Nigerian
Journal of Soil and
Environmental Research

Nig. J. Soil & Env. Res. Vol. 19: 2020 22 - 31
@ Department of Soil Science, Faculty of Agriculture, Ahmadu Bello University, Zaria, Nigeria

Nitrogen Use Efficiency of Maize as Affected by Zinc Fertilization in the Moist Savanna of Nigeria

***Adeboye M. K. A.[1], Afolabi S. G.[2], Lawal B. A.[3] and Mamman I. B.[4]**
[1,2 and 3]Department of Soil Science and Land Management, School of Agriculture and Agricultural Technology. Federal University of Technology, P.M.B. 65,Minna, Niger State, Nigeria.
[4]Notore Chemical Industries Plc, Notore Industrial Complex, Onne, Rivers State, Nigeria.

***Corresponding author's Email:** m.adeboye@futminna.edu.ng

ABSTRACT

Nutrient use efficiency (NUE) is a very important concept in the evaluation of crop production and can be significantly influenced by nutrient management. This study was carried out in 2014 and 2015 cropping seasons to determine the response of maize to nitrogen as affected by zinc fertilization in the moist savanna of Nigeria. The response was evaluatedusing agronomic efficiency (AE), fertilizer response (FR), and partial factor productivity (PFP). The treatments were four N rates; 0. 60, 90, and 120 kg ha^{-1} and three Zn rates; 0, 2.5, and 5 kg ha^{-1}. The experimental design was a 4 x 3 factorial fitted to randomized complete block design with three replicates. There was response to N over the two seasons, however, there was no significant difference among the N rates.There was also response to Zn,even thoughonly in 2015 with the highest grain yield of 6.1 Mg ha^{-1} obtained from maize fertilized with 5 kg Zn ha^{-1}. Interaction of N and Zn on grain yield was not significant.There was no significant effect of Zn on FR in both seasons.The AE and PFP were significantly affected by Zn fertilization in both seasons and their values were significantly reduced with increasing rate of N, irrespective of Zn rate.Application of 60 kg N ha^{-1} plus 5 kg Zn ha^{-1}, had the highest efficiency of N use of 82.72 kg grain kg N^{-1}in both seasons.

Key words: Fertilizer responsiveness, Maize, Moist savanna, Nitrogen, Zinc,

INTRODUCTION

Maize production has increased very much over the years in both moist and semi-arid Sudan savannas of Nigeria. It has become one of the major commercial crops providing food, animal feed, and industrial raw materials (Badu-Apraku and Fakorede, 2017; IITA, 2017). The total annual production has increased from 1.06 M tons in 1976, to about 11.6 M tons in 2016 (FAO, 2018). The average yield per hectare of 1.4 Mg ha^{-1} has been reported for quite a large number of farmers, but an increasing number of farmers referred to as "best-farmers" have been reporting yield of > 7 Mg ha^{-1}, similar to what is obtained in research stations (IITA, 2017). One of the main reasons for the high yields in the best-farmers' fields and research stations is adoption of best agronomic practices including adequate fertilization. Others are selection of appropriate maturity groups and high yielding varieties (Kamara *et al*., 2009).
The introduction of hybrid maize in the moist savanna of Nigeria in the last three decades revealed that majority of the farmers, despite the adoption of fertilizer still report low yields due to inefficient use.The current fertilizer recommendations in the country are mainly blanket fertilizer recommendations and often specified to the level of agroecological zone (AEZ) (Ichami *et al*., 2019). However, environmental factors vary at short distances in the landscape and management factors also vary among smallholder farmers in su b-Saharan Africa (SSA) (Stoorvogel and Smaling, 1998; Tittoneil, *et al*., 2005; Vanlauwe *et al*., 2011; Zingore *et al*., 2007). As a result, there is low response of crops to fertilizer, which makes the recommendations to be of limited in relevance to the farmers (Tittoneil *et al*., 2013).
Blanket fertilizer recommendations both interms of type and amount can be assessed using indicators such as agronomic nutrient use efficiency (AEN), fertilizer response (FR) (Ichami *et al*., 2019) and partial factor productivity (PFP). The AEN is a measure of the increase in crop yield for a given amount of nutrient added and can be used to evaluate the efficiency of a specific nutrient

applied. It indicates how much productivity improvement was gained by the application of the nutrient and used as a short-term indicator of the impact of applied nutrients in productivity (Dooberman, 2007; Ichami *et al*., 2019). The FR is defined as the incremental crop yield due to fertilization, independent of the quantity or type of fertilizers applied. The FR is calculated as the ratio of crop yield in fertilized plot and unfertilized control plot(Ichami *et al*., 2019). It is a useful concept for identifying responsive and non-responsive soils (Njoroge, *et al*., 2017; Tittoneil, *et al*., 2007; Zingore *et al*., 2007). The concept of non-responsive soils, which are soils on which crops do not respond to mineral fertilizers application, was introduced by Giller *et al*. (2006). The PFP is determined by dividing the grain yield with the amount of nutrient applied; therefore, it is an indication of production per unit of nutrient applied. The PFP addresses how productive the cropping system is compared to its nutrient input. It is considered the most important index for on-farm studies, among the different indices of nutrient use efficiency, as it integrates the use efficiency of both indigenous and applied nutrients (Dooberman, 2007; Mandal *et al*., 2015).

Nitrogen is the most limiting nutrient in maize production in SSA (Ma *et al*., 2016; Nziguheba, *et al*., 2009). It is a major yield determining factor and essential for optimum maize growth and yield (Kogbe and Adediran, 2003). Nitrogen fertilizers have therefore, become the primary nutrient sources for maize over the last fifty years (Hossain *et al*., 2012) and a key input for achieving highest yield of maize in the savanna AEZ (Sajedi *et*., 2009). Several workers have reported response of maize to N fertilization in the moist savannas of Nigeria (Adnan *et al*., 2020; Afolabi *et al*., 2017). Even though, the blanket N fertilizer recommendation in the moist savannas is 120 kg ha^{-1}, some studies have reported 60 kg ha^{-1} as optimum for maize production (Adeboye *et al*., 2010; Afolabi *et al*., 2017).

