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Full Length Research Paper

Effect of Zinc Application Rates on Manihot esculenta Yield Grown in Coastal Plain Sand Soils of Nigeria

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Two experiments at greenhouse and field scale were undertaken to determine the optimum rate of zinc sulphate for cassava tuber production in coastal plain sand derived soil of southeastern Nigeria. The results of greenhouse experiment showed that the application of Zn into the soils significantly ($P < 0.05$) increased cassava dry matter production, concentration, uptake and tuber yields. The estimated optimum rates for Zn under greenhouse environments were established at 7 kg Zn ha^{-1} for Zn uptake of cassava shoots. Also established were optimum Zn levels of 12, 13 and 15 kg Zn ha^{-1}, and maximum cassava tuber yields, respectively. In conclusion, it is recommended that application of zinc sulphate at a rate of 15 kg Zn ha^{-1} is essential for cassava production (t ha^{-1}) at coastal plain sand derived soils of southeast agro-ecological zone of Nigeria.

Keywords: Cassava, coastal plain sand, nutrient uptake, optimum yield, tuber yield and Zn levels

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) has been declared as one of the most important root crops in the world, and has contributed greatly to the economic growth (IITA, 2017; FAO, 2016). Cassava is a high-valued root crop consumed in many households in different parts of Nigeria as staple food (Onwueme, 2002) and it constitutes important ingredient and raw material in animal feed production, brewing industry, bakery industry and as starch in textile industry (FAO, 2018; IITA, 2018). However, sustained cultivation of cassava has been marred by decreased land productivity that is linked to soil infertility (Enwezor *et al*., 1981; FAO, 2016; Gichuru *et al.,* 2003).

Although farmers in South Eastern Nigeria grow both local and various genetically improved cassava (*Manihot esculenta* Crantz) varieties with high yielding potential, crop yields have been observed to be very low, rarely exceeding 10.0 t ha^{-1} in an average farmers field (Chude *et al.,* 2004; CBN, 2015). The low root crops yields gave rise to the suspicion of possible deficiencies of other important essential nutrients (Sillanpaa, 1990; Brennan and Bolland, 2002) and could be attributed in part to the absence of some micronutrients in fertilizers available in the region (Oyinlola and Chude, 2010).

Production of cassava tuber is likely to increase if there is sufficient supply of essential micronutrients (Cu, Fe, Zn and Mn) (Oyinlola and Chude, 2010), especially with the development of improved high yield cassava varieties (IITA, 2018). As the crop nutrient removal increased with high yields of crops, soil reserves of plant nutrients, particularly Zn began to deplete, resulting in nutrient deficiencies and lower yield (Brennan and Bolland, 2002; Broadley *et al*., 2007). Available information on soil micronutrients status of soils formed from coastal plain sands in South Eastern Nigeria is currently limited. However, investigations carried out so far have revealed that there is Zn deficiency in some coastal plain sandy soils of South Eastern Nigeria (Eteng *et al.,* 2014; Essien and Eteng, 2016). The objectives of this study were to: (i) evaluate the levels of Zn in coastal plain sand soils, and (ii) to assess whether the addition of Zn would increase cassava yields in the soils and, possibly, in other soils

Table 1. Mean climatic data of the experimental site during the 2018 cropping seasons.

Month	Rainfall (mm)	Temperature (°C)	Relative Humidity (%)	Sunshine duration (hd^{-1})	Wind speed (kmh^{-1})	ETo (mmd^{-1})
Total	2252.95	345.45	838.21	51.94	109.1	42.45
Mean	187.75	29.79	69.02	4.23	9.09	3.59

Key: ETo = reference crop evapotranspiration

with similar characteristics.

MATERIALS AND METHODS

Location of study area

The study was conducted in a coastal plain sand derived soils across three contiguous states in South-Eastern, region of Nigeria; Abia, Akwa Ibom and Imo. The location in Abia State lies between longitude 07° 33' E and latitude 05°20' N at an elevation of 122 m above sea level and located within the southeast tropical rain forest and agro-ecological zone of Nigeria (Chude, *et al.,* 2012; Enwezer, *et al.,* 1981). The location in Akwa Ibom state lies between longitude 7°30' and 8°20' E and latitude 4°30' and 5°30' N and elevation of 120 m above sea level also in the tropical rain forest and agro-ecological zone of South East Nigeria (Udo *et al.,* 2008), while the location in Imo State lies between longitude 9°21' E and latitude 7°26' N at an elevation of 123 m above sea level also in the tropical rain forest and agro-ecological zone of South East Nigeria. The mean climatic data of the experimental sites during the 2018 cropping seasons are presented in (Table 1). The soils are mainly derived from coastal plain sands and alluvial deposits.

