



Efficacious Response of Maize (*Zea mays* L.) Growth and Soil Changes to Phosphorous and Zinc Applications on Chromic Luvisols in North-Eastern Part of Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author MA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript while author AAS managed the analyses of the study and author AB managed the literature searches and development. All authors read and approved the final manuscript.

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ABSTRACT

The study aimed to study the efficacious response of maize growth and soil changes to phosphorous and zinc application on chromic luvisols in North-eastern part of Nigeria conducted at Teaching and Research Farm of School of Agriculture and Agricultural Technology, Modibbo Adama University, Yola during 2018 and 2019 cropping seasons. Randomized Complete Block Design (RCBD) was used in the experiment to test the various levels of P and Zn applications on TZL composite white improved variety of maize. Four levels of phosphorus (0, 10, 20 and 30 kg Pha⁻¹) and three levels of zinc (0, 5 and 10 Zn ha⁻¹) were applied on experimental plots of 4.5m x 5m replicated three times. Data obtained on the growth parameters and soil properties were measured and analyzed using ANOVA statistical package. Result indicate that the soil was predominantly sandy loam, organic matter (mean =0.92 gkg⁻¹), total N (mean = 0.35 gkg⁻¹) Available phosphorous (mean = 8.6 mgkg⁻¹) Zinc (mean = 7.25 mgkg⁻¹) and exchangeable cations

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(means= Ca^{2+} =0.26 cmolkg⁻¹, Mg^{2+} =0.27 cmolkg⁻¹, K^+ =1.83, Na^+ =0.85 cmolkg⁻¹) and CEC = 5.32 respectively. The effects of P and Zn did not show any significant difference on plants height in both years of experimentation except at harvest where main effect of P showed slightly taller plants at 30 kg Pha⁻¹ level in 2018 (202.11 cm) and 2019 (206.11 cm). Generally the mean values of plant heights at various P levels are higher than that at the Zn levels. Similarly, there were no significant differences in the leaf area, however, highest mean values of 236.1 cm² and 227.6 cm² was observed at 30 kg Pha⁻¹ and 10 kg Znha⁻¹ in both 2018 and 2019 cropping years. while Leaf Area Index shows highest values of 2.98 cm² and 2.54 cm² observed at 30 kg Pha⁻¹ and 10 kg Znha⁻¹ and interaction effects was significant P = (0.05) in both years respectively. Available P in soil after the harvest of 2018 the available P was significantly affected. Highest mean values of P content were 13.14 mgkg⁻¹ and 14.97 mgkg⁻¹ in 2018 and 2019 with 30kg Pha⁻¹. Also, there was significant difference in the main effect of the Zinc treatments on available Zn in the soil in 2019 where the highest mean value of 4.03 mgkg⁻¹ was recorded at 0 kg Zn ha⁻¹. Therefore, application of 30 kg P ha⁻¹ and 10 kg Zn ha⁻¹ as evidenced to maintain the soil nutrients and thus should be employed for sustainable maize production in the area.

Keywords: Application; efficacious; growth; maize; phosphorous; soil; zinc.

1. INTRODUCTION

Maize (*Zea mays* L.) is the 3rd highest yielding cereal crop in the world after wheat and rice [1]. Similarly, is the most important cereal crop in Sub-Saharan Africa [2]. In Nigeria, maize is the second most important cereal crop and its importance in Nigeria is evidenced by the continued increase in production over the years [3]. However, the soils of West Africa are low in fertility and chemically fragile. Small farmers had traditionally coped with the system by resorting to the bush fallow system which permitted low but relatively stable levels of crop production. However, the bush fallow system has become less feasible because of increasing population and higher demand for land usage. This has since been replaced by continuous cropping of depleted soils in many areas in the Savannah and Sahelian zones [4]. The demand for fertilizer for agricultural production continues to increase as more and more farmers continue to realize the relevance of fertilizer in crop production. This is because fertility status of any soil depends on both the macro and micro nutrient statuses. Amongst several nutrients, phosphorus and zinc are two important macro and micro nutrients that play a pivotal role for cereal particularly in maize production respectively. Phosphorus (P) plays a major role in several physiological processes like photo-synthesis, respiration, energy storage and transfer, cell division, cell enlargement and development of meristematic tissues [5]. In addition, P is also an integral structural component of many biochemicals i.e. nucleic acid, which is the basic component of gene and chromosomes and assess to heredity [6]. It stimulates root development, increases strength