Globally, apart from deficiencies of N and P, inadequate soil Zn also poses a serious threat to crop production (Nube and Voortman, 2006). Deficiency of zinc (Zn) is the most widespread micronutrient disorder among different crops (Naik and Das, 2008) and the most commonly deficient trace element in plants (Cakmak, 2002). Zinc has been reported as one of the most limiting nutrients for maize production in savanna soils (Chude *et al*., 2003). Zinc fertilizers increase both yield and quality of cereal crops (Abunyewa and Mercer-Quarshie, 2004; Cakmak, 2008). Judicious application of Zn fertilizer increase crop production and enrich plant organs, including grains (Jiang *et al*., 2008; Khan *et al*., 2002; Phattarakul *et al*., 2012; Sudhalakshmi *et al*., 2007). In the moist savanna of Nigeria, application of Zn fertilizer has been reported to increase grain yield and grain N concentration of maize (Afolabi *et al*., 2017).

There is an urgent need for the review of the blanket fertilizer recommendation as a result of increasing number of smallholder farmers reporting decreasing fertilizer response for staple food crops such as maize (Ichami *et al*., 2019). Blanket fertilizer recommendations can be improved upon when there is better understanding of the factors that affect variability in response to fertilizers. Environmental factors including climatic such as rainfall variability, soil-related such as low level oforganic carbon, and secondary and micronutrient deficiencies affect response to fertilizers across smallholder farming systems in SSA (Ichami *et al*., 2019).Low levels of soil organic carbon in maize fields of Zimbabwe led to a poor fertilizer response (Zingore *et al*., 2007). Low response to fertilizer has also been attributed to a high variability in rainfall amounts (Sileshi *et al*., 2008). The importance of secondary and macronutrient deficiencies in SSA has been responsible for low response to fertilizer using meta-analysis by Kihara *et al*. (2017).

This subject of understanding the factors that influence the variation in fertilizer response remains understudied in the moist savanna of Nigeria. Studies that systematically identify the main factors that affect fertilizer response across smallholder farmer's fields in SSA are lacking (Ichami *et. al*., 2017). There is dearth of published studies on the effect of Zn fertilization on the response of maize to mineral or organic fertilizer N in the moist savannas of Nigeria to our knowledge. Therefore, we conducted this experiment to determine the effect of Zn fertilization on the response of maize to mineral fertilizer N as part of a broad study to identify the factors that influence AEN, FR, and PFP to refine blanket fertilizer recommendations for maize in smallholder farmer's fields in the moist savannas of Nigeria. Our objectives are to quantify the interactive effects of N and Zn fertilizations on maize grain yield and use AEN, FR and PFP to evaluate the effect of Zn fertilization on the response of maize to N fertilization.

MATERIALS AND METHODS

Study site

The study site was the Teaching and Research Farm, Federal University of Technology, Minna, located at Latitude 9° 30′ 49.8″ N; Longitude 6° 26′ 17.5″ E, 207.8 m above sea level in the moist savanna of Nigeria. The climate of Minna is sub-humid and the rainfall pattern is monomodal, with the rainy season starting in March and ending in October. The monthly rainfall during the period of the study is shown in Figure 1. The physical features around Minna consist of gently undulating high plains developed on basement complex rocks made up of granites, migmatites, gneisses and schists (Ojanuga, 2006). The soil of the site was classified as Typic Plinthustalf (Lawal *et al*., 2012). The site has been under fallow for a long period of time due to its inaccessibility.