Soil sampling and sample preparation

Composite surface (0-20 cm) soil samples were collected in 2016 from 20 different cultivated and uncultivated areas formed from coastal plain sands (CPS) parent materials. The samples were air dried and screened through a 2 mm sieve for soil physical and chemical analyses. Sub samples of 200 g was crushed with agate mortar and pestle and subsequently sieved through a 0.5 mm sieve for the determination of organic carbon and extractable Zinc.

Soil sample analysis

The twenty (20) soil samples were analyzed according to the universally acceptable standard methods of analytical procedures. Particle size distribution analysis was determined by the hydrometer method as reported in Gee and Or, (2002). Soil samples were dispersed in 5 percent sodium hexameta-phosphate solution. Soil reaction (pH) was determined with a combined glass electrode pH meter in a 1:2.5 soil: water ratio (Thomas, 1996). Soil organic carbon was measured using the wet oxidation colorimetric method (Nelson and Sommers, 1996).The organic carbon values were multiplied by the Van Bremelen factor of 1.724 based on the assumption that organic matter contains 58% carbon. Exchangeable cations were extracted with neutral ammonium acetate and the Na and K contents were determined using flame photometer method whereas the Mg and Ca contents were determined by the EDTA complexometric titration method. Total exchangeable acidity (TEA) was determined using Mclean (1982) method. Total exchangeable bases (TEB) were obtained by summation of exchangeable cations (Ca, Mg, K and Na) values (Thomas, 1996). Effective Cation Exchange Capacity (ECEC) was calculated as the sum of TEA and TEB (Sumner and Miller, 1996). Available Zn was extracted using the 0.1M HCl (Whitney, 1988).

Pot experiment

The greenhouse study was conducted in 2016 cropping season to determine the optimum rate of Zn on cassava Zn uptake, having in the preceding laboratory study observed zinc to be one of the most limiting micronutrients in the soils. A total number of 450 plastic pots (10 soil locations x 5 Zn levels x 3 replications) were arranged in CRD. Each of the plastic pots was filed with air-dried 5.0 kg of soil samples where the cassava variety TMS 01/1368 (UMUCASS 38) stem cuttings were sown. 120 kg N ha^{-1} (mg N kg^{-1} soil) as Urea, 60 kg P_2O_5 ha^{-1} (mg P kg^{-1} soil) as single super phosphate (SSP) and 60 kg K_2O ha^{-1} (mg K kg^{-1}) as muriate of potash (MOP), respectively, as a basal N, P, and K fertilizer, were respectively applied uniformly to all the containers in solution form, at two weeks after planting (WAP) and different levels of Zn ($ZnSO_4.7H_2O$): 0.0, 2.0, 4.0, 6.0 and 8.0 $kgha^{-1}$ were applied in solution form. The soils in the pots were maintained at approximately field capacity during the experimental period by watering with deionized water. Plant shoots were harvested at 42 d after planting by cutting the stems at 1.0 cm above the soil surface. Plants were dried at 70°C to a constant weight for 72 hours and weighed for dry matter yield (DMY) was determined. The dried plant samples were cut into small pieces and ground to pass through a 0.5-mm sieve for analysis.

The samples were then digested with a mixture of a tri-acid using sulphuric acid (H_2SO_4), Nitric acid (HNO_3) and Perchloric acid ($HClO_4$) digestion method (Shuman, 1985) in Teflon crucible, and heated on a hot plate. The digest was filtered and the filtrate or extract was analyzed for micronutrient content (conc. mg kg^{-1}) using AAS. Nutrient Uptake (mg $plant^{-1}$) of the cassava plant was determined by the product of the dry matter yield (g $plant^{-1}$ DMY) and nutrient concentrations of Zn, Fe and Mn (mg kg^{-1}) in the plant.

