Nigerian
Journal of Soil and
Environmental Research

Nig. J. Soil & Env. Res. Vol. 14: 2016, 92-
@ Department of Soil Science,
Faculty of Agriculture,
Ahmadu Bello University, Zaria,
Nigeria

Effects of Methods and Time of Application of Zinc on Maize (*Zea Mays L.*) Productivity in the Southern Guinea Savanna of Nigeria.

Afolabi, S.G.[1*], Adeboye, M.K.A[1], Lawal, B.A.[1], Daniya, E.[2] and Chinma, C.E.[3]
[1]Department of Soil Science and Land Management.
[2] Department of Crop Production.
[3]Department of Food Science and Technology.
School of Agriculture and Agricultural Technology, Federal University of Technology, P.M.B. 65, Minna, Niger State, Nigeria.

***Corresponding Author e-mail:** afolabi.gbolahan@futminna.edu.ng

ABSTRACT

Zinc (Zn) deficiency has started manifesting on some crops and in some soils in Nigeria, due to reduction in the length of fallow periods, continuous cropping and planting of high-nutrients demanding and high-yielding varieties of crops. In this study, field study was conducted during the 2014 and 2015 cropping seasons at the Teaching and Research Farm of the Federal University of Technology, Minna, southern Guinea savanna of Nigeria, to investigate the effects of application method of Zn on the growth and yields of maize. The treatments consisted of three rates of soil applied Zn (0, 2.5, and 5 kg Zn ha^{-1}) at 2 weeks after sowing (WAS) and two rates of foliar applied Zn at 2.5 and 5 kg Zn ha^{-1} at 3 and 6 WAS. The experimental design was randomized complete block with three replications. The initial soil extractable Zn was high, resulting in lack of response to Zn fertilization by maize yields in 2014. Soil and foliar Zn application significantly improved the plant height of maize at 4 and 12 WAS only in both years. Maize stover and grain yields were increased by over 1 ton ha^{-1} in 2015. Grain yield in 2015 was significantly higher by 24 % over that of 2014. There was a build-up of soil extractable Zn by adequate fertilization with Zn fertilizers. It was concluded that Zn fertilization will not only increase yields of maize, but also build-up soil Zn to a concentration level that will forestall deficiency in the foreseeable future.

Keywords: Foliar application, Maize, Savanna, Soil application, Zinc.

INTRODUCTION

Zinc (Zn) is an essential trace element for the growth and development of plants. Some of the physiological functions of Zn in plants include carbohydrate, protein, lipid, nucleic acid and auxin metabolism, enzyme activation like RNA polymerases, alcohol dehydrogenase, carbonic anhydrase, cell proliferation, and differentiation and membrane integrity (Alloway, 2008; Palmer and Guerinot, 2009). Besides these, Zn plays a major role in chlorophyll development and function, of which most important are the Zn-dependent activity of spp peptidase and the repair process of photo system II by turning over photo damaged D1 protein.(Hansch and Mendel, 2009). Deficiency of Zn reduces growth, tolerance to stress and chlorophyll synthesis (Kawachi, *et al*., 2009; Lee *et al*., 2010).

Zinc occurs in soil in five distinct pools as water soluble, exchangeable, adsorbed, chellated or complexed Zn with each pool having different strength that determines their solubility and susceptibility to plant uptake, leaching and extractability (Deb, 1992; Sharma et *al*., 2013). The Zn that is available for plant uptake in the soil is that which is present in the soil solution or adsorbed in a labile form and thus, soil factors that affect its availability to plants are those which control the amount of Zn in soil solution and its sorption – desorption from into the soil solution (Sharma *et al.*, 2013). Some of these factors include total Zn content, clay content, calcium carbonate content, redox condition, soil available moisture status, microbial activity in the rhizosphere, concentration of micronutrients, especially iron and manganese, concentration of macronutrients, especially phosphorous and climate (Alloway, 2008). The various methods of Zn application may differentially affect grain yield (Velu *et al.*, 2014). The deficiency of Zn in plants may still be observed in plants with soil application of Zn in spite of high amount of Zn in the soil.