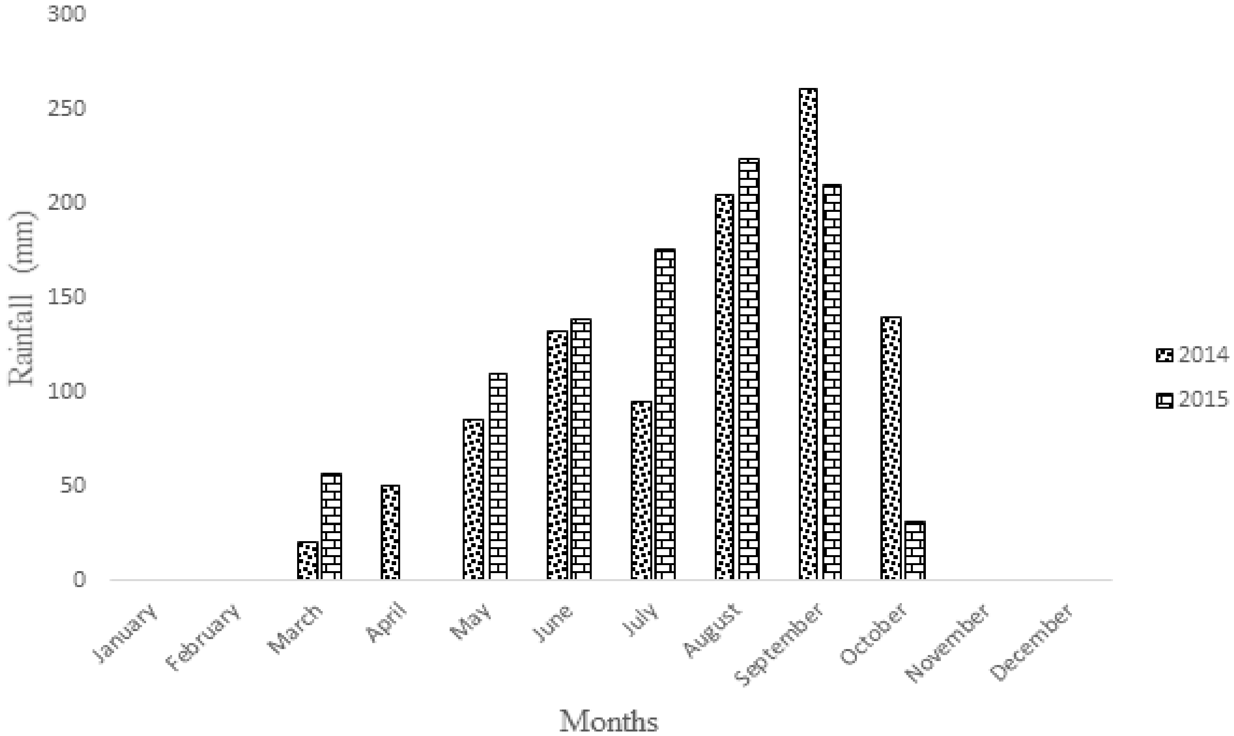

Figure 1. Monthly rainfall distribution in Minna, Nigeria during the period of the study

Treatments and experimental design:
The application rate included four levels of N; 0, 60, 90, 120 kg $ha^{-1}$and three levels of Zn; 0, 2.5, 5 kg ha^{-1}. The experimental design was a 4x3 factorial design fitted to a randomized complete block design with three replications to give a total of 36 experimental plots. The size of the experimental plot was 4 m by 6 m (24 m^2) with an alley of 1 m between the plots.

Agronomic practices
The field was manually cleared and ridged at 75 cm apart. The maize variety, Oba super 2 (quality protein maize) was sown (2 plants per stand) at 25 cm within the ridge. Thinning was done to one plant per stand at 2 weeks after sowing (WAS). All the plots received basal fertilizer application of 30 kg P ha^{-1} as single superphosphate, 30 kg K ha^{-1} as muriate of potash at 2 WAS. The N was applied in split application, one-third at 2 WAS while the remaining two-thirds were applied at 5 WAS. The Zn was mixed thoroughly with the N fertilizers. The N fertilizer was applied as urea and Zn as $ZnSO_4$ to required plots. Fertilizers were applied by side banding, 5 cm away from the seedlings and about 5 cm deep. All the plots were hoe-weeded at 2 and 5 WAS and manual remoulding was done using hoe in place of the last weeding at 8 WAS to control weeds.

Soil Sampling and Analysis
Surface soil (0–15 cm) samples were collected from ten points along four diagonal transects. The samples from each transect were bulked together to give four composite samples, which were used to characterize the field before land preparation. The soil samples collected were air-dried, crushed gently, passed through 2-mm sieve and taken to the laboratory for physical and chemical analyses using the method described by Agbenin (1995). Briefly, particle size distribution was determined by the Bouyoucos hydrometer method. 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. Exchangeable bases were determined by extraction with 1 N NH_4OAC. Potassium in the extract was determined with a flame photometer, while calcium and magnesium were determined using an atomic absorption spectrophotometer. Available phosphorous was extracted by the Bray No. 1 method and the P concentration in the extract was determined colorimetrically using spectrophotometer. Total N was determined by the Kjeldahl digestion method. Zinc was extracted using the diethylenetriamine penta-acetic acid (DTPA) extractant and Zn in solution determined by atomic absorption spectrophotometer.
Maize grain yield analysis was carried out by harvesting

maize ears in the three central rows, leaving out border plants at both ends (net plot of 8.7 m^2). These ears were shelled, air-dried and weighed. The grain yield was adjusted to 12 % moisture content for each plot.

Calculation and Statistical analysis

The FR, AE, and PFP were calculated using the formulae below:

$FR = Y_f / Y_c$ (Ichami *et. al*., 2019) Eq.1

Where,
FR-Fertilizer Response
Y_f–Yield in kilogram of fertilized crop
Y_c–Yield of in kilogram of control crop

ii. $AE = Y_f – Y_c /N$ (Ichami *et. al*., 2019) Eq. 2

Where,
AE –Agronomic Efficiency
Y_f– Yield in kilogram of fertilized crop
Y_c–Yield in kilogram of control crop
N –Nutrient applied in kilogram

iii. $PFP = Y_f / N$ (Doberman, 2007) Eq. 3

Where,
PFP – Partial Factor Productivity
Y_f– Yield in kilogram of fertilized crop
N – Nutrient applied in kilogram

The General Linear Model Procedure of SAS (SAS Institute, 2015) was used for statistical analysis of the data including analysis of variance (ANOVA) and means separation where F values were significant was carried out by Duncan's multiple range test (DMRT) at the 5% level of probability, unless otherwise stated.

RESULTS AND DISCUSSION

Initial soil characteristics

The initial properties of the soil at the commencement of the experiment in 2014 season are shown in Table 1. Sand was the dominant fine earth fraction in the soil with a value of 881 g kg^{-1}. This confers on the soil a sandy loam texture. The coarse nature of the soil indicates low water-holding capacity and availability, making the soil susceptible to drought stress during even short rainless period. The sandy nature of the soil allows for tillage of the soil, even at high moisture content, with less damage to the structure of the soil.