Field experiment

Field experiments were conducted in late 2016 and in early 2017 and 2018 cropping seasons to estimate the optimum zinc level and maximum cassava tuber production (tha^{-1}) in coastal plain sand soil. The experimental area was located at Umudike, a typical degraded humid forest zone of southeastern Nigeria. It is located between latitude 05°29[1] N and longitudes 07°33[1] E and at an elevation of 122 m above sea level (NRCRI, 2008). A long-term weather study of Umudike shows a monthly mean minimum temperature range of 21-24° C and mean maximum temperature range of 29-34° C (NRCRI, 2008). The humid environment has an average rainfall of about 2200 mm per annum (NRCRI, 2017).

Experimental design, field plan and treatments

A cassava variety TMS 01/1368 (UMUCASS 38), a yellow tuber stem cuttings of approximately 4-5cm in length and with 6-7 nodes were arranged according to a randomized complete block design (RCBD) was used in this experiment, with 5 treatments, and the treatments were replicated four times to give 20 experimental plots. The dimensions of each experimental plot were 5.0 by 4.0 m, with interblock and interplot spacing of 1 and 0.5 m, respectively. A 2 m-wide pathway was maintained around the entire experimental area. The cassava cuttings were sown at the spacing of 1m x 1 m. NPK fertilizer rates of 120kg N ha^{-1} as urea; 60 kg P_205 ha^{-1} as single super phosphate, SSP, and 60 kg K_2O ha^{-1} as murriate of potash, MOP as basal NPK broadcasting and different levels of Zn ($ZnSO_4.7H_2O$): 0, 4, 8, 12 and 16 $kgha^{-1}$ were applied one week after germination, to all the respective experimental plots recommended for the southeast region (Enwezor *et al.,* 1981).

Determination of optimum rate of Zn for cassava tuber in soils of the study area

The optimum rates of the Zn application was determined following graphical method using Microsoft Excel 2007 to obtain Regression equations which when differentiated produced X-values representing optimum rates of fertilizer application in the soils.

Statistical analysis

The data collected were subjected to analysis of variance (ANOVA) procedure, using general linear model using general linear model of Genstat (2013) and PASW Statistics 18 for Window 7.0, Significant means were separated using Fisher's least significant difference (LSD) and appropriated at P<0.05 (two-tailed). Also Pearson correlation as well as regression analyses at different probability levels were conducted to evaluate the association between soil properties and extractable Zn in soils and to predict optimum yield. The graphical analysis was performed using PASW Statistics software, version 18 for Window 7.0.

The highest correlation coefficient (r) with the cassava uptake was recommended for the determination of available Zn content of the coastal plain sand soils. The statistical model used for data analysis was as described by Snedecor and Cochran, (1989):

$$Yij = \mu + Ti + \beta j + Eij \text{ for } i + 1,2,\ldots b$$
$$j = 1, 2,\ldots t$$

where

Yij = observation for each of the treatments
μ = overall mean
Ti = effects due to treatments
βj = effects due to the block
Eij = variation within treatments and blocks (i.e., error term)

RESULTS AND DISCUSSION

Soil properties of the study site

Some physical and chemical properties of the experimental soils derived from coastal plain sand presented in (Table 2), showed that, the pH of the soil is 4.67 and is rate as low (Chude *et al*., 2012). The optimum soil pH range for cassava production is between 5 and 7 (Chude *et al*., 2012).

The pH of 4.67 could be considered suitable for crop production when other soil and plant factors are not limiting. Soil organic matter in soil was found to be 1.06%. This value is rated to be low according to Landon (1991) and Tandon, (1995). The low organic matter could be explained by the fact that coastal plain sand derived soils normally have low organic matter content (Chude *et al*., 2012; Eteng *et al*., 2014).

Table 2. The mean physical and chemical characteristics of the coastal plain sand soil (N = 20).

Soil characteristics	Levels	Rating
Particle size distribution		
Sand fraction g kg^{-1}	724.23	-
Silt fraction g kg^{-1}	165.04	-
Clay fraction g kg^{-1}	110.73	-
Soil Texture	-	Sandy loam
Chemical properties		
pH (H_2O)	4.88	Very strongly acidic
SOM g kg^{-1}	1.93	Low
ECEC cmol kg^{-1}	10.86	Low
BS %	66.88	Marginal
Total Zn mg kg^{-1}	123.54	Moderate
HCl-Extractable Zn mg kg^{-1}	0.18	Low

Table 3. Concentrations and uptake of Zn on cassava dry matter (DM) yield in a pot experiment.