The entry of Zn into the plant is not hindered by soil condition in the case of foliar application. Foliarly – applied Zn can be absorbed by leaf epidermis and then transported to the other plant parts via the xylem and the phloem (Haslett *et al.*, 2001). This is the reason why soil Zn application is less effective in increasing grain Zn concentration. However, when a high grain Zn concentration is targeted, in addition to a high grain yield, combined soil and foliar application is recommended (Velu *et al.*, 2014). Generally judicious application of Zn fertilizer helps to not only increase crop production, but also helps to enrich Zn in plant organs including grains ([illegible] *et al.*, 2008; Khan *et al.*, 2002; Phaltarakul *et al.*, [illegible]; Sudhalakshmi *et al.*, 2007).

Maize (*Zea mays L*) is an important cereal crop in Nigeria with a total production of about 7.3 million metric tons in 2009. (FAO, 2011). It is important in the context of nutrition for humans and livestock and as raw materials for industries (Nuss and Tanumihadjo, 2010). Maize is gradually replacing millet and sorghum in the traditional farming systems of northern Nigeria (Chude *et al.*, 2003). It has become a major staple crop with a per capital consumption of 60 kg year^{-1} (Bauernfeind and Deritter, [illegible]). It is usually eaten fresh or milled into flour and serves as a valuable ingredient for baby food, cookies, biscuits, ice cream, pan cake mixes, livestock feeds and a variety of traditional beverages (Eleweanya *et al.*, 2005).

Table 1: Monthly rainfall for the period of study

Month	Rainfall (mm)	
	Year	
	2014	2015
June	131.5	138.7
July	95.0	175.5
August	204.3	223.5
September	260.7	209.9
October	139.2	30.8
Total Rainfall	**830.7**	**778.4**

Source: Department of Geography, Federal University of Technology, Minna.

The deficiency of Zn in some soils of Nigeria had been predicted long time ago by Lombin (1983) and its manifestation in recent times has been documented by Kparmwang *et al.*, 1998. Soils of the savanna are the most likely to be deficient in Zn due to their low soil organic matter resulting from sparse vegetation cover and annual bush burning, as organic matter has been reported to be the main reservoir of available Zn in savanna soils of Nigeria (Kparmwang *et al.*, 1998; Mustapha and Singh, 2003). Zinc has been described as one of the most limiting nutrient for maize production in savanna soils (Chude *et al.,* 2003). Response to soil application of Zn in some savanna soils have been reported by some workers Chude *et al.,* 2003; Uyovbsiere and Lombin, 1990). In a pot experiment with some savanna soils, maize yield was increased by soil application of Zn (Yusuf *et al.*, 2005).

Overall, the very few attempts made to explore the effect of Zn application on the growth and yields of maize on the field in savanna soils have been on soil application method, but not foliarly – applied Zn. This study therefore had the objectives of investigating the effect of soil and foliar application of Zn on the growth and yields of maize in the southern Guinea savanna of Nigeria.

MATERIALS AND METHODS

Experimental site

The field experiments were conducted in 2014 and 2015 cropping seasons, at the Teaching and Research Farms of Federal University of Technology, Gidan Kwano, Minna (9° 30′ 49.8″ N; 6° 26′ 17.5″ E, 207.8 m) in the southern Guinea savanna ecology. Rainfall pattern is monomodal with rainy season starting in March and ending in October, Monthly rainfalls for the period of study are shown in Table 1. The soil was classified as Typic plinthustalf (Lawal *et al.*, 2012). Prior to this study, the field has been under fallow for many years, after being sparing cultivated with maize and yam with no fertilizer application.

Treatments and experimental design

Treatment consisted of 3 rates of soil applied Zn (0, 2.5, and 5 kg Zn ha^{-1}) at 2 WAS and 2 rates of foliar applied (2.5 and 5kg Zn ha^{-1})at 3 and 6 WAS. The relatively low rate of Zn was applied, because previous studies have indicated relatively high extractable Zn contents of the soils of the area (Lawal *et al.*, 2014). The experimental design was randomized complete block with three replications. The plot size was 6 m × 4 m to give a gross plot size of 24 m^2. The net plot was 12 m^2.

Agronomic practices

The field was manually cleared and ridged at 75 cm apart. Maize variety, Oba super 2 (quality protein maize) was sown (2 plants per stand) at 25cm within the ridge. All the plots have basal fertilizer application of 30 kg P ha^{-1} as single superphosphate, 30 kg K ha^{-1} as muriate of potash at 2 weeks after sowing (WAS) after thinning was done to one plant per stand. The recommended rate of N (90 kg N ha^{-1}) was applied in two split to all the plots. One – third was applied at 2 WAS, while the remaining two-third was applied at 5 WAS. The fertilizers were applied by side banding at about 5 cm away from the seedlings and at about 5 cm deep along the ridge. The source of Zn was $ZnSO_4.7H_2O$. The soil applied Zn was done by mixing the $ZnSO_4$ thoroughly with muriate of potash and applied together. Foliar application was by preparing a spray solution of 1.80 kg $ZnSO_4$ ha^{-1} in 400 litres of water as described by Muhammad *et. al.*, (2010) and sprayed onto the leaves using hand sprayer. All the plots were hoe-weeded at 2 and 5 WAS and remoulding was done at 8 WAS.