The soil has a slightly acidic reaction, implying that nearly all plant nutrients are available in optimum amount. The pH range of 6.0 to 7.0 is the most suitable for the release of many plant nutrients for uptake and optimum growth and development of most plants (Tan, 2000). The soil organic carbon, N, and phosphorus (P) were all low in the soil (Chude *et al*., 2011). The low content of soil organic carbon implies low reserve of soil organic matter which is responsible for low N and P in the soil. Soil organic matter is the major source of N and to a large extent P in the soil (Brady and Weil, 2010). The low organic carbon with consequent low N and P are characteristics of savanna soils, due partly to rapid decomposition in tropical climates which makes it difficult to build-up soil fertility (Andrén *et al*., 2007). The typically insufficient rates of organic inputs such as manure or crop residues applied to croplands due to low crop productivity and livestock density, and alternative use of crop biomass for energy and construction are also partly responsible for the low content of organic matter in tropical soils (Kätterer,*et al*., 2011). The relatively low N compared to organic carbon

Table 1: Means of initial soil properties prior to land preparation in 2014

Parameters	Values
Sand (g kg^{-1})	881
Silt (g kg^{-1})	36
Clay (g kg^{-1})	83
Textural class	Sandy loam
pH in H_2O (1:2.5)	6.6
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})	
Ca^{2+}	2.80
Mg^{2+}	2.00
K^+	0.72
Na^+	0.05
Exchangeable Acidity (cmol kg^{-1})	0.36
Effective cation exchange capacity (cmol kg^{-1})	5.93
Extractable zinc (mg kg^{-1})	2.30

will lead to stabilization of N in the soil and minimize its via nitrification coupled to nitrate leaching and denitrification due to high microbial N use efficiency (Zhang *et al*., 2019). Microbial N use efficiency is the proportion of N allocated to biosynthesis, mainly growth, relative to acquired N or organic N uptake (Mooshammer *et al*., 2014). Microbial N use efficiency reflects the capacity of organic N retention in microbial biomass. It has been demonstrated that under N limitation and relatively high amount of organic carbon in the soil, most acquired organic N is allocated to growth and microbial biomass, resulting in high microbial N use efficiency and immobilization of the N (Zhang *et al*., 2019).

The exchangeable cationic plant nutrients; $Ca^{2+,}$ Mg^{2+}, and K^{+} are all rated low (Chude *et al*., 2011). The low content of these cationic nutrients is a reflection of the low organic matter content in the soil. In tropical soils, organic matter is the main source of negative charges that these nutrients are adsorbed to,which prevents them from being leached down the soil profile beyond the root zone (Brady and Weil, 2010). The exchangeable acidity was 0.36 cmol kg^{-1} and rated low. The soil is thus low in potential acidity, will not contribute to the active acidity, may not constitute toxicity to crops or have an adverse effect on root development. High amount of aluminium is toxic to roots and cause swelling of the roots thereby impeding their ability to absorb water and nutrients from the soil (Brady and Weil, 2010).

The extractable Zn concentration is relatively high in the soil, 2.30 mg kg^{-1}, which may be attributed to the soil being under fallow for a long period of time without cultivation. Similar amount of extractable Zn has been documented for some soils of the study area by other workers (Lawal *et al*., 2014). The extractable Zn was above the critical level of 2.20 mg kg^{-1} established for some soils of the moist savanna by Yusuf *et al.* (2005). Extractable Zn values below 1.5 mg kg^{-1}indicate deficiency of the nutrient in cropping systems (Dobermann and Fairhurst, 2000; Zare *et al*., 2009). The soil can therefore, be regarded as adequate in available Zn for the successful cultivation of most crops and its deficiency is currently not expected on crops grown in the soil.

Effects of nitrogen and zinc on grain yield

The effects of N and Zn on the grain yield of maize in 2014 and 2015 seasons are shown in Table 2. Grain yields were significantly affected by the application of N in both seasons. Highest grain yields of 5.9 and 4.6 Mg ha^{-1} were recorded for 2015 and 2014 respectively with application of 120 kg N ha^{-1} significantly out-yielding the non-fertilized control by 47 % in 2015 and 33 % in 2014. These results confirm the assertion that N fertilization is important for maize in the moist savanna. Numerous studies have reported increased grain yield of maize with N fertilization in the moist savanna of Nigeria (Adeboye *et al*., 2010; Lawal *et al*., 2015; Afolabi *et al*., 2017). There was no significant difference in grain yield among the N-fertilized maize in both seasons. These results suggest that application of the lowest rate (60 kg N ha^{-1}) seems to be optimum for profitable maize production in the area. Adeboye *et al.* (2010) have also reported 60 kg N ha^{-1} to be optimum for maize in the area. In the West African savanna, 60 to 120 kg N ha^{-1}has been recommended for

Table 2: Effects of nitrogen and zinc fertilization on the grain yield of maize in 2014 and 2015 seasons.

Treatment	Grain yield (Mg ha^{-1})	
	2014	2015
Nitrogen(N) ($kg\ ha^{-1}$)		
0	3.1b	3.1b
60	4.4a	5.6a
90	4.4a	5.5a
120	4.6a	5.9a
SE ±	188	445
Zinc (Zn) ($kg\ ha^{-1}$)		
0	3.9	3.5b
2.5	4.3	5.3a
5	4.1	6.1a
SE ±	163	386
Interaction		
NxZn	NS	NS

Means in the same column for a factor followed by the same letter are not significantly different at 5 % level of probability.

maize by Carsky and Iwuafor (1999). Grain yields of non-fertilized control were higher than the national average of below 1.4 Mg ha^{-1} for most farmers in Nigeria, probably due to the land having been under fallow for a long period of time. The national average yields per hectare of a large number of farmers are below 1.4 Mg ha^{-1} (IITA, 2017). In 2015, the N-fertilized maize had higher grain yields compared to their counterparts in 2014. The lower amounts of rainfall in 2014 compared to 2015 in July and August (Fig. 1), which is the period of rapid vegetative growth and tasselling of maize when it requires more water might have been responsible for the lower grain yields recorded in 2014. Maize requirement of water and nutrients is usually relatively high during the period of rapid vegetative growth and tasselling.

