CRITICAL LIMITS AND ZINC REQUIREMENT FOR MAIZE (*Zea mays L.*) PRODUCTION IN ACID SOILS OF SOUTH-EASTERN NIGERIA

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Abstract
The study was conducted to determine available Zn in the soils, evaluate the critical limits of Zn for maize and then establish optimum rate of Zn fertilizer required to achieve maximum Zn uptake and grain yield in maize producing area of southeastern Nigeria. Results of the 20 surface (0-20 cm) soil samples analyzed were sandy loam (SL), very strongly acidic (4.62) in reaction, low in organic carbon (0.98 gkg^{-1}) and in ECEC (8.15 cmol kg^{-1}). The status of available Zn in the soils by different extractants were found to be very low and ranged from 0.38 $mgkg^{-1}$ to 2.24 $mgkg^{-1}$ extracted by NH_4OAc, and Coca-Cola methods, respectively. The critical limits of Zn in the soils and maize plant, below which high response of applied $ZnSO_4$ to maize could be expected were determined by Cate-Nelson according to the extraction methods as: 0.90-1.52, 1.10-1.65, and 0.70-1.13, 2.40-3.92 and 2.50-4.24 $mgkg^{-1}$ for Coca-Cola, EDTA, HCl, NH_4OAc + EDTA and NH_4OAc, respectively. The results of the pot and field experiments shows that levels of Zn significantly ($P<0.05$) increased both DMY and grain yields. Approximately 11 kg Zn ha^{-1} was estimated to be the optimum level of $ZnSO_4$ required for Zn uptake in maize producing for soils of southeastern Nigeria. Similarly, in the field experiment, Zn fertilizers significantly improved grain yields. The application of $ZnSO_4$ fertilizer yielded maximum grain yield of 7.9 and 5.1 tha^{-1} at the optimum rates of 9.0 and 9.6 kg ha^{-1} in the 2009 and 2010 plantings.

Keywords: Acid sand, critical limit, extractable Zn, maize grain, optimum yield and $ZnSO_4$ fertilizer

Introduction
Maize (*Zea mays*, L) is an important high value cereal crop consumed in many household in Nigeria after wheat and rice (FAO, 2015; Nuss and Tanumihardjo, 2010). The crop has great economic value which serves as feed for livestock and poultry production and in recent era, is being processed as raw materials for several agro-based industrial products and food for human consumption (Iken et al., 2002). However, average yield of maize in southeastern part of Nigeria is far below compared to maize grown in savanna soils of northern Nigeria (Ojanuga, 2006). One of the important factors in increasing maize production is supply of sufficient amount of nutrient elements (Alloway, 2008). The poor performance of maize grain yield leads to the suspicion of possible deficiencies of Zn nutrient (Sillanpaa, 1982; Kabata-Pendias, 2010). Because the soils are low in organic matter, CEC and clay which is predominantly kaolinitic and very strongly acid in nature. These characteristics are often associated with low levels of available Zn (Enwezor et al., 1981; Chude et al 2004). Zinc-deficient soils generally do not support optimum crop yields because plant growth becomes retarded by the deficiency leading to low yields (Sillanpaa, 1990). Since plants absorb nutrient element from the soil, one can make a relationship between soil nutrient levels and plant response (Cate and Nelson, 1965). This relationship is often made through soil testing and calibration studies. Several chemical soil test methods have been used to extract Zn from soil in an attempt to correlate the status extracted with the nutrient uptake by the plant (Sillanpaa, 1990)**.** The determination of critical level of micronutrients in the soil is most principle basis for fertilizer recommendation in annual

crops like maize (Malakouti and Gheybi, 1997; Kanwal, et al., 2010). The general critical levels of Zn deficiency in soils and crops falls in the range of 0.6 – 1.0 $mgkg^{-1}$ and 10-20 $mgkg^{-1}$ in dry matter, respectively (Badole et al., 2001); Sharma, 1991; Feiziasl et al., 2009) but, vary with soils and crops (Tariq et al., 2002; 2014). For clear prediction of possible deficiencies, the critical limits must be refined with reference to the soil characteristics and plant components for individual crop as the soils and crop vary widely in their nutrient supplying and utilization efficiency (Srinivasan et al., 2009). The critical limits is quite often used for wide range of soils and crop varieties. However, the critical limits may be different among the soil types and crop varieties. The limits for critically distinguishing Zn deficiency in soils and plants are well reported by many research workers for several crops under deficient soil conditions (Tariq et al., 2002; 2014; Badole et al., 2001); Sharma, 1991; Kanwal et al., 2010; Feiziasl et al., 2009). The determination of critical nutrient level (CNL) of the plant in soil is essential in predicting response of crops to nutrient fertilization. The technique was found useful for a number of crops (Abdu et al., 2007). Another useful concept widely used to relate the soil nutrient, plant nutrient and crop yield in crop production is the optimum concentration level (Calmak, 2008). Suitable fertilizer recommendation can be presented by calibration experiments with crop response results for each crop (Abdu et al., 2007). The aim of the study was to determine available Zn in the soils, evaluate the critical level of Zn and then establish optimum rate of Zn fertilizer required to achieve maximum grain yield of maize in the soil.

