	16.01	6.22
Etoi	2.32	9.76	4.93	6.01	9.84	6.57
Ibesi Ikpo	2.97	6.81	1.49	10.74	11.37	6.68
Ikono	2.67	7.24	12.01	9.62	2.51	6.81
Ikot Ekpene	1.79	6.10	2.37	5.22	10.62	5.22
Ikot Ewang	1.90	6.51	5.61	9.84	15.22	7.82
Mbaise	0.31	24.50	4.16	2.12	1.76	6.57
Mbeke	1.40	6.19	2.01	0.95	8.07	3.72
Ngor Okpuala	1.00	7.67	2.21	3.56	7.06	4.32
Nkwere	2.60	5.82	2.21	1.45	19.01	6.22
Nsulu	2.29	1.71	2.39	2.39	1.57	2.07
Ntigha	2.42	2.10	1.92	3.11	0.98	2.11
Obehie	1.60	0.96	1.84	2.98	3.75	2.23
Obinze	0.80	5.73	2.22	4.27	11.28	4.86
Obowo	1.10	5.83	3.01	2.88	1.60	2.88
Ogbaku	2.10	8.82	3.90	9.28	11.23	7.07
Olokoro	3.66	1.49	1.92	4.65	4.55	3.25
Orlu	1.12	0.17	2.01	3.73	6.02	2.61
Oron	0.14	1.87	1.46	10.62	11.48	5.11
Ubakala	1.46	1.72	2.96	3.03	3.16	2.47
Umuagwo	1.20	5.57	2.19	3.01	10.49	4.49
Umudike	3.56	1.89	2.39	11.48	4.41	4.75
Umuezeugwu	2.11	1.72	1.81	3.56	2.14	2.27
Umuoba	1.95	1.80	1.46	3.02	3.54	2.35
Uruan	0.69	6.46	12.11	8.25	10.74	7.65
Uyo	1.71	5.57	9.72	2.15	9.62	5.75
Min.	0.14	0.17	1.46	0.95	0.98	2.07
Max.	3.66	24.50	12.11	11.48	19.01	7.82
Mean	1.78	5.04	3.51	5.10	7.87	4.66

POTENTIALS OF DIFFERENT EXTRACTANTS FOR THE EXTRACTION OF ZN

The concentrations of available Zn determined in soils derived from coastal plain sands by the five extraction methods are shown in Table 4.6.

Table5. *Effectiveness of the extractants used for the determination of Zn in soils of coastal plain sands*

Extraction method	Extractable micronutrients (mg kg^{-1}) Zn
Coca-Cola	1.78
EDTA	5.04
EDTA+NH_4OAc	3.52
HCl	5.10
NH_4OAc	7.87
$LSD_{(0.05)}$	2.32

The content of available Zn varied from 1.78 to 7.87 mg kg^{-1} with a mean value of 4.66 mg kg^{-1}. NH_4OAc extracted significantly ($P < 0.05$) more Zn than the other extractants. Also HCl and EDTA extracted significantly ($P < 0.05$) more Zn than Coca-Cola respectively (Table 5).

Prediction of Micronutrient (Zn) Availability to Cassava Crop

The usefulness of any extractant to predict the availability of soil nutrient element to plant is dependent on the ability of the extracting solution which determines the extent to which plants accumulate a given nutrient element.

Linear correlation coefficients (r) (Table 4.7) and regression model (Table 4.8) were employed to assess the relationship between zinc availability and Zn uptake by cassava (*Manihot esculenta* Crantz) plant. Zinc uptake significantly correlated positively with NH_4OAc (r = 0.748**) and EDTA (r = 0.485*) but negatively correlated with HCl (-0.681**).

The significant positive correlation suggests that the amount of Zn extracted from the soil has strong association with plant uptake. This may be due to Zn transformation and availability in soils which depend on various forms of the nutrient element with which Zn have significant and positive correlation (Dahnke and Olson, 1990).

Linear regression analysis conducted for Zn uptake showed that only NH_4OAc and HCl have higher significant coefficient of determination, R^2 values. Their R^2 values were determined to be 0.759** and 0.679** respectively. This was followed by EDTA with R^2 value of 0.534* (Table 4.8).

Although the results obtained from the methods of Zn extractability agreed with Angelova (2003), which reported that NH_4OAc method regarding extractability of Zn gave the best correlation coefficients. According to Angelova *et al.,* (2003) neutral NH_4OAc is used for extraction of the exchangeable or easily mobile forms of Zn from neutral or weak acid soils, which are considered to be fully available to plants.

Table6. *Relationship (r) between extractable zinc (Zn) by the different extraction methods and cassava uptake of zinc*

Cassava yield parameter	Extractants				
	Coca-cola	EDTA	EDTA+NH_4OAc	HCl	NH_4OAc
Zn uptake	-0.168 ^{ns}	0.485*	-0.306 ^{ns}	-0.681**	0.748**

Ns = not significant at P < 0.05
** = Significant at P < 0.05*
*** = Significant at P < 0.01*

Table7. *Regression equation and coefficient of determination (R^2) of Zn uptake by different extractants (N=30)*

Regression equation	R^2 value
Zn uptake = 0.641 + 0.178 Zn Coca-Cola	0.030 ^{ns}
Zn uptake = 1.341 + -0.072 Zn EDTA	0.534*
Zn uptake = 1.164 - 0.029 Zn EDTA+NH_4OAc	0.093^{ns}
Zn uptake = -0.944 + 0.023 Zn HCl	0.679**
Zn uptake = 1.238 - 0.024 Zn NH_4OAc	0.759**

Ns = not significant at P < 0.05
** = Significant at P < 0.05*
*** = Significant at P < 0.01*

Determination of Critical Values of Zn

The critical ranges of Zn estimated by the extractants in the soils and determined graphically by Cate-Nelson method are presented in table 4.11 and figure 4.1a-e.The critical level obtained by HCl extractable respectively (Table 4.11). The ranges between the lower and upper limits could be Zn was found to be above the range of 2.2 mg kg^{-1} estimated by Abdu *et al.,* (2007) for 0.1N HCl extractable Zn.