Soil sampling and analysis

Surface soil, (0 – 15 cm) samples were collected from ten points along four diagonal transects. The samples were bulked together to form a composite sample which was used to characterize the field before land preparation. At maize physiological maturity, surface soil samples were collected between two plants stand and the furrow along two diagonal transects, bulked together to give a composite sample per plot for determination of soil extractable Zn. The soil samples collected were air–dried, crushed gently and passed through 2 mm sieve and stored for analysis.

Particle size distribution was determined by Bouyoucos hydrometer method (Klute, 1986). Soil reaction was determined potentiometrically in 1: 2.5 soil to water suspension with the glass electrode pH meter. Organic carbon was determined by the Walkley and Black wet oxidation method (Nelson and Somers, 1982). Exchangeable bases were determined by extraction with neutral 1 N NH_4OAc. Potassium in the extract was determined with flame photometer, while calcium and magnesium was determined using atomic absorption spectrophotometer. Available phosphorous was extracted by the Bray P1 method and the P concentration in the extract was determined colorimetrically using spectrophotometer. Total N was determined by Kjeldahl digestion method (Bremner and Mulvaney, 1982). Zinc was extracted using the diethylenetriamine penta-acetic acid (DTPA) extractant (0.005 M DTPA + 0.01 M $CaCl_2$ + 0.1 M TEA) and Zn in solution were determined by atomic absorption spectrophotometer.

Plant height and yield components

Plant height was recorded at 4, 8 and 12 WAS by measuring from the soil level of maize plants to the tips of the tallest leaf using meter rule. Ten maize stands from middle row in each of the plot were selected and the mean determined. The maize in the net plot was cut above ground level at physiological maturity, dried and wei using weighing balance to determine the stover yi Maize grain yield was measured by harvesting maize in the net plot. The ears were air dried , shelled weighed. The grain yield was adjusted to 12 % mois content for each plot.

Statistical Analysis

Analysis of variance (ANOVA) was used evaluate the treatment effects on data collected. M separation was carried out on means using Du multiple range test (DMRT) at 5 % level of probabili computation was carried out by General Linear M (GLM) procedure of SAS (SAS, 2002).

RESULTS AND DISCUSSION

Initial soil Properties

Some selected physical and chemical propert the soil prior to land preparation in 2014 are show Table 2. The textural class of the surface soil was sa loam. It had a slightly acidic soil reaction. The reaction implies that most plant nutrients may be re available for the uptake of plants in the soil. Brady Weil (2010) reported that most plant nutrients available for plants uptake in the pH range of 5.5 – The soil organic carbon, total N and available P we low, while exchangeable Ca, Mg and K are me (Chude *et al.*, 2011; Esu, 1991).

Table 2. Some physical and chemical properties of soil prior to planting in 2014

Parameters	Values
Sand (g kg^{-1})	881
Silt (g kg^{-1})	36
Clay (g kg^{-1})	83
Textural class	Sandy loa
pH in H_2O (1:2.5)	6.6
pH in $CaCl_2$ (1 : 2.5)	5.5
Organic Carbon (g kg^{-1})	5.08
Total Nitrogen (g kg^{-1})	0.06
Available P (mg kg^{-1})	9
Exchangeable Bases (cmol kg^{-1})	2.80
Ca^{2+}	0.66
Mg^{2+}	0.18
K^+	2.30
DTPA Extractable Zn (mg kg^{-1})	

Table 3: Effect of zinc fertilization on soil extractable zinc in 2014 and 2015 seasons.