of cereal straw, hasten flowering and maturity of crops and increase seed formation [7,8]. It improves the quality of certain fruits, vegetables and grain crops and increases resistance to disease and adverse conditions [9]. On the other hand, Zinc (Zn) is very important for various physiological functions in plants [10,11,12,13]. Zinc deficiency not only reduces the crop production but also cause Zn deficiency in our diet [14]. Application of Zn to zinc deficient soils increased maize grain yield as well as the Zn and N concentrations in maize grains. Application of Zn increases dry matter by increasing leaf chlorophyll contents [15] and increase in N and P efficiencies [16]. In soils, the P interferes Zn uptake by the plants [17]. About the interaction of zinc and phosphorus numerous studies have been done and all confirms this point that zinc and phosphorus imbalance in the plant, as a result of excessive accumulation of phosphorus, causing zinc imposed deficiency [18]. The requirements of fertilizers in maize are important for the early growth and total production of yield. Maize requires heavy feeding for its potential production of yield. Indiscriminate use of inorganic fertilizers leads to nutrient imbalance in soil causing ill effect on soil health and micro flora [19]. Unfortunately, continuous application of higher amount of fertilizer may pose deleterious effects which leads to decline in productivity, deteriorates the physical, chemical and biological properties of soil. Land being marginal and farmers poorer, it is important to prevent the unnecessary over use of fertilizer to minimize the effect on the soil and most importantly, reduce the production cost [20]. Thus, several studies have been carried out on response of phosphorous and zinc on maize

production in relation to several mineral nutrients in the soils of various parts of the world and in some States of North Eastern Nigeria [21,22,23]. In soil solution and plants, phosphorus binds with Zn by forming insoluble Zn-phosphate complexes, which inhibits the Zn uptake via roots and its movement in the plants. It has been reported that although higher phosphorus application to soil increases the plants P uptake but decreases the uptake of Zn that causes Zn deficiency [24,25,26]. However, little work has been undertaken in Yola and near environment of Adamawa State Nigeria on the effects of phosphorus and zinc fertilizers on the growth of maize and changes in soil properties. In addition, intensification of agriculture due to growing population and increased pressure on land forced most farmers in the study area to increase the use of inorganic fertilizers particularly P and Zn fertilizers which consequently resulted into unbalanced soil nutrients within the soil and affect both the vegetative growth and yield of crop most especially maize leading to economic lost and unprofitable farming among the small scale farmers. Therefore, it is highly imperative to study the efficient responses of maize as affected by P and Zn application and the changes that may caused in the soil system. Thus, this paper saddled to study the efficacious response of maize growth and soil changes to phosphorous and zinc application on the Chromic Luvisols in the North-eastern part of Nigeria.

2. MATERIALS AND METHODS

2.1 Study Area

The study was experimentally conducted at Teaching and Research Farm of School of Agriculture and Agricultural Technology, Modibbo Adama University, Yola situated at 9°16'N 12° 35E and is 152m above sea level, with an average rainfall of 910.8mm which occurred between May to October. The soil of the study area is sandy loam and it is classified as Typic Paleustaff (USDA) or Chromic Luvisols (FAO/UNESCO) [27]. The study area falls within the Northern guinea savannah zone having maximum temperature in the state can reach 40°C with the mean monthly temperature in the state ranges from 26.7°C in the northeastern part [28,29].

2.2 Experimental Design and Layout

Experiments were conducted during 2018 and 2019 rainy seasons. The experimental plots were

marked out into 4.5m x 5m basically giving a total area of 810m² for all the 36 plots. Randomized Complete Block Design (RCBD) was used in the experiment to test the various levels of P and Zn applications on TZL composite white improved variety of maize. Four levels of phosphorus (0, 10, 20 and 30kg P/ha) and three levels of zinc (0, 5 and 10 kg/ha⁻¹) were combined to a tested to give a total of twelve treatment combinations. The treatments were replicated three times culminated to a total of 36 experimental plots with the size of 22.5m each respectively.