The study shows that the soils with values of available Zn below the corresponding critical value rated low were deficient (responsive), while those soils with values above the critical levels rated high were sufficient (non-responsive) or toxicity symptoms may appear. Thus, for those soils which appears to be deficient in Zn content, adequate Zn fertilizer carriers should be applied.

Table9. *Critical ranges of the Zinc (Zn) ($mgkg^{-1}$) determined by five extraction methods*

Extraction methods	Rating (Zn $mgkg^{-1}$) levels		
	Low	Moderate	High
Coca-Cola	<1.52	1.52-4.00	>4.00

EDTA	<1.20	1.20-3.43	>3.43
EDTA+NH_4OAc	<2.15	2.15-3.76	>3.76
HCl	<5.60	5.60-9.06	>9.06
NH_4OAc	<1.20	1.20-1.54	>1.54

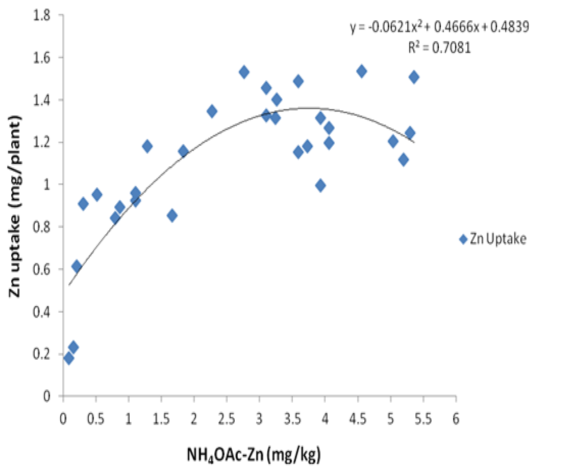

Figure1a. *Graph showing relationship between Zn uptake and extractable Zn by Ammonium Acetate extractant.*

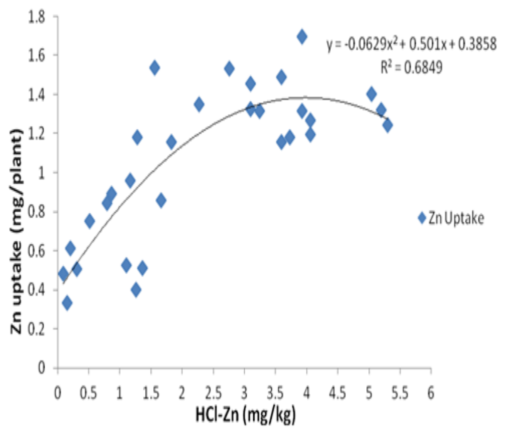

Figure1b. *Graph showing relationship between Zn uptake and extractable Zn by Hydrochloric acid extractant.*

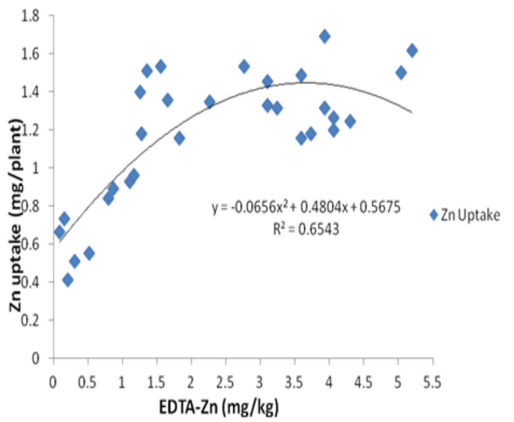

Figure4.1c. *Graph showing relationship between Zn uptake and extractable Zn by Ethylene di-amine tetra acetic acid extractant.*

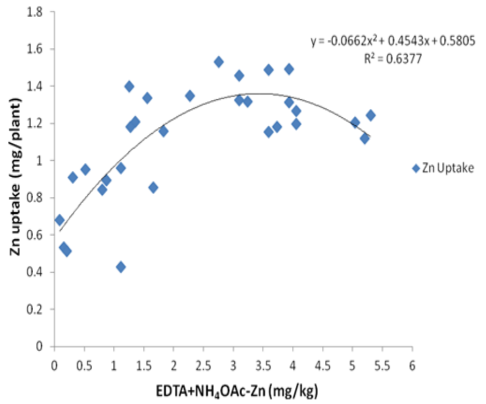

Figure4.1d. *Graph showing relationship between Zn uptake and extractable Zn by Ethylene di-amine tetra acetic acid + Ammonium Acetate extractant*

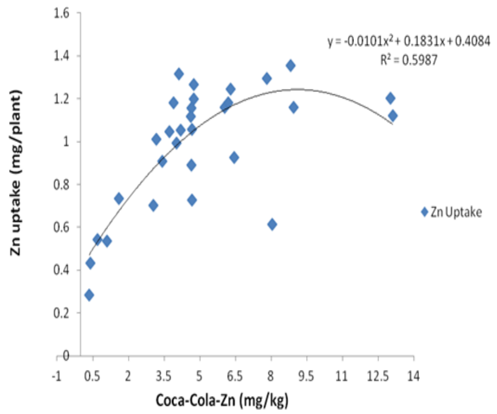

Figure4.1e. *Graph showing relationship between Zn uptake and extractable Zn by Coca-Cola extractant*