Treatment	Extractable Zn (mg kg^{-1}) Year 2014	2015
T1	3.60c	3.12a
T2	3.80c	4.32a
T3	12.03b	4.06a
T4	7.70bc	4.02a
T5	4.63c	3.23a
T6	18.17a	4.22a
T7	8.67b	4.04a
SE±	1.83	0.91

Means with the same letter (s) in a column are not significantly different at 5 % level of probability.
T1- control, T2 - 2.5 kg Zn ha^{-1}soil application at 2 WAS, T3-2.5 kg Zn ha^{-1} foliar application at 3 WAS, T4 - 2.5 kg Zn ha^{-1} foliar application at 6 WAS, T5 -5 kg Zn ha^{-1}soil application at 2 WAS, T6- 5 kg Zn ha^{-1} foliar application at 3 WAS, T7- 5 kg Zn ha^{-1} foliar application at 6 WAS

The extractable Zn content of the soil was high in soil (Esu, 1991) and above the critical range of 0.2 t0 2.0 mg kg $^{-1}$ for DTPA extractable Zn established by Sims and Johnson (1991). The soil could therefore be regarded as being adequate in extractable Zn. Adequate extractable Zn have also been reported for soils of the area by Lawal *et al.* (2014) and some soils of the same southern Guinea savanna by Kparmwang *et al.* (2000). The value of Zn obtained (2.30 mg kg^{-1}) is similar to the critical level of 2.20 mg kg^{-1} established for some savanna soils in pot experiment by Yusuf *et al.* (2005). The relatively high extractable Zn of the soil may be attributed to the soil having been under fallow for many years resulting in Zn not mined from the soil. Low extractable Zn in soils usually results from reduction in length of fallow period, crop intensification, planting of high yielding varieties, use of high analysis fertilizers with very little or no micronutrients and increased Zn removal (Singh *et al.*, 1999; Slaton *et al.*, 2001).

Soil Zinc

The effect of Zn fertilization on the extractable soil Zn is shown in Table 3. Zinc fertilization had significant effect on soil extractable Zn only in 2014. Foliar application of 5 kg Zn ha^{-1} at 3 WAS recorded the highest Zn content of 18.17 mg kg^{-1} which was significantly different from all other treatments. Some of the foliar applied Zn might have been washed into the soil

Table 4: Effect of zinc fertilization on growth of maize in 2014 and 2015 seasons.

Treatment	Plant height (cm) Year 2014 4WAS	8WAS	12WAS	2015 4WAS	8WAS	12WAS
T1	41.00b	158.17a	188.33ab	37.67b	148.17a	208.67ab
T2	41.67b	146.7a	166.83ab	46.90ab	156.00a	183.17b
T3	45.67ab	135.40a	180.07ab	47.23ab	158.80a	198.73ab
T4	46.00ab	138.53a	155.67b	48.53a	155.00a	188.67ab
T5	45.33ab	138.48a	198.50ab	50.33a	150.67a	215.17a
T6	49.00a	153.79a	201.67a	50.00a	147.33a	202.87ab
T7	49.67a	142.67a	188.67ab	52.00a	159.00a	193.07ab
SE±	1.86	13.15	14.68	3.34	5.33	9.72

Means with the same letter (s) in a column are not significantly different at 5 % level of probability.
WAS- Week After Sowing.
T1- control, T2 - 2.5 kg Zn ha^{-1}soil application at 2 WAS, T3-2.5 kg Zn ha^{-1} foliar application at 3 WAS, T4 - 2.5 kg Zn ha^{-1} foliar application at 6 WAS, T5 -5 kg Zn ha^{-1}soil application at 2 WAS, T6- 5 kg Zn ha^{-1} foliar application at 3 WAS, T7- 5 kg Zn ha^{-1} foliar application at 6 WAS.

by rain, before entry into the leaves, thereby increasing the soil extractable Zn. The $ZnSO_4$ which is the source of Zn increased the soil extractable Zn when it get into the soil. Zinc sulphate has a high water solubility of 95 % which is above the least acceptable range of 40 to 50 % required for nutrients in granular fertilizers to be in available form in the soil (Mortvedt, 1992).

Generally, there was build-up of soil extractable Zn even without Zn fertilization. The application of N, P and K fertilizers resulted in increase in their concentration in the soil with concomitant increase in microbial activity in the rhizosphere might have enhanced the desorption of Zn into the soil solution. The amount of Zn in solution and its sorption-desorption from / into the soil solution are controlled by soil factors including microbial activity in the rhizosphere and soil micronutrients concentration and pH (Alloway, 2008; Sharma *et al.*, 2013).