Zn Levels (kg ha^{-1})	Dm Production (g plant^{-1})	Zn Conc. (mg kg^{-1})
0	15.70	36.16
2	38.35	66.58
4	40.40	85.58
6	58.95	109.71
8	54.24	97.19
10	51.62	89.34
Mean	43.21	80.76
LSD (P<0.05)	5.01	2.54
CV (%)	12.15	15.22

Concentration of available zinc in the soil before the experiment

The HCl extractable Zn was found to be 0.18 mg·kg^{-1}. Accordingly, (Tandon, 1995; Kparmwang *et al*., 2000) reported that the critical level of HCl-extractable Zn in the soil ranged from 0.2 to 1.0 mg·kg^{-1}; therefore, an HCl-extractable Zn level of 0.19 mg·kg^{-1} in the soil is deficient, since it is below the soil critical levels as reported by Alloway (2004).This finding is also in agreement with the report presented by (Abdu *et al*., 2007) elsewhere in savanna soils of Northern Nigeria. The low available Zn in the soil, may be attributed to their low content in the parent material (Akamigbo and Asadu, 1983), low soil organic matter (Ano and Agwu, 2005) and sorption or redox potential due to the prevailing pH of the soil (Eshiet, 1992).

Glasshouse pot experiments

Response of cassava DM and Zn concentration to different levels of Zn applied in the greenhouse

A dramatic effect on DM yields was observed in the Zn treatment, which significantly (P<0.05) increased DM yields from 15.70 to 58.95 g pot^{-1} with an average of 43.21 (Table 3). The very dramatic effect of Zn in increasing the DM yields suggests that Zn is a limiting nutrient in the coastal plain sand soil of southeastern Nigeria, and hence the significant (P < 0.05) increase in yields following its use. The concentrations of Zn in cassava shoots are shown in (Table 3). Zinc application increased Zn concentrations significantly compared with the control, signifying that Zn was one of the limiting nutrients in this soil and it was in this treatment where significantly higher DM yields were obtained. Zinc concentrations in cassava shoots ranged from 36.16 to 109.71 mg kg^{-1} with an average of 80.76 mg kg^{-1} (Table 3) and, these were within the critical range of 25 to 60 mg kg^{-1} established by Melsted *et al.* (1969) and Tisdale *et al.* (1993). Similarly, soil analysis data for Zn indicated that coastal plain sand soil had a marginal level of Zn. Addition of Zn in the soil after the application of 6 kg Zn ha^{-1} did not increase Zn concentrations in cassava shoots significantly, probably due to a dilution effect as a result of the increase in DM.

Estimation of optimum zinc levels for cassava production in coastal plain sand soil

Response of Zn uptake to different levels of Zn applied in the greenhouse experiment