FIELD STUDY

Calibration of Zn Requirement Of Cassava

Optimal Zn levels for cassava production for first and second years of the field experiments in soils of coastal plain sands are presented in Table 4.17. Zn application to the field had a significant ($P< 0.05$) effect on cassava root yield obtained from both the first and second planting years. This observation is supported by similar observation by Rego *et al.*, (2007) who also noted an increase in grain yield of maize with application of Zn fertilizer. Polynomial regression analysis determined for cassava root yield as function of Zn application was also significant (R^2 = 0.9002 and 0.9667) for first and second plantings respectively (Figure 4.4). The maximum increase (14.3t ha^{-1}) cassava root yield was determined at 10.81 kg Zn ha^{-1} for the first planting season while maximum increase of (10.3t ha^{-1}) cassava root yield was recorded for second planting at 10.35 kg Zn ha^{-1} with a mean value of 12.3 t ha^{-1} for the root yield and 10.58 kg Zn ha^{-1} fertilizer application. Harris *et al*, (2007), Kanwal *et al.*, (2010) and Eteng (2011) also confirmed an increase in corresponding maize grain yield with increase in Zn rates.

Table4.17. *Optimal values of Zn levels for cassava production in soils of coastal plain sands*

Cropping year	Cassava root yield (t ha^{-1})	Optimal value for Zn (kg ha^{-1})	Predicted value (R^2)
First year	14.3	10.81	0.9002
Second year	10.3	10.35	0.9667
Mean value	12.3	10.58	

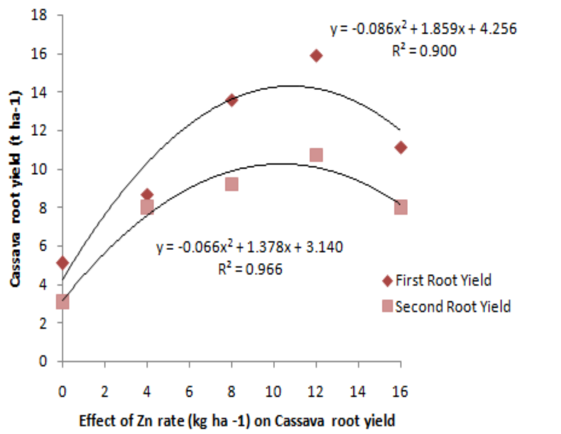

Figure2. *Calibration curves for optimum Zn fertilizer rates (kg ha^{-1}) on cassava root yield*

CONCLUSION

Results obtained from the laboratory studies, Greenhouse pot experiments and field experiments showed that the soils of Coastal Plain Sands of Southeastern Nigeria were generally acidic (pH in H_2O = 4.87; pH in KCl = 3.40. The soils were texturally predominantly sandy loam. Results also showed that soils of the study areas have moderately low total N (0.13%), low to moderate organic carbon (1.19%), low to moderate basic cations, moderate available P(8.30 $mgkg^{-1}$).

The available Zn content obtained by different extraction methods was observed to be high (> 2.0) 4.66 mg kg^{-1} and varied significantly ($P < 0.05$) across the soils of the study area. The extractant 1.0 N NH_4OAc gave the highest mean value relative to other extractants and therefore adjudged the most efficient extractant for available Zn in soils formed from coastal plain sands of Southeast Nigeria.

The estimated critical level 1.20 mg kg^{-1} of Zn (Table 4.18) by the five extraction methods is recommended for use to predict and interpret soil and plant test values for Zn. Zn fertilizer required to obtain optimum cassava root yield based on the calibration curves to be 10.58 kg Zn ha^{-1}.

REFERENCES

[1] Abdu, N., Yusuf, A. A., Abdulkadir, A., Arunah, U. L., Chude, V. O. and Pam, S. G. (2007). Zinc soil calibration based on 0.1 N HCl extractable Zinc and Cation Exchangeable Capacity from upland soils of Northern Nigeria. Journal of Agronomy 6 (1): 179-182.

[2] Adiloglu, A. (2003). Determination of suitable chemical extraction methods for available iron content of the soils from Edine Province in Turkey. Pakistan Journal of Biological Sciences, 6 (5), pp 505 – 510.

[3] Aduloju, M. O. (2004). Acid Extractable Micronutrients (Mn and Zn) in selected soils of vegetable producing areas of Kwara State, Nigeria. Nigerian Journal of Horticultural Science 9: 116 – 119.

[4] Akinrinde, E. A., Obiagbesa, G. O., Ojanuga, O. A. (2005). Extractable Micronutrients in Relation to Physicochemical Properties of soils in four Ecological Zones in Nigeria. Global Journal of Pure Applied Science (II) 2: 197-200.

[5] Alam, S. M. and Raza, S. (2001). Micronutrient Fertilizers. Pakistan Journal of Biological Sciences. 4(11): 1446-1450.

[6] Allem, A. C. (2002). The origins and taxanomy of cassava. In: Hillocks, R. J, Thresh, J. M. and Belloti, A. C. (eds). Cassava, Biology, Production and utilization. CABI publishing. Pp. 1 – 16.

[7] Alloway, B. J. (2003). Zinc in soils and crop nutrition, International zinc Association, Box 4, B-1150 Brussels-Belgium., 114pp. http:// www. Zinc-crops.org.

[8] Alloway, B. J. (2004). Zinc deficiency in crops: Causes and correction. Reading RG6 6DW, United Kingdom. Pp 32.