The main effect of Zn fertilization on grain yield was insignificant in 2014. This might be due to relatively high extractable Zn concentration in the experimental soil and thus, high Zn nutritional status of the maize. The initial extractable Zn was 2.30 mg kg^{-1} which was above the critical level of 2.20 mg kg^{-1} established for maize in some savanna soils by Yusuf *et al.* (2005). Lack of response to Zn application with similar concentration of soil extractable Zn has been reported for wheat (Zhang *et al*., 2012). In contrast to 2014, in 2015, the main effect of Zn application on grain yield was significant with the Zn-fertilized maize out-yielding the control by over 34 %. However, the Zn-fertilized ones have statistically similar grain yields. The highest grain yield of 6.1 Mg ha^{-1} across both seasons was obtained with application of 5 kg Zn ha^{-1}. Judicious application of fertilizer Zn helps to increase crop production (Slaton *et al*., 2001; Khan *et al*., 2002; Manzeke *et al*., 2014). The response of grain yield to Zn application in 2015 may be attributed to the build-up of Zn in the soil resulting from the residual effect of 2014 application, combined with the application at the beginning of 2015 cropping season. Zinc fertilizers are known to have residual effects which can last up to four years (Mertens and Westermann, 1991) and this can result in good distribution of Zn in the soil which would enhance its uptake. One of the problems associated with soil application of Zn is being not well distributed in the soil which will affect uptake by roots (Holloway *et al*., 2010). The interaction of N and Zn fertilization on grain yield was insignificant which indicates that the response of grain yield to addition of N and Zn was additive.

Agronomic nitrogen use efficiency as affected by zinc fertilization

The AE of N, as affected by Zn application in both 2014 and 2015 seasons are shown in Tables 3 and 4. The AE values were slightly higher in 2015, ranging from the lowest value of 14.44 kg kg^{-1} obtained in the treatment, 120 kg N ha^{-1} plus 5 kg Zn ha^{-1} in 2014 to the highest value of 82.72 kg kg^{-1} recorded for the treatment, 60 kg N ha^{-1} plus 5 kg Zn ha^{-1} in 2015. The values recorded in this study were higher than 18 kg kg^{-1} reported in smallholder maize farms in SSA (Ichami *et al*., 2019) and 19 kg kg^{-1} in farmer-managed experiments in maize fields in SSA (Vanlauwe, *et al*., 2011). The values were also higher than the range of 15 to 30 kg kg^{-1}, obtained where recommended management practices were employed and when soil K and P were optimum (Fixen*et al*., 2015), while the world average of 24 kg kg^{-1} reported by Ladha *et al* (2005). Dobermann (2007) reported that AE of N in cereals varied between 10 to 30 kg kg^{-1} and could reach > 30 kg kg^{-1} in well managed systems with low levels of N, or with low soil N supply. The relatively high values recorded in this study are a reflection of the high grain yield obtained in the control plots in both seasons (Table 2). Agronomic efficiency of N is a function of maize grain yield in the control plot (Ichami *et al*., 2019).

The AE was significantly affected by zinc fertilization in both seasons. In most cases, in both seasons, across the Zn levels, there was significant reduction in AE at high rate of N. the lower N rate of 60 kg ha^{-1} produced the highest AE

Table 3: Fertilizer response, agronomic efficiency and partial factor productivity of nitrogen as affected by zinc fertilization in 2014 cropping season.

Nitrogen (kg ha^{-1})	Zinc (kg ha^{-1})	Fertilizer Response	Agronomic Efficiency (kg grain kg N^{-1})	Partial Factor Productivity (kg grain kg N^{-1})
60	0	2	26.56b	63.39b
60	2.5	2.	40.44a	77.23a
60	5	2	40.78a	77.61a
90	0	2	21.52b	46.07c
90	2.5	2	25.56b	49.82c
90	5	2	27.78b	52.33bc
120	0	2	22.86b	41.23cd
120	2.5	2	22.11b	40.53cd
120	5	2	14.44b	32.86d
SE ±		0.05	2.00	3.17

Means in the same column followed by the same letter (s) are not significantly different at 5 % level of probability. NS -Not Significant.

Table 4: Fertilizer response, agronomic efficiency and partial factor productivity of nitrogen as affected by zinc fertilization in 2015 cropping season.

Nitrogen (kg ha^{-1})	Zinc (kg ha^{-1})	Fertilizer Response	Agronomic Efficiency (kg grain kg N^{-1})	Partial Factor Productivity (kg grain kg N^{-1})
60	0	4	7.78ab	95.11ab
60	2.5	4	59.72abc	82.06abc
60	5	5	82.72a	10.556a
90	0	3	35.67c	50.56cd
90	2.5	5	52.85abc	67.74bcd
90	5	4	49.48bc	64.37bcd
120	0	4	35.72c	46.89d
120	2.5	4	35.14c	46.31d
120	5	5	44.28bc	55.44cd
SE ±		0.20	4.16	4.82

Means in the same column followed by the same letter (s) are not significantly different at 5 % level of probability. NS- Not Significant.

of 22.72 kg kg^{-1} in 2015. These results appeared to be related to the statistically similar grain yield at all levels of N supplied. Similarly, across the N levels, AE was highest in plots with the highest rate of 5 kg Zn ha^{-1}, suggesting higher rate of Zn results in more efficient use of N for production of grain yield. Higher values were recorded in 2015 than in 2014 due to higher grain yield recorded in 2015.

Fertilizer response to nitrogen as affected by zinc fertilization

The effect of Zn fertilization on response of maize to N fertilization in 2014 and 2015 seasons are shown in Tables 3 and 4. The FR values increased slightly in 2015 ranging from 2 in 2014 to 5 in 2015. Fertilization increased the maize grain yield by > 30 % in both seasons. The values are within the range of 1 to 12 reported for smallholder farmers in SSA using meta-analysis by other workers (Ichami *et al*., 2019). No statistical difference in FR was found among the Zn rates in both seasons. Our results suggested that the inherent and applied Zn are sufficient for adequate nutrition of maize and thus, not a factor limiting grain yield. The total carbon, soil pH, exchangeable K, and P-Olsen have been identified as some of the factors that led to responsiveness of soils in SSA to fertilization (Ichami *et al*., 2019).