Growth and yields of maize

Maize plants height were significantly affected by Zn fertilization at 4 and 12 WAS only in both seasons (Table 4). At 4 WAS foliar applied 5 kg Zn ha^{-1} at 3 and 6 WAS resulted to taller plants only when compared to the control and soil applied 2.5 kg Zn ha^{-1} in 2014. However, at the last sampled period, 5kg Zn ha^{-1} foliar applied at 3WAS recorded the tallest plants only to foliar applied 2.5 kg Zn ha^{-1}. The increase in plant height with Zn fertilization may be attributed to increase in intern distances on the plant (Kaya *et. al.*, 2010). F application of Zn has been reported to increase heig wheat, by Majid *et al* (2014).

The effects of Zn fertilization on yields of ma both seasons are shown in Table 5. Zinc fertilizatio no significant effect on both stover and grain yie 2014. The lack of significant response might be due relatively high Zn concentration in the experimenta This is corroborated in the high Zn nutritional status of plants in 2014 in the absence of Zn applicatio critical soil Zn level for maize on the field have established to range between 1.0 to 1.4 mg kg^{-1} (Ritc *al.*, 1986). Field soil values below 1.5 mg Zn k usually considered as indicating deficiencies in cro systems (Dobbermann and Fairhurst, 2000; Zare 2009).

There was response to Zn fertiliz irrespective of method and time of application by and grain yields of maize in 2015. Treatments w fertilization recorded significantly higher grain yie the control without Zn fertilization. Fertilization w increased stover and grain yields by > 1 ton ha^{-1} ov control. Under field conditions, Zn fertilization has reported to increase yields (Manzeke *et al.*, 2014 *et al.*, 2001). It has been documented that Zn kick growth of plants through enhanced seedling vigou

Table 5: Effect of zinc fertilization on yields of maize in 2014 and 2015 seasons.

Treatment	Stover yield (kg ha^{-1}) Year		Grain yield (kg ha^{-1}) Year	
	2014	2015	2014	2015
T1	5500a	4700b	4100a	4067b
T2	4700a	5730ab	4100a	6517a
T3	4920a	6500a	4000a	6223a
T4	4900a	6390a	4200a	5387a
T5	5480a	6040a	4913a	5510a
T6	4900a	6263a	4700a	5930a
T7	4500a	6343a	4080a	5953a
SE±	410	421	502	475

Means with the same letter (s) in a column are not significantly different at 5 % level of probability.

T1- control, T2 - 2.5 kg Zn ha^{-1}soil application at 2 WAS, T3-2.5 kg Zn ha^{-1} foliar application at 3 WAS, T4 - 2.5 kg Zn ha foliar application at 6 WAS, T5 -5 kg Zn ha^{-1}soil application at 2 WAS. T6- 5 kg Zn ha^{-1} foliar application at 3 WAS, T7- 5 kg Zn ha^{-1} foliar application at 6 WAS

Table 6. Effect of zinc fertilization and season on yields of maize.

Treatments	Stover yield (kg ha^{-1})	Grain yield (kg ha^{-1})
Season (S)		
2014	4986b	4299b
2015	5995a	5655a
SE ±	162.91	186.61
Treatment (T)		
T1	5100a	4083b
T2	5215a	4793ab
T3	5645a	5017ab
T4	5710a	5308a
T5	5582a	5112a
T6	5760a	5315a
T7	5422a	5212a
SE±	304.78	349.11
Interaction		
SxT	NS	NS

Means with the same letter(s) in a column of a treatment group are not significantly different at 5 % level of probability. T1-control, T2 - 2.5 kg Zn ha^{-1} soil application at 2 WAS, T3-2.5 kg Zn ha^{-1} foliar application at 3 WAS, T4 - 2.5 kg Zn ha^{-1} foliar application at 6 WAS, T5 -5 kg Zn ha^{-1} soil application at 2 WAS, T6- 5 kg Zn ha^{-1} foliar application at 3 WAS, T7- 5 kg Zn ha^{-1} foliar application at 6 WAS

growth and chloropy11 concentration resulting in increased uptake of nutrients and crop productivity (Alloway, 2008; Cakmak *et al.*, 1999; Manzeke *et al.*, 2014).

Improved Zn nutrition of crops can alleviate biotic and abiotic stress events in crops on the field due to benefits derivable from several physiological processes including biosynthesis of growth hormones essential for photosynthesis (Cakmak, 2000; Oosterhuis *et al.*, 1991; Manzeke *et al.*, 2014; Sharma *et al.*, 1982).