[9] Alves, A.A.C. (2002). Cassava Botany and Physiology, In. Cassava: Biology, Production and Utilization (eds) Hillocks, R.J., Thresh, J.M., and Belloti, A. CABI Publishing, U.K. Pp. 67-89.

[10] Angelova,V., Ivanova, K. and Zaprijanova, P. (2003). Atomic Absorption spectrophotometer: Defining of the mobile forms of Pb, Cu, Zn and Cd in soil from industrially polluted Regions. Journal of Environmental Protection and Ecology. 4 (3): 600 – 612.

[11] Anikwe, M. A. N. and Eze, D. C. (2010). Effect of indigenous legumes on soil properties and yield of maize on an utisol in southeastern Nigeria. Nigeria Journal of soil science. Vol. 20 (2), 47 – 53.

[12] Ano, A. O. (2003). Studies on the effect of living on yield of two cassava cultivars. In: NRCRI Annual Report (2003). Pp 9.

[13] Aruleba, J. O. and Ogunkunle, A. O. (2006). Characterization, Classification and Suitability Evaluation of the Forest-Savanna soils of Oyo State. Nigeria Journal of Soil Science.16:1016.

[14] Borggard, O. K. (1976). The use of EDTA in soil analysis. ACTA Agricultural Scandinavia., 26: 144 – 150.

[15] Brennan, R. F. and Bolland, M. D. A. (2002). Relative effectiveness of soil-applied zinc for four crop species. Australian Journal of Experimental agriculture, 41:541-547.

[16] Bukvic, G., Antunovic, M., Popovic, S. Rastija, M. (2003). Effect of P and Zn fertilization on biomass yield and its uptake by maize lines (Zea mays L.). Plant soil Environment 49 (11): 505 – 510.

[17] Cajuste, L. J., Cruz-Diaz, J. and Garcia-Osorio, C. (2000). Extraction of heavy metals from contamination soils: I. sequential extraction in surface soils and their relationship to DTPA extractable metals and metal plant uptake. Part A: Toxic – Hazardous substance & Environmental Engineering. Journal of Environmental Science and Health, 35: 1141 – 1152.

[18] Cakmak, I. (2008). Enrichment of cereal grains with zinc: Agronomic or genetic bio fortification. Journal of Plant and Soil 302:1-17.

[19] Cate, R. B. Jr. and Nelson, L. A. (1971). A simple statistical Procedure for partitioning soil test correlation Data in two Soils: Soil Science Society American Proceedings. 35. 658 – 659.

[20] Chude, V. O., Malgwi, W. B., Amapu, I. Y. and Ano. A. O. (2004). Manual on soil fertility Assessment. Federal Fertilizer Department/ National Special Food Programme for security, Abuja pg. 12.

[21] Egesi, C. N. Dixon, A. Maziya-Dixon, B., Ogbe, F. O. and Njoku, S. (2008). Harvest plus Activities: Breeding for enhanced micronutrient contents in cassava. In: NRCRI Annual Report 2008. Pp. 25.

[22] Egli, M., Fitze, P. and Oswald, M. (1999). Changes in heavy metal contents in and acidic forest soil affected by depletion of soil organic matter within the time span 1969 – 93. Journal of Environmental Pollution 105: 367 – 379.

[23] Ekanayake, I.J. (1996). Cassava: Procedure for growth analysis – a procedure manual. Crop Improvement Division, IITA, Ibadan, Nigeria. 25pp.

[24] Enwezor, W. O., Ohiri, O. C., Opuwaribu, E. E. and Udo, E. J. (1990). A review of fertilizer use on crop in Southeastern zones of Nigeria (in five vols). (FFDD eds). Boboma pub.Ibadan, 47-70 pages.

[25] Enwezor, W. O., Ohiri, O. C., Opuwaribu, E. E. and Udo, E. J. (1990). A review of fertilizer use on crop in Southeastern zones of Nigeria (in five vols). (FFDD eds). Boboma pub.Ibadan, 47-70 pages.

[26] Eshiett, E. T. (1992). Physio-chemical, morphological and mineralogical characteristics of selected Humid Region profiles in southeastern Nigeria. In: J. M. Kimble (Ed). Proceedings of the Eighth International Soil Correlation meetins; characterization, classification and utilization of wet soils USDA, Soil conservation, service, National Soil Survey centre, Lincoln, NE, 100 – 105.

[27] Eteng, E. U. Asawalam, D. O. and Ano, A. O. (2014). Total and available Micronutrients in soils of contrasting parent materials in Southeastern Nigeria. Journal Agricultural Biotechnology and Ecology. 7 (20): 1 – 16.

[28] Eteng, E. U. and Asawalam, D. O. (2015). Evaluation of Five Extraction methods for predicting Available forms of Iron in soils of southeastern Nigeria. Evaluation and Improvement of organic manure. Journal of Agriculture and Veterinary Science Technical Bulletin. No. 7. (I0SR – JAVS), Vol. 8 (1): 1 – 8.

[29] Ezeilo, W.N.O. (1979). Intercropping with cassava in Africa. In. Weber, E., Nestel, B., and Campbell, M. (eds), Proceedings of an International Workshop on intercropping with cassava. International Development Research Centre, Ottawa, Canada. Series IDRC – 142c, pp. 49-56.

[30] Ezumah, H.C. and Okigbo, B.N. (1980).Cassava planting systems in Africa. In: Weber E.J., Toro, J.C. and Graham, M. (eds) Cassava Cultural Practices. Proceedings of a workshop. Salvador, Bahia, Brazil, 18-21 March.IDRC Publication No. 151c. IDRC, Ottawa, Canada, pp. 44-49.