Partial factor productivity of nitrogen as affected by zinc fertilization

The PFP of N as affected by Zn fertilization in both 2014 and 2015 seasons are shown in Tables 3 and 4. There was significant effect of Zn on the PFP of N in both seasons. In 2014 and 201, the highest values of PFP were 77.61 kg kg^{-1} and 105.56 kg kg^{-1} respectively, which were recorded in the treatment, 60 kg N ha^{-1} plus 5 kg Zn ha^{-1} in both seasons. The values obtained in this same treatment were significantly higher than the values recorded for higher rates of N at all levels of Zn in both seasons. There was significant reduction in PFP with increasing rate of N in both seasons irrespective of the Zn level due to statistically similar grain yield at all levels of N that appear to suggest 60 kg N ha^{-1} is optimum for profitable grain yield of maize in the area as reported by other workers (Adeboye *et al*., 2010; Lawal *et al*., 2015; Afolabi *et al*., 2017). The PFP values ranged from 32.86 to 105. 56 kg kg^{-1} which is within the range of 40 to 90 kg kg^{-1} reported by Fixen *et al* (2015), where recommended management practices are employed and when soil available P and K are optimum and similar to the world average of 72 kg kg^{-1} reported for maize by Ladha*et al* (2005). The lower values at high N rate, suggest over-application of N, while the higher values at lower rates suggest other nutrients supply are likely limiting grain yield. (Fixen *et al*., 2015). However, the values obtained in this study are lower than the 122 kg kg^{-1} at 9 kg N ha^{-1} reported for SSA by Dobermann and Cassman (2005). Similar to the results of AE, in both seasons, the highest value of PFP was recorded in the treatment having application of 60 kg N ha^{-1} plus 5 kg Zn ha^{-1} and higher values were obtained in 2015 than in 2014, again due to the higher grain yield in 2015.

CONCLUSION

The basic premise of this study was to evaluate the effect of Zn fertilization on the efficiency of N use by maize as part of a broad study to identify the major factors that can be used to refine blanket fertilizer recommendations currently in use in Nigeria. The findings of the study indicate that N is important in maize production and the current blanket recommended N rate of 120 kg ha^{-1}for the crop in the moist savanna agroecological zone of Nigeria could be reduced to as low as 60 kg ha^{-1}. Zinc fertilization can help to increase the efficiency of N use by maize and thus, fertilizer recommendation for the area can be modified to include Zn application at the rate of 5 kg ha^{-1}.

REFERENCES

Abunyewa, A.A. and Mercer-Quarshie, H. 2004. Response of maize to magnesium and zinc application in the semi-arid zone of West Africa. *Asian Journal of Plant Science*, 3: 1-5.

Adeboye, M.K.A**.,** Osunde, A.O., Tsado, P.A., Odofin, J.A., Bala, A. and Adeyemi, R.A. 2010. Response of maize grain yields to rates and split applications of nitrogen and NPK combinations in the southern Guinea savanna of Nigeria. *Journal of Agriculture and Agricultural Technology*, 2 (1): 108-118.

Adnan, A.A., Diels, J., Jibrin, J.M., Kamara, A.Y., Shaibu, A.S., Crawfurd, P. and Abebe, M. 2020. CERES-Maize model for stimulating genotype-by-environment interaction of maize and its stability in the dry and wet savannas of Nigeria. *Field Crops Research*, 253: 2-11.

Agbenin, J.O. 1995. Laboratory Manual for Soil and Plant Analysis. (Selected Methods and Data Analysis). Published by the author. pp. 140.

Afolabi, S.G., Adeboye, M.K.A., Lawal, B.A., Moses, S. B. and Usman, A. 2017. Cereal/legume rotation effects on soil carbon and nitrogen and grain yield of maize in the southern Guinea savanna of Nigeria. *Nigerian Journal of Soil Science*, 27: 1-14.

Andrѓen, O., Kihara, J., Bationo, A., Vanlauwe, B. and Kätterer, T. 2007. Soil, climate and decomposer activity in sub-Saharan Africa estimated from standard weather station data: a simple climatic index for soil carbon balance calculations. *Ambio*, 36: 379-386.

Badu-Apraku, B. and Fakorede, M.A.B. 2017. Climatology of maize in sub-Saharan Africa. Advances in Genetic Enhancement of Early and Extra-Early Maize for sub-Saharan Africa. Springer International Publishing, Cham, pp 11-31. https://doi.org/10.1007/978-3-319.

Brady, N.C. and Weil, R. 2010. The Nature and Properties of Soils. 3rd Edition. Pearson Education Inc., Upper Saddle River, New Jersey. 07456. 960 pp.

Cakmak, I. 2002. Plant nutrition research: priorities to meet human needs for food in sustainable ways. *Plant and Soil*, 247: 3-24.

Cakmak,I. 2008. Enrichment of cereal grains with zinc: agronomic or genetic biofortification? *Plant and Soil*, 302: 1-7.

Carsky, R.J. and Iwuafor, E.N.O. 1999. Contribution of soil fertility research and maintenance to improved maize production and productivity in sub-Saharan Africa. In,B. Badu-Apraku, M.A.B. Fakorede, M. Ouedraogo and P.M. Quinn (eds). *Strategy for Sustainable Maize Production in West and Central Africa.* Proceedings of a Regional Maize Workshop, IITA, Cotonou, Benin Republic,21-25, April, 1997. WECAMAN/IITA. pp. 3-20

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 Mechlich III extractable zinc. In, B.Badu-Apraku, M.A.B. Fakorede, M. Ouedraogo, R.J. Carsky and A.Menkir (eds*). Maize Revolution in West and Central Africa.* Proceedings of a Regional Maize Workshop, IITA, Cotonou, Benin Republic, 21-25, May, 2001. WECAMAN/IITA. pp. 201-207.