Materials and Methods

Sampling Site, Collection and Laboratory Analysis

The sampling sites selected covered a wide range of soil types from 20 locations representing soils across Southeastern Nigeria (Table 1) which is located at Latitude 4^o 20’ and 7^o 25 North of the Equator and Longitude 5^o 25’ and 8^o 51’ East of the Greenwich meridian (Ojanuga, 2006). A laboratory study was conducted on these surface (0-20) soils to determine some physical and chemical properties (Table 3). The soil samples were air-dried and screened through a 2 mm sieve. The 2 mm sieved soils were analysed for particle size analysis by the hydrometer method (Gee and Bauder, 1986); Soil pH (soil: water ratio of 1: 2.5) was determined with a combined electrode pH meter (Thomas, 1996); Soil organic carbon was determined by the potassium dichromate wet oxidation method (Nelson and Sommer, 1996) and the content of the organic carbon was converted to organic matter (OC x 1.724) while, the effective cations exchange capacity (ECEC) was determined by the method described by Sumner and Miller (1996). For the estimation of available Fe contents in soils, the following chemical properties of the extractants as shown in Table 2 were used.

Screen-house Study

The experiment was conducted on soils collected from 20 locations in southeastern Nigeria to evaluate the critical levels and optimum rate of Zn required to maximize growth and Zn uptake in maize shoots. Maize (Zea mays L.) var. Oba supper-2-Y was used as the test crop. Five kilogrammes of soil each from 20 locations were weighed into plastic pots of 7 L capacity placed on flat plastic receiver. The pots were arranged in completely randomized design (CRD), replicated four times to give a total of 400 (20 soils x 5 rate x 4 reps.) pots for each soil. A recommended basal dosage of N, P_2O_5 and K_2O at rates of 120, 60, 60 $kgha^{-1}$ were applied as urea, single super phosphate and potassium sulphate, respectively (Ewerzor *et al.*, 1981). Treatments consists of five levels of Zn (0, 4, 8, 12 and 16 kg ha^{-1}) converted to mg kg^{-1} and applied as $ZnSO_4.7H_2O$. Both the NPK and Zn treatments were applied as solution to all 400 pots. Before planting, the soils in all the pots were moistened with distilled water to field capacity. Six maize seeds were sown in each pot and thinned to four plants pot^{-1}, 7 days after sowing (DAS). The plants (shoots and roots) were harvested 42 DAS, rinsed in distilled water, pre-dried under shade to remove excess water and later placed in large envelopes and oven-dried at 65°C for 72 hrs. The oven-dried plants parts were weighed and recorded for dry-matter yield. The dried plant samples of each pot were separately ground into powder in a warring stainless steel grinder to pass through a 0.5 mm. The dry powdered plant samples were digested in a tri-acid mixture of 10:2:1 of HNO_3: $HClO_4$: H_2SO_4 on a hot plate and filtered through Whatman No.42 for estimation of Zn. Atomic Absorption Spectrophotometer (AAS) (Unicam Solaar 32: Zn ASTM D1688) was used to measure the concentration of Zn in the digest. Zn uptake in plant shoots (mg plant^{-1}) were calculated by multiplying the dry matter yield (g plant^{-1}) by the concentration (mg kg^{-1}) in plant materials.