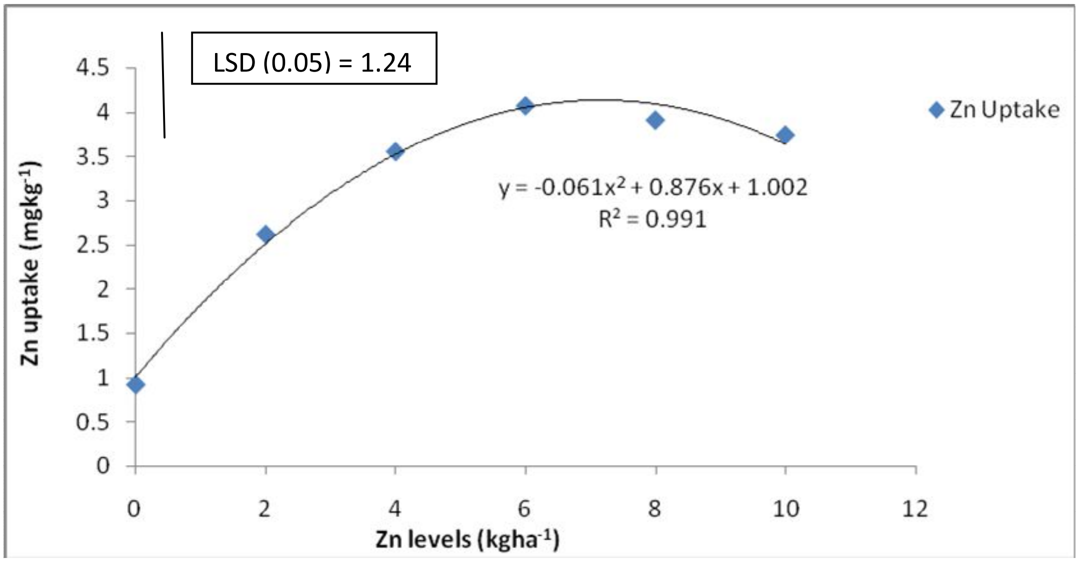

Figure 1. Optimum levels of Zn uptake on cassava plants in greenhouse study. Vertical bar represents LSD at 0.05.

Zinc application increased Zn uptake in cassava shoots significantly ($P < 0.05$), compared with the control, with LSD (0.05) of 1.24 indicating that Zn must have been one of the limiting nutrients in the soil (Fig. 1) and it was also in this treatment level where significantly, higher Dm yield and Zn concentration (Table 3) was obtained. The incremental addition of ZnSO4 to the soil significantly ($P < 0.05$) improved Zn uptake in cassava, leading to the maximum increase in Zn uptake of cassava shoots and this was obtained in Zn applied at 6 kg Zn ha^{-1} over the control treatment (Fig. 1). This result may be due to the increase in either DM yield or Zn concentration which accumulated Zn content in the various plant shoots. It is however, noted in (Figure 1) that, Zn uptake was significantly ($P < 0.05$) increased according to levels of Zn fertilizer applied, while at 8 kg Zn ha^{-1}, Zn uptake in cassava declined to 10 kg Zn ha^{-1} level. Furthermore, the polynomial regression analysis computed for Zn uptake ($Y = 1.0023 + 0.8766X - 0.0612X^2$; $R^2 = 0.991$) indicated that the optimum level for Zn uptake in cassava shoots as influenced by levels of Zn was determined to be 7 kg Zn ha^{-1} in the soil under reviewed. The result of this study indicates that the soils of coastal plain sands exhibited a highly variable capacity to accumulate Zn due to Zn supplement, less fixation and greater transport of the nutrient to plant roots.

Cassava tuber yields

The results in (Figure 2 and Table 4) showed that maximum tuber yields were obtained with the optimum rates of 12.14, 12.75 and 15.43 kg Zn ha^{-1} and minimum were recorded in the control plot for 1st, 2nd and 3rd cropping seasons, respectively. It is also evident from Fig. 2 that all the zinc treated plots significantly ($P < 0.05$) increased the tuber yields over the control, as there was a consistent increase in tuber yield up to 12 kg Zn ha^{-1}, in the first and second cropping seasons and 15 kg Zn ha^{-1} in the third seasons cropping however, further addition did not significantly result in corresponding yield increase (Fig. 2). This may be due to Zn levels in the soils and further observed that, the application of Zn significantly ($P < 0.05$) influenced the increase in cassava tuber yield. However, the low cassava yield obtained from the control plots suggests that the soils were actually deficient in Zn available to the plants, being that this level is critical for growing cassava. Generally, the tuber yield enhancement at these optimum levels suggest that, these are the levels required for maximum cassava production for three consecutive cropping seasons in the soils under review.

Moreover, considering the low levels of Zn uptake by cassava plants (Figure 1) and the maximum tuber yield obtained at about 12 kg Zn ha^{-1} in the first cropping season (Figure 2 and Table 4), higher tuber yields beyond the 33 t ha^{-1} may be obtained from the soil under review, if the Zn supply and other agronomic conditions are optimized. A Zn level of at least 15 kg ha^{-1} is suggested, on the basis of the second and third cultivation, as the level that can optimize cassava yields under the currently used nutrient application rates. It is an impression that $ZnSO_4$ application at this level could be appropriate for cassava production in the soils (Alloway, 2004; Abdu *et al.*, 2007). However, the application of Zn fertilizers to the cassava crop in different

Table 4. Maximum yield, optimum Zn level and coefficient of determination.