The effect of Zn fertilization on yield when the two seasons were combined together is shown in Table 6. Yields were significantly higher in 2015 compared to 2014. Grain yield was increased by more than 1.3 t ha^{-1} in 2015. These results may be due to the residual effects of Zn coupled with its build – up in the soil. Zinc fertilizers are known to have residual effects that can last up to 4 years (Martens and Westermann, 1991). When yield of the two seasons were combined, foliar application had the highest grain yield even though not significantly different from that of the soil applications. Judicious application of Zn fertilizer helps to increase crop production (Sharma *et al.*, 2013). Soil or foliar application or combination of both of them is an effective way to improve grain yield. (Velu *et al.*, 2014).

CONCLUSION

Soil and foliar Zn application methods significantly increased yields of maize in the second cropping season, implying the potential benefit of build – up of soil Zn even in soil with initial sufficient concentration level of extractable Zn. Fertilization with Zn either by soil or foliar will build – up the soil Zn level to prevent Zn deficiency in the future. Adequate fertilization with N, P and K fertilizers enhanced the soil Zn concentration and Zn nutrition of maize plant, thereby improving its productivity.

REFERENCES

Alloway, B. J. (2008). Zinc in soils and crop nutrition. Second edition. International Zinc Association (IZA) and International Fertilizer Association (IFA). Brussels, Belgium and Paris, France.

Bauernfeind, C.J. and Deritter, E. (1991). Foods considered for nutrient addition: cereal grain products. In Nutrient additions to food: nutritional, technological and regulatory aspects Bauernfeind, C. J. and Lachance, P. A. (ed). Food and Nutrition press Inc., USA.

Brady, N.C. and Weil, R. (2010). The nature and properties of soils. 3rd edition, person education, Inc., Upper Saddle River, New Jersey 07456, Pp 960.

Bremner, J.M. and Mulvaney, C.S. (1982). Nitrogen-total. In, Page, A.L., Miller, R.S., Keeney, D.R. (eds.). Methods of Soil Analysis. Part II. Chemical and Microbiological Properties. Am.Soc.Agron, Madison, Wisconsin. Pp. 643-698.

Cakmak, I. (2000). Role of zinc in protecting plant cells from reactive oxygen species. *New Phytologist*, 146: 185-205.

Cakmak, I., Kalayei, M., Ekiz, H., Brain, H.J. and Yimaz, A. (1999). Zinc deficiency as an actual problem in plant and human nutrition in Turkey: A NATO science for stability project. *Field Crops Research,* 60: 175 - 188.

Chude, V.O., Iwuafor, E.N.O., Amapu, I.Y., Pam, S.G. and Yusuf, A.A. (2003). Response of maize (*Zea mays*) to zinc fertilization in relation to Mehlich III extractable zinc. Badu-Apraku, B., Fakorede. M. A. B., Ouedraogo, M., Carsky, R. J. and Menkir, A.(eds). Maize revolution *in*West and Central Africa. Proceedings of a Regional Maize Workshop. IITA-Cotonou Benin Republic, 14 – 18 May, 2001. WECAMAN?IITA,. pp 201 – 207.

Chude, V.O., Olayiwola, S.O., Osho, A.O. and Daudu, O.K. (2011). Fertilizer use and management practices for crops in Nigeria. Fourth edition. Federal Fertilizer Department, Federal Ministry of Agriculture and Rural Development, Abuja, Nigeria. 215pp.

Deb, D.L. (1992). Development of soil and plant analytical methods for micronutrients and sulphur in Sri Lanka GCPF/SR/047/NET field document No 11.

Dobbermann, A. and Fairhurst, T. (2000). Nutrient Disorders and Nutrient Management Handbook Series, Potash Phosphate Institute (PPI), Potash and Phosphate Institute of Canada (PPIC) and International Rice Research Institute.

Eleweanya, N. P., Uguru, M. I., Enebong, E. E and Okoche, P. I. (2005). Correlation and path coefficient analysis of grain yield and related characteristics in maize under Umudike conditions of South East Nigeria. *Agro-science Journal of Tropical Agriculture, Food, Environment and Extension* 1: 24 - 28.

Esu, I.E. (1991) Detailed soil survey of NIHORT Farm at Bunkure, Kano State, Nigeria. Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria. 72 pp.

FAO, (2011). Food and Agricultural Organization, FAOSTAT on crop production, Rome, Italy.