Field Studies

Two years (2010 and 2011) field experiments for maize crop were conducted in Calabar, Cross River State, located within Latitude 4° N' and 7° N', and Longitude 8° E' and 8.30° E' and in southern part of the rain forest zone of Nigeria, to study the effects of various levels of Zn on grain yield and yielding component. The field was fairly flat and had been under continuous and intensive cultivation without Zn fertilization. The soil was classified as Psammentic Paleudult according to USDA and FAO soil classification systems, respectively (Ibanga and Udo, 1996). The parent materials of the area consist of tertiary coastal sand deposits identified as quaternary (Ibanga and Udo, 1996). The field experiments were laid out in randomized completely blocks design (RCBD) with four replications to give 28 (7 treatments x 4 reps.) sub-plots. Each block had seven plots, with plot sizes of 5.0 x 4.0 m (20 m^2). The same maize (Zea mays L.) variety Oba Supper 2-Y was sown as the test crop. Four maize seeds per hole were sown manually at 75 cm by 25 cm. 14 days after emergence, thinning was performed to two per hole in order to maintain uniform number of plants in all the plots. In the first cropping year (2010), Zn fertilizer was applied at seven rates: 0, 2, 4, 6, 8, 10, 12 kg Zn ha^{-1} as $ZnSO_4.7H_2O$ and its residual effect was evaluated on the second year (2011) maize crop. Recommended doses of 120 kg N, 30 kg P and 60 kg K fertilizers per hectare were soil-applied uniformly as urea, single super phosphate, and muriate of potash, respectively to all the plots at sowing. The application was carried out by mixing the recommended Zn dose with the NPK fertilizers and applied by band placement. In the second cropping year (2010) the trial was repeated without applying any fertilizer except for the repeat of the NPK fertilizer.

All the recommended cultural practices were followed uniformly throughout the two planting seasons. Agronomic parameters taken were; plant height, grain yield and dry matter yields. Maize grains were harvested at physiological maturity (120 DAP) and grain weight was taken at 14 % moisture content. The maize plants were grown till maturity, after which cobs were harvested at 120 days and grain weight was taken at 14 % moisture content and shelled; grain yields were measured and converted into tones ha^{-1}. Maize grain samples were finely ground using a Willey mill and digested using a di-acid mixture of HNO_3: $HClO_4$ at a ratio (5:1). AAS (Unicam Solaar 32 Zn ASTM D1688) was used to measure the concentration of Zn in the digest. Zn uptake in grains were calculated by multiplying the grain yield (kg ha^{-1}) by the concentration in grains mgkg^{-1}.

The critical limits of Zn were evaluated following the statistical (R^2-technique) and graphical procedures of Cate and Nelson (1965; 1971); Eteng and Asawalam (2016). In the graphical presentation (Fig. 1), Zn soil test values were plotted on X-axis and Zn uptake values on the Y-axis. Following this method, a plastic cross overlay was moved in such a way that the opposite quadrants upper right and lower left should have maximum coverage of points. The intercepting point touches to the X-axis which will be considered as a critical level of soil available zinc. The critical value divides soils as highly responsive and nonresponsive to $ZnSO_4$ application. In this study response and non-response of maize to Zn fertilizer was the basis on classifying them to deficient and sufficient levels at P<0.05%. The maximum uptake by maize (mg plant^{-1}) corresponds to the critical soil extractable Zn values (mg kg^{-1}), under which a high response of added Zn to maize crop is expected. Based on the highest predictability (R^2) value, a population can easily be partitioned which corresponds to the postulating critical level (Fig. 2).

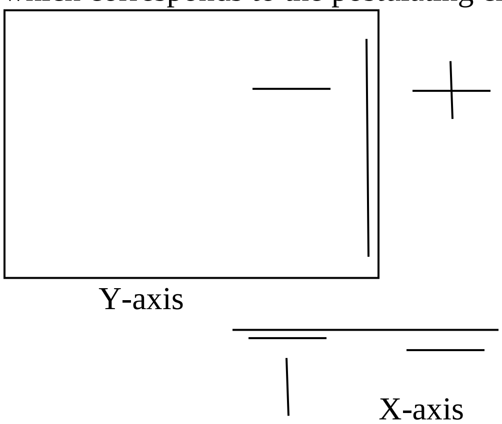

Figure 1: Format of clear plastic overlay which is used for finding critical soil test values (Cate and Nelson, 1965)

Statistical Analysis

The data collected were subjected to analysis of variance (ANOVA) procedure, GenStat and PASW Statistics 18 for Window 7.0. Significant means were separated using Fisher's Least Significant Different were appropriate at the probability level set at 5%. Also correlation and regression analysis was carried out to establish the relationship between soil Zn content and yield parameters. Microsoft Excel Windows 2010 package was used to produce response curve graphs. The coefficient of determination (r^2) was used to select the best-fitted model. The best extraction method for soils of southeastern Nigeria was selected by correlating available Zn for maize uptake presented as mg per kg soil with extracted Zn using each extraction solution.