[31] Fageria, N. K. (2001). Screening method of Lowland genotypes for zinc uptake Efficiency. Scientia Agricola Vol. 58, pp 623 – 626.

[32] FAO (2003). Food and Agricultural Organisation, cassava production statistics. 2002. http// www. fao.org.

[33] FAO (2006). The state of food Insecurity in the World, 2006 Rome Panel on Global Hunger. Report One, pp. 76 – 120.

[34] FAO (2015). Quarterly Bulletin of Statistics. Food and Agricultural Organisation of United Nations, Rome. Itay. Pp. 45 - 50 Available www. infobrie. org/asp/practice

[35] Fasina, A. S. (2005). Influence of Land Use on the Variability of topsoil properties of an Alfisol in

Southern Nigeria. Journal of Sustainable Agriculture and Environment. 6(2): 171-178.

[36] Feiziasl, V. (2006). Determination of Fe, Mn, Zn and Cu Critical levels and classification by cate-nelson ANOVA methods for Dryland Wheat (T. aestivum. L.) in Western Iran. Iran Journal of Agricultural Science, 37: 389-401.

[37] FFDD (Federal Fertilizer Distribution Department (2002). Fertilizer use and management practices for crops in Nigeria. Aduayi, E. A., Chude, V. O., Adebusuyi, B. A. and Olayiwola, S. O. (eds). Federal Ministry of Agriculture and Rural Development, Abuja, Nigeria.

[38] Gee, G. W. and Or, D. (2002). Particle size analysis. In: methods of soil analysis. Dan, D. J. and Topps, G. C. (eds) Part 4, Physical methods. Soil Science. Society of America Book series No. 5, American Science Association and Soil Science Society of America, Madison, Wisconsin. Pp 225 – 293.

[39] Gichuru, M. P, Bationo, A., Bekunda, M. A., Goma, H. C., Mafongonya, P. I., Mugendi, D. N., Murwir, J. M. Nnadwa, S. M., Nyathii, P., and Swift, M. J. (2003). Soil Fertility Management in Africa: A Regional Perspective. Academy Science Publ. in Association with the Tropical soil Biological and fertility of CIAT. Pp 29.

[40] Graham, R. D., and Rengel, Z., (1993). Genotype variation in Zn uptake and utilization by plants.In Zinc in soils and plant (ed. Robson, A. D.), Kluwer, Dordrecht, The Netherlands, Pp. 107-14.

[41] Graham, R. D., and Rengel, Z., (1993). Genotype variation in Zn uptake and utilization by plants.In Zinc in soils and plant (ed. Robson, A. D.), Kluwer, Dordrecht, The Netherlands, Pp. 107-14.

[42] Graham, R. D., Welch, R. M. and Bouis, H. (2001).Addressing micronutrient malnutrition through enhancing the quality of staple foods: principles, perspectives and knowledge gaps. Advances in Agronomy, 70:77-142.

[43] Harmsen, A. K. and Vlek, P. L. G. (1985).The chemistry of micronutrient in soils. In: Vlek, P. L. G. (ed) Micronutrients in tropical food crop production. Matinus Nijhoff/Dr. W. Junk publishers, Dordrecht. The Netherlands: 1 – 42.

[44] Harris, A. Rashid, G. Miraj. Arif, M. and Shah, H. (2007). On-farm seed priming with zinc sulphate solution. Cost-effective way to increase the maize yields of resources-poor farmers. Field crops Research., 110; 119-127.

[45] Harter, R. D. (1991). Micronutrient adsorption-desorption reactions in soils. In: Mortvedt, J. J. et al. (eds) micronutrients in Agriculture. (2nded.). pp 59 – 87. Soil Science Society of America. Madison, Wisconsin.

[46] Hillocks, R.J. (2002).Cassava in Africa. In. Cassava: Biology, Production and Utilization (eds) Hillocks, R.J., Thresh, J.M., and Belloti, A. CABI Publishing, U.K. pp. 41-54.

[47] Howeler, R. H. (1983). Abalists del tejido vegetal eb el diagnostic de problems nutricionales de algunos cultivos tropicales. Centro international de Agricultural Tropical (CIAT), Cali, Colombia 28p.

[48] Howeler, R. H. (1985a). Potassium nutrition of cassava. In: Potassium in Agriculture. International Symposium held in Atlanta Ga. USA. July 7 – 10, 1985. ASA, CSSA, Soil Science Society of America, Madison, Wise, USA. 819 – 842.

[49] Howeler, R. H. (1985b). Mineral nutrition and fertilization of cassava. In: cassava: Research, Production and Utilization. UNDP – CIAT Cassava Program. Cali, Colombia. 249 – 320.

[50] Howeler, R. H. and Cadavid, L. F. (1990).Short and long-term fertility trials in Colombia to determine the nutrient requirements of cassava. Fertilizer Research, 26: 61 – 80.

[51] Howeler, R. H. and Cadavid, L. F. (1990).Short and long-term fertility trials in Colombia to determine the nutrient requirements of cassava. Fertilizer Research, 26: 61 – 80.

[52] Howeler, R. H., Edwards, D. G. and Asher, C. J. (1982).Micronutrient deficiencies and toxicities of cassava plants grown in nutrient solutions. J. Critical tissue concentration. Journal of Plant Nutrition. 5: 1059 – 1076.

[53] IITA (2008).Annual Report 2008.International Institute of Tropical Agriculture, Ibadan, Nigeria. Pp 54.

[54] Jennings, D.L. (1976). Cassava, Manihot esculenta (Euphorbiaceae). In: Simmonds, N. (ed.) Evolution of Crop Plants. Longman, London, pp. 81-84.

[55] Joergensen, K. (2005). Micronutrients: The New York Times publishing Company. Pp 5.