Hansch, R. and Mendel, R. R. (2009). Physiological functions of mineral micronutrients (Cu, Zn, Mn, Fe, Ni, Mo, B, Cl). *Current Opinion in Plant Biology,* 12: 259 - 266.

Haslett, B.S., Reid, N.J. and Rengel, Z. (2001). Zinc mobility in wheat, uptake and distribution of zinc applied to ieaves or roots. *Annals of Botany,* 87: 379-386.

Jiang, W., Struik, P.C., Kevlin, H.V. Zhao, M., Jin, L.N and Stomph, T.J. (2008). Does increased zinc uptake enhance grain zinc mass concentration in rice? *Annals of applied biology*, 153: 135 – 147.

Kawachi, M., Kobac, Y., Mori, H., Tomioka, R., Lee, Y. and Maeshima, M. (2009). A mutant strain *Arabidopsis thaliama* that lacks vacuolar membrane zinc transporter. MTPI revealed the latent tolerance to excessive zinc. *Plant cell physiology*, 50: 1156 – 1170.

Kaya, C., Higgs, D. and Burton, A. (2000) Phosphorus acid phosphates enzyme activity in leaves of tomato cultivars in relation to Zn supply. *Communications in Soil Science and PlantAnalysis*, 31: 3239-3248.

Khan, M.V., Quasim, M. and Jamil, M. (2002). Response of rice to zinc fertilizer in calcareous soils of D. I. Khan. *Asian Journal of Plant Science,* 1: 1 – 2.

Kparmwang, T., Esu, I.E. and Chude, V.O. (1998 Available and *total* forms of copper and zinc in basaltic soils of the Nigerian savanna *Communication in soil and plant Analysis,* 2 (15/16): 2215 – 2216.

Kparmwang, T., Chude, V.O., Raji, B.A. and Odunze A.C. (2000). Extractable micronutrients in some soils developed on sandstone and shale in th Benue valley, Nigeria. *Nigerian Journal of S Research*, !: 42-48.

Klute, A. (1986). Methods of Soil Analysis. No. 9. Part Physical and Mineralogical Properties. Americ Society of Agronomy, Madison, Wisconsin.

Lawal, B.A., Adeboye, M.K.A., Tsado, P.A. Elebi M.G. and Nwajoku, C.R. (2012). Propert classification and agricultural potential of late soils of Minna in sub-humid agroecological z Nigeria. *International Journal of Develop and* Sustainability, 1(3): 903-911.

Lawal, B.A., Adeboye, M.K.A., Mbaoji, C., Abbah, and Abdulrasak, Y.L. (2014) Assesinent of micronutrients in profiles of Typic Plinthust Minna, southern Guinea savanna, Ni *Nigerian Journal of Soil and Environ Research*, 12: 104-114.

Lee, S., Kim, S.A., Lee, J. and Guerinot, M.I. (2010 deficiency – inducible os ZIP8 encodes a membrane – localized zinc transporter *Molecular Cells*, 29: 551 – 558.

Lombin, G. (1983). Evaluating the micronutrients of Nigeria`s semi-arid savanna soils. II. Z *Science*, 136: 42-47.

Majid, A., Ezabollah, E., Seyed, B.M. and B (2014). Effects of foliar application of zi at different phonological stages on yield formation and grain zinc content of bread wheat, *Azarian Journal of Agriculture* 1(1): 11-16.

Manzeke, G.M., Mtambanengiue, F., Nezomba, H. and Mapfumo, P. (2014). Zinc fertilization influence 0n maize productivity and grain nutritional quality under intergrated soil fertility management in Zimbabwe, *Field Crops Research*, 166: 128 – 136.

Martens. D.C. and Westermann, D.T. (1991). Fertilizer applications for correcting micronutrient deficiencies. Second ed. In Mortvedt, J.J., Cox, F.R., Schuman, L.M.. Welch, R.M. (Eds). Micronutrients in Agriculture. Book Series No 4. Soil Science Society of America, Madison, Wisconsin. Pp 549 – 592 (Chapter 15).

Mortvedt, J.J. (1992). Crop response to level of water soluble zinc in granular zinc fertilizers. *Fertilizer Research,* 33: 249 – 255.

Muhammad, S., Abdur, R., Nawab, A., Muhammad, A., Louise, F. and Masood, A. (2010). Effect of foliar application of zn and b on fruit production and physiological disordersin sweet orange. *Sarhad Journal of Agriculture, 26 (:): 354 – 360.*

Mustapha, S. and Singh, B.R. (2003). Available zinc, copper, iron and manganese status of the basement complex rock derived Ultisols in Bauchi State, Nigeria: A case study. *Nigerian Journal of Soil Research*, 4: 35- 40.