Results and Discussion

Soil Properties

The soil samples used in this study varied remarkably in their soil properties (Table 1), where the pH of all the 20 locations were very strongly acidic (4.62) in reaction and ranged from 4.01 to 5.52. Based on the soil test data, all the soil samples were found to be low in organic carbon which, fluctuated between 0.12 and 1.64 gkg^{-1} with an average of 0.98 gkg^{-1}. In addition to the above properties, ECEC in the surface (0-20 cm) soils ranged from 0.78 to 16.63 cmol kg^{-1} with an average of 8.15 cmol kg^{-1}. Most of the soils samples determined were sandy loam (SL).

Table 1: Mean values of physical and chemical properties of the soil samples (N=20) in soils of southeastern Nigeria

Range	pH ($CaCl_2$) (1:2.5)	Org carbon	ECEC	Particle size distribution			Textural Class
				Sand	Silt	Clay	
		gkg^{-1}	Cmol kg^{-1}		gkg^{-1}		
Min.	4.01	0.12	0.78	390	70	60	
Max.	5.52	1.64	16.63	840	300	340	
Mean	4.62	0.98	8.15	680	160	160	Sandy loam

Extractable Zn in soils by different extractants

Results of extractable Zn by different extractants are presented in Table 2 gives a clear indication of Zn availability to maize production. The content of extractable Zn varied markedly according to the extraction solution used (Munter, 1988; Kabata-Pendias, 2010) and the different soil characteristics (Sillanpaa, 1990; Kabata-Pendias, 2010; Eteng et al., 2014a). The lowest content of extractable Zn was extracted by 1M NH_4OAc (1.09 $mgkg^{-1}$) while the highest by Coca-cola (2.24 $mgkg^{-1}$) with a mean value of 1.33 $mgkg^{-1}$ which was above the critical limit by Coca-cola method (Table 3). Extractable-Coca-cola Zn correlated positively with Zn uptake in maize shoots (Table 4) and was determined to have the highest R^2 values of 80 % probability. Similar result were reported by Rahman et al. (2007); Udo and Fagbami (1979); Schnug et al. (2001).

Table 2: Content of available Zn extracted by 5 extractants in soils of southeastern Nigeria (N=20)

Soil Location	Extractable Zinc content					Mean
	Coca-Cola	EDTA	HCl	EDTA-NH_4OAc	NH_4OAc	
	←		$mgkg^{-1}$	→		
Mean	2.24	2.04	1.43	0.54	0.38	1.33
Min.	0.42	0.07	0.11	0.18	0.07	0.19
Max.	3.95	1.64	3.67	4.95	1.09	2.14
LSD (P<0.05)	1.92	1.16	0.25	0.35	0.11	0.84
CV (%)	10.1	8.6	12.5	10.5	17.6	14.9

Screen-House Study

Critical Limit of Soil Extractable Zn

The critical levels of the extractable Zn ($mgkg^{-1}$) in the soil test calibration by five extractants are shown in Table 3 while, the scatter diagrams by graphical methods of Cate and Nelson (1965) showing relationship between Zn uptake in maize shoot (values on Y-axis) and different forms of extractable Zn in soils (plotted on X-axis) are presented in Fig 1. The critical limits of Zn in the soils, below which high response of applied $ZnSO_4$ to maize could be expected were determined according to extraction methods as: 0.90-1.52, 1.10-1.65, and 0.70-1.13, 2.40-3.92 and 2.50-4.24 mgkg-1 by Coca-Cola, EDTA, HCl, NH4OAc + EDTA and NH_4OAc respectively (Table 3). The critical value divides soils as highly responsive and non-responsive to Zn application (Feiziasl et al., 2009). The R^2 indicated in Fig 2, are coefficients of determination for delineation of responsive soils from non-responsive soils of southeastern Nigeria. The highest coefficients of determination (R^2 = 0.808) (Fig 2) and correlation coefficient (r = 0.875**) (Table 4) were determined in Coca-Cola-extractable Zn, which suggests that, 0.90-1.52 $mgkg^{-1}$ by Coca-Cola-extractable Zn can be adopted as the new critical limits of Zn below which maize plants may respond to $ZnSO_4$ application for maize production soils of southeastern Nigeria. Similar results were reported by Tariq et al (2014); Badole et al. (2001); Srinivasan et al. (2009); Sharma (1991); Schnug et al. (2001).