Cropping season	Tuber yield prediction (Regression equation)	Maximum tuber yield (tha^{-1}) (Y)	Optimum Zn level ($kgha^{-1}$) (X)	Coefficient of determination (R^2)
First	$Y = 9.3134 + 3.9663x - 0.1634x^2$	33.38	12.14	0.98
Second	$Y = 8.0494 + 3.0843x - 0.1209x^2$	27.72	12.75	0.99
Third	$Y = 4.8451 + 2.2414x - 0.0726x^2$	22.13	15.43	0.90

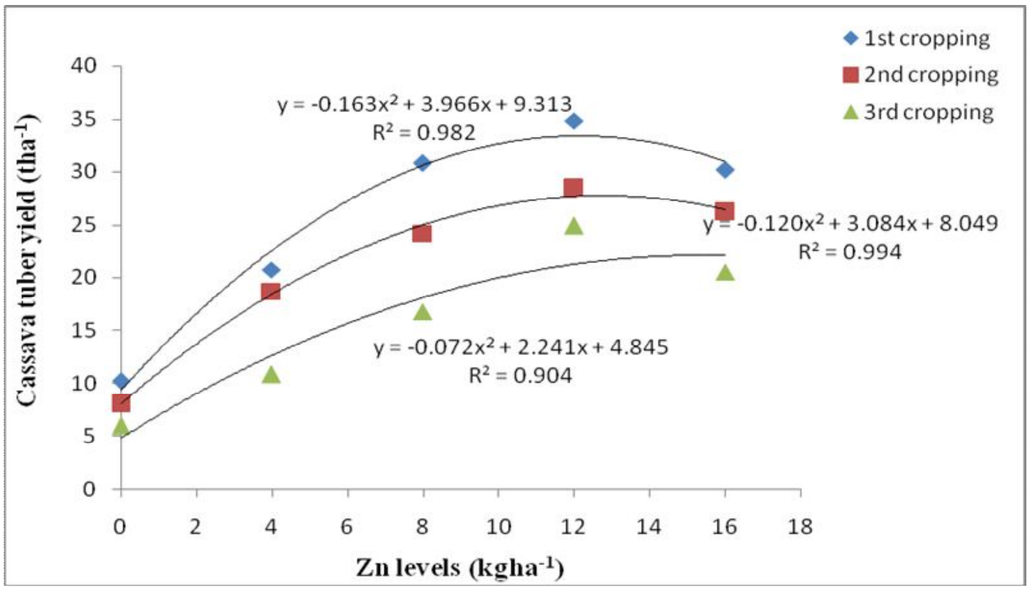

Figure 2. Estimation of optimum zinc level for cassava production in coastal plain sand soil.

cropping seasons, not only enhances its production in the soils, but also increases tissue content and this can cure the micronutrients deficiency problem in human nutrition (Rengel *et al.,* 1999; Welch, 2002; White and Brown, 2010). Moreover, the response of cassava tuber as influenced by levels of Zn fertilizers in successive field experiments are in agreement with those obtained from greenhouse experiments.

Conclusion

The use of Zn fertilizer improved cassava tuber yields appreciably. A greenhouse experiment estimated approximately a level of 7 kg Zn ha^{-1} to be optimum levels for Zn uptake in cassava shoots in the study area. While, the application of Zn fertilizer in the field yielded maximum tuber yields of about 33, 27 and 22 tha^{-1} at the rate of approximately, 12, 13 and 15 kg Zn ha^{-1}, for first, second and third cropping, respectively. The rate of 15 kg Zn ha^{-1} is recommended for the immediate objective of increasing cassava tuber yields for an appreciable residue effect of subsequent cassava cultivation and to account for sorption factors in the study area, and to ensure that the yield potential is reached after optimization of Zn application.

Further research on the chemistry and adsorption of Zn soil should also be performed to identify the adsorption or retention characteristics of this soil for sustainable cassava production, because management of nutrients seems to be very challenging under these circumstances, and to ensure that the yield potential is reached after optimization of Zn nutrition.

Authors' declaration

We declared that this study is an original research by our research team and we agree to publish it in the journal.

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