Nelson. D.W. and Sommers, L.E. (1982). Total carbon, organic carbon and organic matter. In, A.L. Page, R.H. Miller, D.R. Keeney (eds.). Methods of Soil Analysis. No. 9, Part 2. Chemical and Microbiological Properties. Am. Soc. Agron., Madison, Wisconsin.

Nuss. E.T and Tanumihardjo, S.A. (2010) Maize: a paramount staple crop in the context of global nutrition. *Comprehensive Reviews in Food Science and Food Safety*. 9:417–436.

Oosterhuis, D., Hake, K. and Burmester, C. (1991). Foliar feeding cotton. Cotton Physiology Today. National Cotton Council of America, 2: 1 – 7.

Palmer, C. M. and Guerinot, M. L. (2009). Facing the challenges of Cu, Fe and Zn homeostasis in plants. *Natural Chemistry and Biology*, 5: 333-340.

Phaltarakul, N., Rarkasem, B., Li, L.J., Wu, L.H., Zou, C.Q., Ram, H., Sohu, V.S., Kang, B.S. Surek, H., Kalayei, M., Yazici, A., Zang, F.S. and Cakmak, I. (2012). Biofortification of rice grain with zinc through zinc fertilization in different countries. *Plant and Soil,* doi:10,1007/s 1104 – 012 -1211 –x.

Ritchey, K.D., Cox, F.R., Galrao, E.Z. and Yost, R.S. (1986). Zinc availability for maize, sorghum and soybean on a dark clay Latosol. *Pesquisa Agropeauaria Brasilera,* 22(2): 213 – 217.

SAS (2002). SAS user`s guide; statistical Cary N.C. Statistical Analysis System Institute Inc.

Sharma, C.P., Sharma, P.N., Bisht, S.S. and Nautiyal, B.D. (1982). Zinc deficiency induced charges in cabbage, farmham Royal, England In: Scaife, A. (ed) proceedings of the Ninth International Plant Nutrition Colloquium. Commonwealth Agricultural Bureaux, 2. Pp 601 – 606.

Sharma, A., Patri, B., Shankhdhar, D. and Shankhdhar, S.C. (2013). Zinc – An indispensable micronutrient. *Physiology and Molecular Biology of Plants*, 19(1): 11-20.

Sims, J.T. and Johnson, G.V. (1991). Micronutrients Soil Tests. Second Edition. In Mortvedt, J.J., Cox, F.R., Shirman, L.M., Welch, R.M. (Eds). Micronutrients in Agriculure. Soil Science Society of America Inc., Madison, Wisconsin, USA.

Singh, A.K., Khan, S.K. and Nongkyarih, P. (1999). Transformation of Zinc in wetland rice soils in relation to nutrition of rice crop. *Journal of Indian Society of Soil Science*, 47: 248 – 253.

Slaton, N.A., Wilson, C.E., Ntamatungiro, S., Norman, R.J. and Boothe, D.I. (2001). Evaluation of zinc seed treatments for rice *Agronomy Journal*, 93: 152 – 157.

Sudhalakshmi, C., Krishnasamy, R. and Rajarajan, R. (2007). Influence of zinc deficiency in shoot / root dry weight ratio of rice genotypes. *Research Journal of Agriculture and Biological Sciences,* 3: 295 – 298.

Uyovbisere, E.O. and Lombin, G. (1990). Field evaluation of early maturing maize (*Zea mays L.*) variety to potassium and zinc fertilization in the Nigerian savanna. *Fertilizer Research*, 23: 73 – 80.

Velu, G., Oritz-Monasterio, I., Cakmak, I., Hao, Y. and Singh, R. P. (2014). Biofortification strategies to increase grain zinc and iron concentrations in wheat. *Journal of Cereal Science*, 59: 365-372.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 extractable zinc in northern Nigeria. *Nigerian Journal of Soil Research*, 6: 32-41.

Zare, M., Khoshgoftarmanesh, A.H., Norouzi, M. and Schulin, R. (2009). Critical soil Zn deficiency concentration and tissue iron: zinc ratio as a diagnostic tool for production of zinc deficiency in corn. *Journal of Plant Nutrition*, 32: 1983 – 1995.