Thus, extractable Zn in selected soils of southeastern Nigeria (Table 2) can be categorized into three groups according to Zn deficient (<0.90 $mgZnkg^{-1}$), marginal (0.90-1.52 $mgZnkg^{-1}$) and adequate (>1.52 $mgZnkg^{-1}$) (Table 3). Moreover, the Zn uptake in maize plants varied from 0.33 $mgplant^{-1}$ in Zn-deficient to 2.37 $mgplant^{-1}$ in Zn adequate soils (Fig 2). Thus, the observed variation in the critical limit of the soil Zn, could be attributed partly due to contrasting soil properties and in the effectiveness of the different extractants (Abdu et al., 2007; Eteng et al., 2014b).

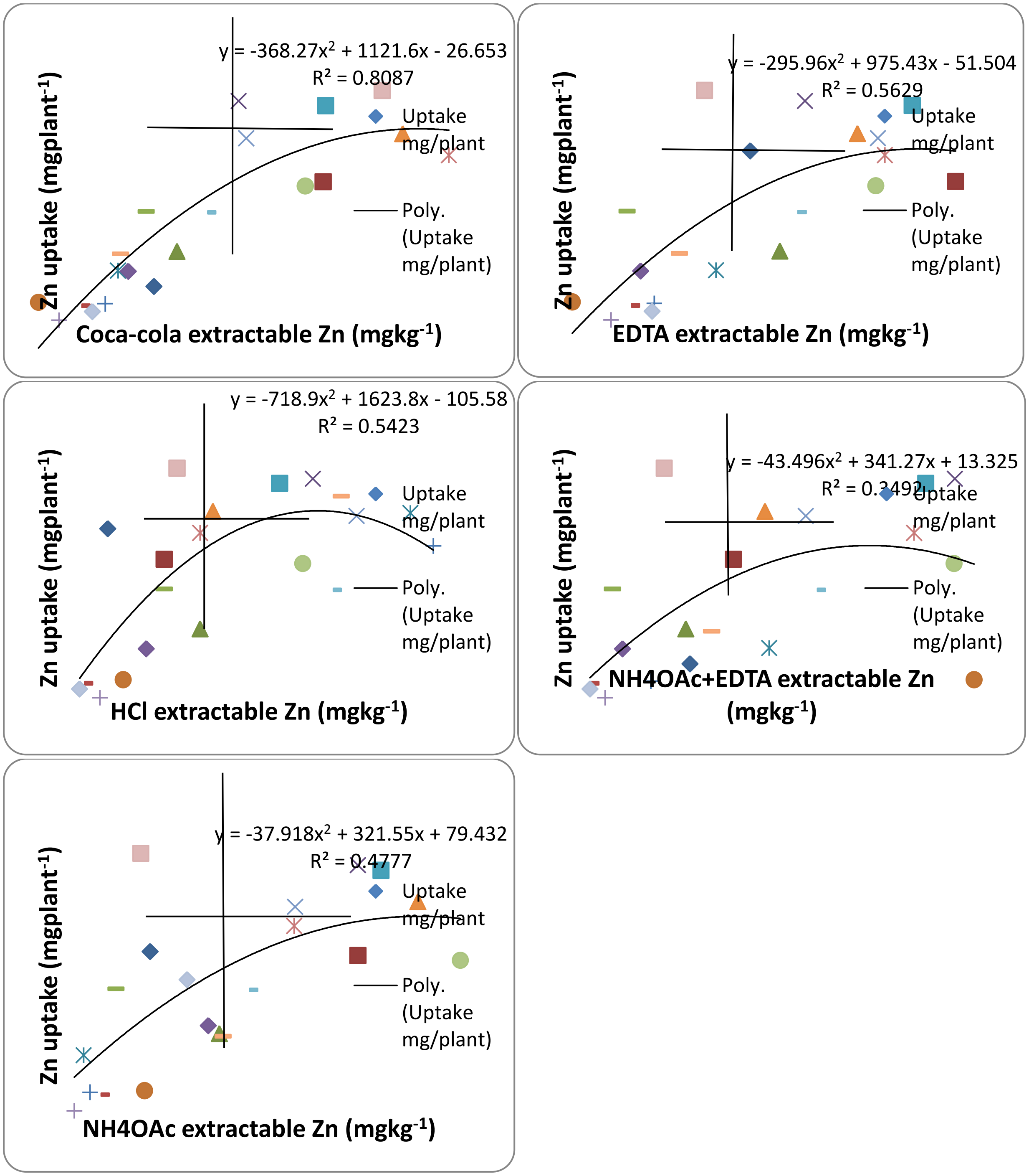

Figure 2: Scatter diagrams between Zn uptake and extractable Zn showing the critical level of soil Zn by the different extractants in soils of southeastern Nigeria

Table 3: Critical levels of extractable zinc ($mgkg^{-1}$) estimated by 5 extractants in soils of southeastern Nigeria (N=20).