Chude, V.O., Malgwi, W.B., Amapu, I.Y. and Ano, A.O. 2011. Manual on Soil Fertility Assessment. Federal Fertilizer Department. FAO and National Programme on Food security, Abuja, Nigeria. CRC Press, Boca Raton, FL, USA. pp. 62.

Dobermann, A. 2007. Nutrient use efficiency – measurement and management. In "IFA International Workshop on Fertilizer Best Management Practices", Brussels, Belgium, pp. 1-28.

Dobermann, A. and Cassman, K.G. 2005. Cereal are nitrogen use efficiency are drivers of future nitrogen fertilizer consumption. *Science in China*, 48: 745-758.

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

FAO 2018. Production Year Book, Food and Agricultural Organization of the United Nations, Rome.

Fixen, P., Brentrup, F., Bruslema, T., Garcia, F., Norton, R. And Zingore, S. 2015. Nutrient/fertilizer use efficiency: measurement, current situation and trends 1. ISBN, 979.10-92366-020-0.Available at: https://www.researchgate.net/publication/2697096-48.

Giller, K.E., Rowe, E.C., de Ridder, N. and van Keulen, H. 2006. Resource use dynamics and interactions in the tropics: scaling up in space and time. *Agricultural Systems*, 88: 8-27. https://doi.org/10.1016/j.ajsy.2005.06.016

Holloway, R.E., Graham, R.D., McBeath, T.M. and Brace, D.M. 2010. The use of a zinc efficient wheat cultivar as an adaptation to calcareous subsoil: a glasshouse study. *Plant and Soil,* 336: 15-24.

Hossain, M.A., Jahiruddin, M., Islam, M.R. and Mian, M.H. 2008. The requirement of zinc for improvement of crop yield and mineral nutrition in the maize-mungbean-rice system. *Plant and Soil,* 306: 13-22.

Ichami, S.M., Shepherd, K.D., Sila, A.M., Stoorvogel, J.J. and Hoffland, E. 2019. Fertilizer response and nitrogen use efficiency in African smallholder maize farm. *Nutrient Cycling in Agroecosystems,* 113: 1-9.

IITA 2017. Annual Report: Serving the African Farmers and the Communities. Ibadan, Nigeria.

Jiang, W., Struik, P.C., Keulen, 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.

Kamara, A.Y., Ekeleme, F., Chikoye, D., and Omoigui, I.O. 2009. Planting date and cultivar effects on grain yield in dryland corn production. *AgronomyJournal*,101, 91.https://doi.org/10.21 34/agronj2008.0090.

Kätterer, T., Bollinder, M.A., Andrén, O., Kirchmann, H. and Menichetti, I. 2011. Roots contribute more to refractory soil organic matter than above-ground crop residues, as revealed by a long-term field experiment. *Agricultural Ecosystems and Environment*, MI: 184-192.

Khan, M.U., 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.

Kihara, J., Sileshi, G.W. and Nziguheba, G. 2017. Application of secondary nutrients and micronutrients increases crop yields in sub-Saharan Africa. *Agronomic Sustainable Development*, https//doi.org/10.1007/s13593-017-0431-0.

Kogbe, J.O.S. and Adediran, J.A. 2003. Influence of nitrogen, phosphorus and potassium application on the yield of maize in the savanna zone of Nigeria. *African Journal of Biotechnology*, 2 (10): 345-349.

Ladha, J.K., Pathak, H., Krupnick, T.J., Six, J. and van Kessel, C. 2015. Efficiency of fertilizer nitrogen in cereal production: retrospects and prospects. *Advances in Agronomy*, 87: 85-156.

Lawal, B.A., Adeboye, M.K.A., Tsado,P.A., Elebiyo, M.G. and Nwajoku, C.R. 2012. Properties, classification and agricultural potential of lateritic soils of Minna in sub-humid agroecological zone, Nigeria. *International Journal of Development and Sustainability*, 1(3): 903-911.

Lawal, B.A., Adeboye, M.K.A., Mbaoji, C., Abbah, I.M. and Abdulrasak, Y.L. 2014. Assessment of some micronutrients in profiles of Typic Plinthustalfs in Minna, southern Guinea savanna, Nigeria. *Nigerian Journal of Soil and Environmental Research*, 12: 104-114.

Lawal, B.A., Adeboye, M.K.A., Usman, A., Afolabi, S.G. and Adekanmbi, A.A. 2015. Rotation effect of *Aeschynomene histrix* on soil carbon and nitrogen and maize grain yield in Minna in the southern Guinea savanna of Nigeria. *Journal of Agriculture and Agricultural Technology*, 6(1): 1-9.

Ma, B.L., Zheng, Z.M., Morrison, M.J. and Gregorich, E.G. 2016. Nitrogen and phosphorus nutrition and stoichiometry in the response of maize to various N rates under different rotation systems. *Nutrient Cycling in Agroecosystem*,104: 93-105. https://doi.org/10.1 1007/s10705-016-9761-6

Mandal, M.K., Dutta, S., Majumdar, K., Satyanarayana, I., Pampolino, M., Govil, V., Johnson, A.M. and Shrotriya, G.C. 2015.Enhancing rice yield, profitability, and phosphorus use efficiency in west Bengal using the nutrient expert fertilizer decision support tool. *Better crops – South East Asia,* 12-14.

Manzeke, G.M., Mtambanengwe, F. and Nezomba, H. 2014. Zinc fertilization influence on maize productivity and grain nutritional quality under integrated soil fertility management in Zimbabwe. *Field Crops Research*, 166: 128-136.