[56] Juo, A.S.R. and Ezumah, H.C. (1992). Mixed root-crop systems in wet Sub-Saharn Africa. In: Field Crop Ecosystems. (ed.) C.J. Pearson, Elsevier, Amsterdam. Pp. 243-258.

[57] Kabata-Pendias, A. (2001). Trace Elements in Soils and Plants (3rded) Lewis Pub. Boca Raton. Fl. 480 pages.

[58] Kamprath, E. J., Beegle, D. B., Hodges, S. C., Miller, R. O., Sims, J. T. and Mallarino, A. P. (2000). Relevance of Soil Testing to Agriculture and the Environment, CAST. Issue paper, No. 15:1-12.

[59] Kanwal, S., Rahmatullah, A. M. Ranjha and R. Ahmad (2010). Zinc partitioning in maize grain after fertilization with zinc sulphate. International Journal of Agricultural Biology. 12: 299-302.

[60] Kennedy, V. H., Sanchez, A. I., Oughton, D. H. and Rowland, A. P. (1997). Using of single and sequential chemical extractants to Assess Radionuclide and Heavy metal Availability from

soils for Root uptake: critical Review. The Analyst. Vol. 122: 89 – 100.

[61] Kparmwang T., Chude, V. O. Raji, B. A. and Odunze, A. C. (2000). Extractable micronutrients in some soils developed on sandstone and shale in Benue Valley. Nigeria. Nigerian Journal of Science Research. 1:42-48.

[62] Krishnamurti, G. S. R., Smith, L. H. and Naidu, R. (2000).Method for assessing plant-avaliable Cd in soils. Australian Journal of soil Research, 38: 823 – 836.

[63] Kyuma, K., Rosaki, T. and Juo, A. S. R. (1986).Evaluation of the fertility of the soils. In: A. S. R. Juo and Low (ed). The wetland soil and Rice in Sub Sahara Africa.Proceeding in International conference of Wetland Soil Utilization for Rice Production in Sub Saharan Africa. Pp 21

[64] Lal, R. and B. A. Stewart (1990). Soil Degradation: a Global threat. In: Advances in Soil Sciences. Vol. 11:345.

[65] Lars, J. M., Esu, I. and Moberg, J. P. (1993). Trace elements in some Northern Nigerian soils, commun. Soil Science and Plant Analysis. 24(7&8): 657-672.

[66] Leihner, D.E. (1983). Management and Evaluation of Intercropping Systems with Cassava.CIAT, Cali, Colombia, 70p.

[67] Lekanem, E.and Ervio, E. R. A. (1971). A comparison of eight extractants in soils of Soum Maatl Sey Julk 123: 223-226.

[68] Lindsay, W. L. and Norvell, W. A. (1979).Development of DTPA soil test for Zinc, Iron, Manganese and copper. Soil Science Society of America Journal, 42: 421 – 428.

[69] Marschner, H. (1993). Zinc uptake from soils in zinc in soils and plant (ed. Robson, A.D.), Klu, Wer Dordrecht, the Netherlands. Pp. 57-77.

[70] Marschner, H. (2002). Mineral Nutrition of High Plant.2nd Edn, Elsevier Sciences Ltd. Academic Press. New York.

[71] McBride, M. B., Richards B. K. and Steenhuis, T. (2004). Bioavailability and crop uptake of trace elements in soil columns amended with sewage sludge products. Journal of Plant and soil, 262:71-84.

[72] McLaughlin, M. J., Zarcinas, B., Steven, D. P. and Cook, N. (2000).Soil testing for heavy metals. Communication in Soil Science and Plant Analysis., 31:1661-1700.

[73] McLean, E. O. (1982). Soil pH in: L. A. page (ed) Methods of soil analysis. Agronomy Monogram. No. 9. America society of Agronomy. Madison, Wisconisn Vol. 2. 199-224 pages.

[74] Menzies, N. W., Donn M. J. and Kopitte (2007). Evaluations of Extractants for estimation of the phytoavaliable trace metals in soils. Environmental Pollution. 145: 121-130.

[75] Mitchell, R. L. (1998). Trace element in soils. In: Chemistry of the soil. (ed). F. E. Bear. Reinhold publ. corp. New York., 320 – 368.

[76] Mortvedt, J. J. (1994). Needs for controlled-availability micronutrient fertilizers. Fertilizer research. 38: 213-223.

[77] Nelson, D. W: and Somers, L. E. (1982). Total organic carbon and matter. In: Page, A. L. (ed.). Methods of Soil Analysis. Part 2 Chemical and Microbiological Properties (2nd Ed.). Agronomy series No. 9. ASA, Soil Science Society of America. Madison, Wis. Pp 570.

[78] NFC (National Fertilizer Centre) (1990). Literature Review on soil fertility investigation in Nig. The Fed.Min.of Agric. and National Resources, Lagos. Pp 24.

[79] Nwafor, O. E., Adepoju, S. O., Mba, A. A., Okonkwo, M. C., Emefiene, M., and Aminu, K. (2010). The effect of manual weeding intervals on yield of water melon (Citrulluslanatus) in Jos Metropolis, Nigeria. In: proceedings of the 24th Annual National Conference of Farm management Association of Nigeria. Pp 35 – 38.

[80] Nweke, F.I. (1994a). Cassava Distribution in Africa. COSCA Working paper No. 12. Collaborative Study of Cassava in Africa, IITA, Ibadan, Nigeria. Pp 8.

[81] Nweke, F.I. (1994b). Farm Level Practices relevant to cassava plant protection. African Crop Science Journal 2:563-582.