Extraction method	Rating of critical limit of Zn in the soils.		
	Low	Moderate	High
Coca-cola	<0.90	0.90-1.52	>1.52
EDTA	<1.10	1.10-1.65	>1.65
HCl	<0.71	0.71-1.13	>1.13
NH_4OAc+EDTA	<2.40	2.40-3.92	>3.92
NH_4OAc	<2.50	2.50-4.24	>4.24

Table 4: Correlation coefficients (r) between extractable Zn in soils and Zn uptake by maize shoots (N=20)

Extraction methods	Zn Uptake ($mgplant^{-1}$)
Coca-Cola	0.875**
EDTA	0.617*
HCl	0.582*
NH_4OAc+EDTA	0.337^{ns}
NH_4OAc	0.274^{ns}

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

Effect of zinc levels on performance of maize growth parameters

The analysis of variance conducted on the growth parameters of the maize in the screen-house showed that there were significant differences in plant height, dry matter production (Table 4).

Plant height: Plant height is an important growth component directly linked with the productive potential of plant in terms of fodder, grains and fruit yield. The application of Zn fertilizer at different levels resulted in the increase in plant height of maize from 75.32 cm in control to a maximum height of 105.43 cm at 8 kg ha^{-1}. Badole et al. (2001) obtained plant heights of maize with values ranging from 112.96 cm to 140.51 cm, which are higher than values obtained in this study. However, Furlani *et al*. (2005) reported a range of plants height from 58.4 to 78.6 cm which falls within the range of values obtained in this study.

Stem girth: Similarly, levels of $ZnSO_4$ fertilizer application, significantly (P<0.05) increased stem girth from 38.55 mm in control to a maximum stem girth of 53.63 mm at an optimum Zn level of 8 kg Zn ha^{-1}. While, leaf area was increased from 77.32 cm^2 in control treatment to 125.06 cm^2 at the rate of 8 kg Zn ha^{-1}. Similar trend was obtained for growth components. Hence, 8 kg Zn ha^{-1} treatment significantly (P<0.05) produced higher plant height, leaf area while, 12 kg Zn ha^{-1} produced higher stem diameter to the other treatment levels. These results indicated that on the average, the application of $ZnSO_4$ fertilizer levels at 8 kg ha^{-1} on maize performance seems to be the desired optimum rate in soils where Zn deficiency occurred. This findings are in par with those of Kanwal et al. (2010); Tariq *et al.* (2014); Eteng et al. (2014b) who reported similar results on the effect of different methods of zinc application on growth and yield of maize.

Dry matter yield: An impressive effect of Zn treatment, on DM yields was observed, which significantly (P<0.05) increased DM yields of maize from 10.60 to 19.64 g $plant^{-1}$ (Table 4). The significant ($P<0.05$) increased in DM yield of maize shoots over the control suggests that Zn was a limiting nutrient in the soil. The treatment that received 12 kg Zn ha^{-1} gave significantly higher Dm yield over other treatments. This indicates that at this level, DM yield of maize was further improved thereby leading to Zn supply with better Zn nutrition. Lisuma *et al* (2006) and Tariq et al (2002; 2014) applied higher rates than the rate used in this study, and obtained a similar trend of result. Plant responses in dry matter yield indicated that the Zn was a demanding factor for maize growth in these soils (Iwuafor *et al.*, 1991). However, the rate of 12 kg Zn ha^{-1} will be required for optimizing maize yields in the soil, showing that this treatment improved better Zn nutrition for maize production in the soil.

Zinc concentration in maize shoots: Zn contents in maize shoots are shown in Table 4. Zn concentration in maize plant was significantly ($P<0.05$) increased with levels of applied $ZnSO_4$. Zinc concentrations in maize shoots varied between 3.15 and 12.43 mg kg^{-1} and `these were within the range of 10.8 to 18.9 mg kg^{-1} obtained by Lisuma *et al* (2006). The addition of higher levels of Zn after 8 kg ha^{-1} to the soil did not increase Zn concentrations significantly, rather it decreased Zn concentrations in maize shoots markedly. This finding is confirmed by previous studies of Grzebisz et al. (2008); Potarzycki and Grzebisz (2009). This may probably be due to the dilution effect as a result of the increase in DMY (Kanwal *et al*., 2010). Contrastingly, these values are lower than range of values (28.4-41.6 $mgkg^{-1}$) reported by Furlani *et al*. (2005). However, the results revealed that with increasing levels of applied Zn in soil will significantly ($P<0.05$) increase Zn content in maize plants. These results are in par with previous findings of Furlani *et al*. (2005); Kanwal *et al* (2009); who confirmed that increased in soil Zn also increased the plant Zn content.