Mertens, D.C. and Westermann D.T. 1991. Fertilizer application for correcting micronutrient deficiencies, In, J.J. Mortvedt, F.R. Cox, L.M. Schuman and R.M. Welch (eds), Micronutrients in Agriculture, Book Series, No 4. Second edition. Soil Science Society of America, Madison, Wisconsin, USA. pp.549-592 (Chapter 15).

Mooshammer, M., Wanek, W., Hammerle, I., Fuchslueger, I., Hofhansl, F., Knoltsch, A., Schnecker, J., Takriti, M., Watzka, M. and Wild, B. 2014. Adjustment of microbial nitrogen use efficiency to carbon:nitrogen imbalances regulates soil nitrogen cycling. Nature Communication 5.

Naik, S.K. and Das, K. 2008. Relative performance of chelated zinc and zinc sulphate for lowland rice (*Oryza sativa* L.). *Nutrient Cycle in Agroecosystem,* 81:219-227.

Njoroge, R., Otinga, A.N. and Okalebo, J.R. 2017. Occurence of poorly responsive soils in western Kenya and associated nutrient imbalances in maize (*Zea mays* L.). *Field Crop Research*, 210: 162-174. https://doi.org/10.1016/ j.fer.217.05.015

Nziguheba, G., Tossah, B.K. and Diels, J. 2009. Assessment of nutrient deficiencies in maize in nutrient omission trials and long-term field experiments in the West African savanna. *Plant and Soil*, 314: 143-157. https://doi.org/10.1007/s 11104-008-9714-1

Ojanuga, A,G, 2006. Agroecological Zones of Nigeria Manual. F. Berding and V.O. Chude (eds). National Special Programme for Food Security (NSPFS), Food and Agriculture Organization of the United Nations (FAO), Federal Ministry of Agriculture and Rural Development (FMA&RD), Abuja, Nigeria. pp. 124.

Phattarakul, N., Rarkasem, B., Li, L.J., Wu, L.H., Zuo, C.Q., Ram, H., Sohu, V.S., Kang, B.S., Surek, H., Kalayei, M., Yazici, A., Zhang, F.S., and Cakmak, I. 2012. Biofortification of rice grain with zinc through zinc fertilization in different countries. *Plant and Soil*, doi; 10.1007/s11104-012-1211-x.

Sajedi, N.A., Ardakani, M.R., Naderi, A., Madani, H., Mashhadi, A. and Boojar, M. 2009. Response of maize to nutrients foliar application under water deficit stress condition. *American Journal of Agriculture and Biological Sciences*, 4(3): 242-248.

SAS Institute. 2015. SAS *User's Guide*. SAS Inst., Cary., NC, USA.

Sileshi, G., Akinnifesi, F.K., Ajayi, O.C. and Place, F. 2008. Meta-analysis of maize yield response to woody and herbaceous legumes in sub-Saharan Africa. *Plant and Soil*, 307: 1 -19. https://doi.org/10.1007/s11104-008-9547-y.

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

Stoorvogel, J.J. and Smaling, E.M.A. 1998. Research on soil fertility decline in tropical environments: integration of spatial scales. *Nutrient Cycling in Agroecosystem*, 50: 151 -158.

Sudhalakshmi, C., Krishnasamy, R. and Rajaram, R. 2007. Influence of zinc deficiency on shoot/root dry weight ratio of rice genotypes. *Research Journal of Agriculture and Biological Sciences,* 3:295-298.

Tan, K.H. 2000. Environmental Soil Science. Second edition. Marcel Dekker Inc., New York, USA. pp. 452.

Tittoneill, P., Vanlauwe, B. and Leffelaar, P.A. 2005. Exploring diversity in soil fertility management of smallholder farms in western Kenya.: Heterogeneity at region and farm scale. *Agriculture Ecosystem and Environment*, 110:149-165. https://doi.org/10.1016/j.agee.2005.04.001.

Tittoneill, P., Zingore, S. and van Wijk, M.T. 2007. Nutrient use efficiencies and crop responses to N, P and manure applications in Zimbabwe soils: exploring management strategies across soil fertility gradients. *Field Crop Research*, 100: 348-368. https://doi.org/10.1016/j.fer.2006.09.003.

Tittoneil, P., Muriuki, A. and Klapwijk, C.J. 2013. Soil heterogeneity and soil fertility gradients in smallholder farms of the East African Highlands. *Soil Science Society American Journal,* 177: 525-538. https://doi.org/10.2136/ssaj2012.0250.

Vanlauwe, B., Kihara, J. and Chivenge, P. 2011. Agronomic use efficiency of N fertilizer in maize-based systems in sub-Saharan Africa within the context of integrated soil fertility management. *Plant and Soil*, 339:35-50. https://doi.org/10.1007/s11104.010-0462-7

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 zinc deficiency concentration and tissue iron:zinc ratio as a diagnostic tool for prediction of zinc deficiency in corn. *Journal of Plant Nutrition*, 32: 1983-1993.

Zhang, Y., Sun, Y., Ye, Y., Karim, R.M., Xue, Y., Yan, P., Meng, Q., Cui, Z., Cakmak, I., Zhang, F. and Zuo, C. 2012. Zinc biofortification of wheat through fertilizer applications in different locations of China. *Field Crops Research*, 125: 1-7.

Zhang, S., Zheng, Q., Noli, L., Hu, Y. and Wanek, W. 2019. Environmental effects on soil microbial nitrogen use efficiency are controlled by allocation of organic nitrogen to microbial growth and regulate gross N mineralization. *Soil Biology and Biochemistry*, 135: 304-315.

Zingore, S., Murwira, H.K., Delve, R.J. and Giller, K.E. 2007. Soil type, management history and current resource allocation: three dimensions regulating variability in crop productivity on African smallholder farms. *Field Crop Research,* 102:296-305. https://doi.org/10.1016/fer.2006.12.006.