[82] Nweke, F.I., Ugwu, B.O. and Dixon, A.G.O. (1996).Spread and Performance of improved cassava varieties in Nigeria. Collaborative Study of Cassava in Africa (COSCA). COSCA Working Paper No. 15:43pp.

[83] Odurukwe, S.O., Udealor, A., Ikeorgu, J.E.G., Anuebunwa, F.O., and Iloka, A.W., (1996). Diagnostic Survey of Farming Systems in Southeastern State ADPs: A REFILS Project of NARP, NRCRI, Umudike. Pp. 49-50.

[84] Ogban, P. I., Akwue, I. P. and Mauako, O. (1999).Properties and management of catenary soils on coastal plain sands in southeastern Nigeria. In: Babalolu, O., U. Omoti and A. E. Isenmila (eds). Management of the soil resources of Nigeria for sustainable agricultural production in the 21st century. Proceedings of the 25th Annual conference of the soil science society of Nigeria, held in Benin. Pp 45 – 52.

[85] Okigbo, B.N. (1978). Cropping Systems and related research in Africa for the Advancement of Agricultural Science in Africa.AASA Publication Series OT-1 Addis Ababa, Ethiopia. 81pp.

[86] Okigbo, B.N., and Greenland, D.J. (1976). Intercropping Systems in Tropical Africa. In: Multiple Cropping. R.I. Papendick, P.A. Sanchez, and G.B. Tripplett (eds.), ASA Special Publication, 27. Madison, USA. Pp. 63-101.

[87] Olsen, K.M and Schaal, B.A. (1999). Evidence on the origin of cassava: phylogeography of Manihot esculenta. Proceedings of the National Academy Sciences of the USA 96: 5586-5591.

[88] Olsen, S. R., and Sommer, L. E. (1982). Available Soil P. in: Page et al., (ed). Methods of soil analysis. Part 2.Agron.Monogr.9(2nd edition). Pp 403-430. ASA and Soil Science society of American Journal. Madison WI.

[89] Onwueme, I.C. (1978). The Tropical Tuber Crops.John Willey and Sons. NY. 234 Pp. 12.

[90] Onwueme, I.C. (2002). Cassava in Asia and the Pacific. In: Cassava: Biology, Production and Utilization, (eds.) Hillocks, R.J., Thresh, J.M., and Belloti, A. CABI publishing, U.K. Pp. 55-65.

[91] Osiname, O.A. (2000). Soil Fertility in Nigeria, My Experience in Agronomy in Nigeria. M. O. Akoroda (ed): Department of Agronomy University of Ibadan. Nigeria. Pp 183-187.

[92] Oyinlola E.Y and Chude, V.O. (2010). Status of Available Micronutrients of the Basement Complex Rock – Derived Alfisols in Northern Nigeria Savanna. Tropical and Sub-tropical Agroecosystems Journal.Vol. 12(2): 229-249

[93] Puthacharoen, S., Howeler, R. H., Jantawat, S. and Vichukit, V. (1998). Nutrient uptake and soil erosion losses in cassava and six other crops in a psamment in eastern Thailand, Field Crops Research, 57: 113 – 126.

[94] Rahman, M. A, Jahiruddin, M. and Islam, M. R. (2007). Critical Limit of Zinc for Rice in calcareous soils. Journal of Agriculture and Rural Development. 5 (1&2): 43-47.

[95] Rego, T. J., Shrawat, K. L. Wani, S. P. and Pardhasardhi, G. (2007). Widespread deficiencies of sulphur, boron and zinc in Indian semi-arid tropical soils: on-farm crop. Journal plant Nutrition. 30: 1569-1583.

[96] Relhm G. and Schmitt M. (2002). Regents of the micronutrient zinc, University of Minnesota. Minesota.

[97] Relhm G. and Schmitt M. (2002). Regents of the micronutrient zinc, University of Minnesota. Minesota.

[98] Rengel, Z., Batten, G. D. and Crowley, D. E. (1999). Agronomic approaches for improving the micronutrient density in edible portion of field crops. Field crops Research. 60:27-40.

[99] Roa, A.C., Maya, M M., Duque, M.C., Tohme, J., Allem, A.C. and Bonierbale, M.W. (1997). AFLP analysis of relationships among cassava and other Manihot species. Theoretical and Applied Genetics 95:741-750.

[100] Sanka, M. and Dolezal, M. (1992). Prediction of plant contamination by Cd and Zn based on soil extraction method and contents in seedlings. International Journal of Environmental Analytical Chemistry, 46: 87 – 96.

[101] Sauerbeck, D. and Styperek, P. (1984). Predicting the Cadmium availability from different soils by CaCl2 extraction. In: processing and use of sewage sludge (Eds. P. L. Hermite, H. Ott). D. Reidel Publishing Co. 431 – 435.

[102] Schnug, E., Fleckenstein, J. and Haneklaus, S. (2001). Coca-Cola extractable for the evaluation of available micronutrient concentrations in soils for oil seed Rape. Institute of plant Nutrition and soil Science Fed. Agric. Research Centre, Germany. Pp 43.

[103] Schoeneberger, P. J., A. Wysocki, D. Benham, E. C. Broderson, W. D. (2002). Field Book for Describing, and Sampling Soils, version 2. National Soil Survey Center, Natural Resources Conservation Service, U.S. Department of Agriculture, Lincoln. Pp 47.

[104] Shuman, L.M (1999). Fractionation method for soil micronutrients. Soil Science. GEOBASE 140: 11-22

[105] Sillanpaa, M. (1990). Micronutrient assessment at the country levels: An International study. FAO Soil Bulletin No: 63:208. FAO/Finnish International Development Agency, Rome, Italy. Pp 19 – 22.