Table 4: Growth and yielding components of maize shoots as influenced by Zn levels in screen house study

Zn levels ($Kgha^{-1}$)	Plant height (cm)	Leave area cm^2	Stem girth (mm^2)	Dry matter production ($gplant^{-1}$)	Zn content ($mgkg^{-1}$)
0	75.32	77.32	38.55	9.60	3.15
4	91.81	100.61	50.42	13.24	7.15
8	105.43	115.06	53.63	16.97	12.43
12	91.85	125.49	61.87	21.04	10.21
16	85.55	103.43	50.88	17.23	8.15
$LSD_{(P<0.05)}$	8.25	17.99	6.37	2.28	2.54
CV %	14.4	26.9	19.8	22.8	32.2

Estimation of optimum zinc levels for Zn uptake in maize plant

One parameter that is used to measure the performance of Zn nutrition in maize production after grain yield is dry matter yield. Figure 3 shows a differential growth response curve of Zn uptake at various levels of Zn application which produced the optimum Zn level require to produce maximum Zn uptake in maize shoots grown at 6 WAP. From the result obtained, significant higher Zn uptake (2.37 mg $plant^{-1}$) in maize shoots was produced from the application of 12 kg Zn ha^{-1}.

However, the optimum values for Zn, determined with the quadratic regression method is presented in Figure 3, indicating optimum application of $ZnSO_4$ (11.65 $kgha^{-1}$) (soil application) and maximum accumulation of Zn uptake (1.87 mg $plant^{-1}$) in plant shoot below which, Zn uptake will be improved by applying $ZnSO_4$. The Zn values presented by the quadratic regression curves in figure 3, indicated the optimum points at 11.65 $kgha^{-1}$ with a R^2= 0.94. These graph confirmed that maize yields will keep on improving with additional increments of Zn until the turning points which are slightly higher than the optimum level reached. These results is in agreement with findings of Furlani *et al*. (2005) and Kanwal *et al* (2009), who found that the plant Zn content and uptake increased with soil Zn. However, Van Biljon et al. (2010) reported an inconsistent response for uptake in maize plants by the application of Zn fertilizers and related it to the variation in soil and environmental factors. The variations in DMY, Zn content and uptake of maize shoot in different soils were due to difference in ability of soils to supply Zn to the maize plants.

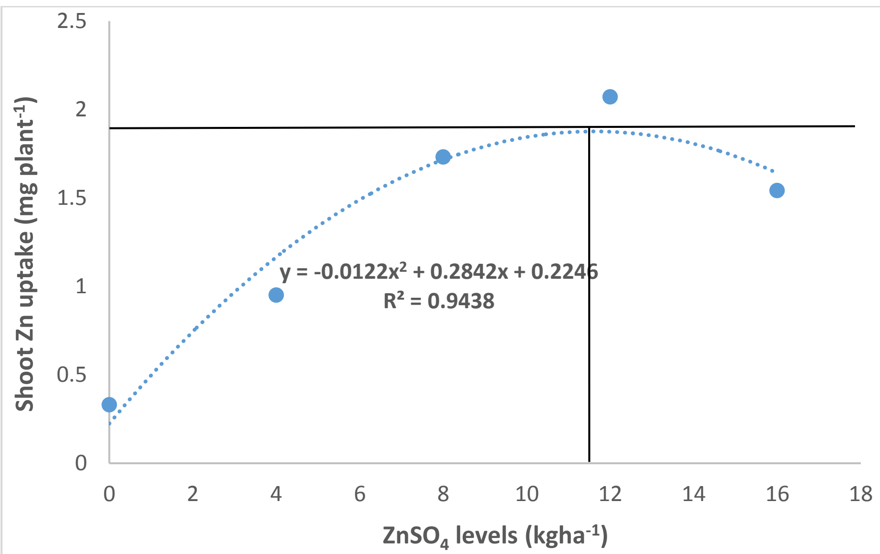

Figure 3: Polynomial graph showing levels of $ZnSO_4$ on Zn uptake in maize plant

Field Calibration Study

Maize grain yield: Results in Fig. 4 showed that $ZnSO_4$ application in the two plantings significantly increased the grain yields over control. at 9 kg Zn ha^{-1} gave Maximum grain yield in the first and second plantings yielded 7.9 t ha^{-1} and 5.1 t ha^{-1} and these were obtained from the application of 9 and 9.6 kg Zn ha^{-1} for first (2009) and second (2010) cropping and their corresponded R^2 of 0.963 (96%) and 0.951 (95%) predictability, respectively. However, the minimum grain yields were consistently obtained in control, indicating that the low yields could be caused by Zn deficiency in the soil (Rashid and Fox, 1992). Similar results were reported by Lisuma at el (2006) Abdu et al. (2007) and Kanwal et al (2009, 2010). Further increase in Zn application causes decrease in yields, presumably due to toxicity level of applied Zn in soil. These results are in par with the findings of Grzebisz et al. 2008; Potarzycki and Grzebisz (2009).

Generally, the significant response of maize to $ZnSO_4$ application was as a result of low zinc concentration in the soil. The improved soil Zn availability resulting from Zn application led to the increase Zn uptake and efficient utilization of applied fertilizer for grain yield. The significant increase in grain yield and the fairly stable yield in spite of the fluctuation in rainfall in the study area, may be due to the capacity of Zn to contribute to the crop as shown in 2010 and this results clearly showed a significant residual effect on maize planted for the second cropping which may be an indication of hidden hunger of Zn in the soil (Alloway, 2008).

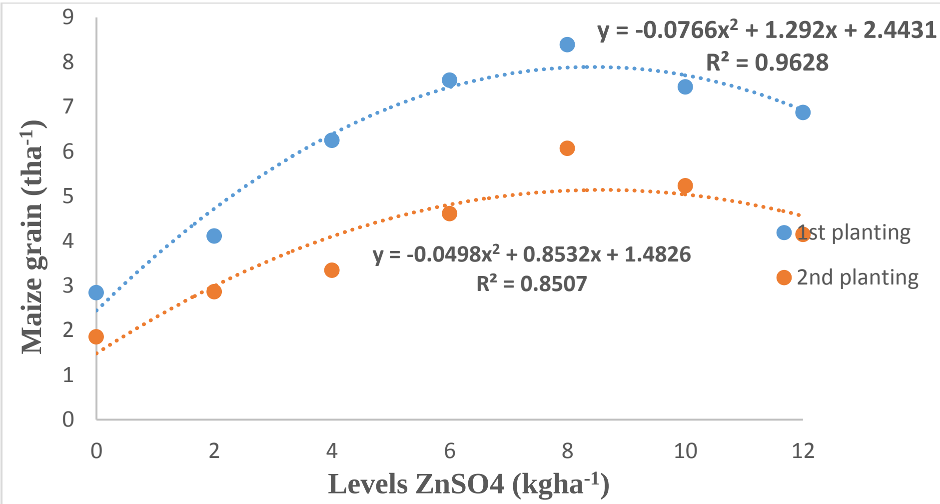

Figure 4: Polynomial graph showing the effect of Zn levels on maize gain yield during the first and second plantings

Conclusion

This work clearly established that soils of south eastern Nigeria have very severe Zn deficiency, probably due to their strong sorption capacity, and nutrient mining and therefore the low yields of maize grown in the soil were partly attributed to their deficiency. The critical limits of Zn in the soils and maize plant, below which high response of applied $ZnSO_4$ to maize could be expected were determined by Cate-Nelson according to the extraction methods as: 0.90-1.52, 1.10-1.65, and 0.70-1.13, 2.40-3.92 and 2.50-4.24 mgkg^{-1} for Coca-Cola, EDTA, HCl, NH_4OAc + EDTA and NH_4OAc, respectively. At the screen house experiment approximately 11 kg Zn ha^{-1} was estimated to be the optimum level of $ZnSO_4$ required for Zn uptake in maize producing for soils of southeastern Nigeria. Similarly, in the field experiment, Zn fertilizers significantly improved grain yields. The application of $ZnSO_4$ fertilizer yielded maximum grain yield of 4.19 and 3.38 tha^{-1} at the optimum rates of 9.0 and 9.6 kg ha^{-1} in the 2009 and 2010 plantings, respectively. The application of Zn within these soils or leaf critical limits will enhance the maize productivity with better economic returns. Accordingly, the application rate of 9.0 or 9.6kg Zn ha^{-1} as $ZnSO_4.7H_2O$ are recommended to ensure the yield potentials of maize in the soils.

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