[106] Sillanpaa, M. (1990). Micronutrient assessment at the country levels: An International study. FAO Soil Bulletin No: 63:208. FAO/Finnish International Development Agency, Rome, Italy. Pp 19 – 22.

[107] Sillanpaa, M. and Janssen, H. (1992). Status of Cadmium, Lead, Cobalt and Selenium in Soils and Plants of Thirty Countries FAO Soil Bulletin 65. Pp 44 – 54.

[108] Simic, D., Sudar, R., Zdunic, Z., Jambrovic, A., Ledencan, T., Kovocvic, V., and Burkvic, I. (2009). Genetypic variability of bioavailable iron and zinc in grain of a maize population. Journal of Cereal Science. 27: 345 – 351.

[109] Sims, J. T., Johnson, G. V. (1991). Micronutrient soil tests. In: Mortvedt, J. J., Cox, F. R., Shuman, L. M., Welch, R. M. (Ed), Micronutrients in Agriculture, 2nd ed, Soil Science Society of America Journal Madison, WI, pp. 4.27-476.

[110] Sistani, K. R., Mays, D. A., Talyor, R. W. and Buford, C. (1995), C. (1995). Evaluation of four chemical extractants for metal determinations in wetland soils. Communication in Soil Science and Plant Analysis., 26:2167-2180.

[111] Soil Survey Staff (1999). Soil Taxonomy: a basic system of soil classification making and interpretation of soil surveys. Agric. Handbook. No. 435. Washington, D. C. USA.

[112] Sorensen, R. C., Oelsligle, D. D. and Knudson, D. (1971). Extraction of Zn, Fe and Mn from soils with 0.1N Hcl as affected by soil properties solution: soil ratio and length of extraction period. Journal of Soil Science. 111: 352-359.

[113] Steel, R. G. D. and J. A. Torrie (1980). Principles and Procedures of Statistics, 2nd ed Tosho Printing Tokyo, Japan., 633pp.

[114] Taker, P. N. and Walker, C. D. (1993). The distribution and correction of zinc deficiency. In: Zinc in soils and plants. Robson, A. D. (ed), Kluwer acad. Plubl. Dordrecht. Pp 151 – 165, The Netherlands.

[115] Thomas, G. W. (1982). Exchangeable Cations. In: Page, et al., (ed). Methods of soil analysis.Part 2.Agronomy Monogram 9 (2nd edition). Pp 159-165. ASA and Soil Science Society of America. Madison, Wisconsin.

[116] Udo, E. J. and Fagbami, A. A. (1979). The profile distribution of total and extractable Zn in selected Nigerian soils. In: Communication in Soil Science and Plant Analysis. 10(8): 1141-1161.

[117] Udoh-Bassey, T. I. Esu, I. E., Ibia, T. O. Onweremadu, E. U. and Unyienyina, B. E. (2013). Agricultural Potential of the Beach Ridge soils of the Niger Delta, Nigeria. Malaysian Journal of soil science. Vol. 17: 17 – 37.

[118] Ugwu, B.O., Ajobo, O. and Orkwor, G.C. (1989).Cassava research, production, and utilization in Nigeria.In F.I. Nweke, J. Lynam and C. Prudencio (eds.) Status of data on cassava in major producing countries in Africa (Cameroon, Cote d'Ivoire, Ghana, Nigeria, Tanzania, Uganda and Zaire). COSCA Working Paper No. 3. Collaborative Study of Cassava in Africa, IITA, Ibadan, Nigeria. Pp. 11-18.

[119] Vanlanwe, B., Aihon, K. Iwuafor, E. N. O. Houngnandan, P. Diels, J. Manyoung, V. M. and Sanginga, N. (2002). Recent development in soil fertility management of maize-based systems. In: the role of legume in N and P nutrition of maize in the moist zone of West Africa. Pp 27.

[120] Welch, R. M. (1995). Micronutrient nutrition of plants. Critical Reviews. Journal of plant science. 14 (1): 49 – 82.

[121] Welch, R. M. and Graham R. D. (2002). Breeding crops for enhancing mineral content. Journal of Plant and Soil 245: 205-214.

[122] Welch, R. M., Alloway, W. H. House, W.A. and Kubota, J. (1991). Geographic distribution of trace element problems, In: Mortvedt, J. J. Cox, F. R., Shuman, L. M., Welch, R. M. (ed). Micronutrients in Agriculture, 2nded, Soil Sci. Soc. Am. Madison, WI. Pp 31 – 57.

[123] White, J. G. and Zasoki, R. J. (1999). Mapping soil micronutrients. Field crops Research. Vol. 66: 1 – 2 (11 – 26).

[124] Whitney, D. A. (1988). Micronutrient soil test zinc, iron, manganese and copper. P. 20 – 22. In: W. C. Dahuke (ed). Recommended chemical soil test procedures for the North Central Region. North Dakota Agricultural Extension Station. Bulletin. 499. Review.

[125] Yusuf, A. A., Abdu, N. Chude, V. O. Yusuf, H. A. and Pam, S. G. (2005). Response of maize (Zea mays L.) to zinc fertilization in relation to Mehlich I extractable zinc in northern Nigeria. Nigeria Journal Soil Research., 6: 32-41.

Citation: *UGWU, C. C., Asawalam, D. O., Eteng, E. U., Ano, A. O., "Determination of Zinc Requirement of Cassava (Manihot Esculenta Crantz) in Soils Derived from Coastal Plain Sands of South Eastern Nigeria", International Journal of Research Studies in Science, Engineering and Technology, vol. 7, no.2, pp. 7-22, 2020.*