2.3 Agronomic Practices

The land was ploughed using tractor and harrowed to break the soil clods. The maize seeds TZL composite white, a hybrid variety were sown in July 8th, 2018 for the first year of experiment and July 10th 2019 for the second year of experiment at the rate of 3 seeds per hole at distance between row to row of 75 cm while plant to plant spacing was 25 cm which gives a total of 120 plant stands per plot. Basal applications of 120 kg/ha N were made in two split applications. The first half was applied at 2 weeks after sowing while second half was applied at 5 weeks after sowing as described by [30]. Phosphorus and zinc fertilizers were applied to each experimental plot according to treatment rates in a single operation at planting.

2.4 Soil Sampling, Preparations and Analysis

Soil samplings consisting of 5 core samples were taken from each plot at the depth of 0 - 30 cm. The samples were air dried to a constant weight, ground and sieved in a 2 mm sieve prepared for both physical and chemical analysis, where the following physico-chemical properties were determined using standard laboratory analysis; Particle-size Analysis was determined using the hydrometer method as described by [31] and using the textural triangle the texture of the soil was determined [32]. Water-Holding Capacity was determined using the gravimetric method by determining the water content in a saturated soil sample based on loss in weight of the moist soil after oven drying at 105°C for 24 hours [31], Soil reaction (pH) was determined using the pH meter method (soil/water ratio of 1:2.5), while the electrical conductivity (EC) was determined in a soil/water extract using an EC meter [33]. Organic carbon was determined by dichromate digestion [34], from where organic matter was calculated. Cations Exchange Capacity (CEC) was determined by neutral

normal ammonium acetate displacement method [31], while the determination of exchangeable acidity was done by displacement with 1N potassium chloride and titrating the extract with 0.025N NaOH using phenolphthaleine indicator [35]. The effective CEC was obtained by summing the exchangeable bases with exchangeable acidity [31]. Zinc content of the soil was determined according to procedure outlined by [36]. Zn was extracted by in ammonium acetate (pH 7.0) and 0.01% dithizone and measured using Atomic Absorption Spectrophotometer, Available P was determined by bicarbonate extraction method [37]. The P extracted from the soil using 0.5M NaHCO₃ was determined calorimetrically, using a photoelectric colorimeter. Total P was determined by HClO₄ digestion of soils followed by a colorimetric determination in the digest [38].

2.5 Growth Parameters

Plant height was measured using meter rule at 30 days, 60 days and at maturity after planting, leaf area was estimated as its length multiplied by its maximum width multiplied by 0.75 as described by [39] while leaf area index was determined using the formula given below;

$$\text{Leaf area index} = \frac{\text{Total leaf area/plant(cm)}}{\text{Area occupied by each plant (cm)}} \quad (1)$$

2.6 Data Analysis

Data obtained were subjected to statistical analysis using the analysis of variance [40]. Means that were significantly different were separated using the least significant difference (LSD).

3. RESULTS

3.1 Physico-chemical Properties of the Experimental Soils

The result of the particle size analysis of the soils of study area on Table 1 reveals that sand, silt and clay was determined with the corresponding values of 712.00 gkg⁻¹, 103.00 gkg⁻¹ and 185.00 gkg⁻¹ in 2018 season while in 2019 the values were recorded as 728.70 gkg⁻¹, 143.20 gkg⁻¹ and 128.10 gkg⁻¹ respectively. the soil is sandy loam in texture in both 2018 and 2019 cropping years as depicted in Table 1. The water holding capacity of the soil was found to be 21.80% in 2018 and 24.20% in 2019 with mean value of 23.00%. The soil pH (H₂O) in 2018 was 6.96 while in 2019 it was 6.89 with the mean of 6.93. The pH (KC1) was 6.12 in 2018 while in 2019; it was 6.02 with a mean of 6.07 indicating that the soil is slightly acidic. The electrical conductivity was found to be 0.37ds/m and 0.35ds/m in 2018 and 2019 with a mean of 0.36ds/m (Table 1).

Table 1. Physico-chemical properties of the soil of the experimental site

Soil properties	Values		
	2018	2019	Mean
Physical Properties			
Sand (gkg ⁻¹)	712.00	728.70	720.35
Silt (gkg ⁻¹)	103.00	143.20	123.10
Clay (gkg ⁻¹)	185.00	128.10	156.55
Textual class	Sandy Loam	Sandy Loam	Sandy Loam
Water- Holding capacity (%)	21.80	24.20	23.00
Chemical Properties			
pH(H ₂ O)	6.96	6.89	6.93
pH (KCl)	6.12	6.02	6.07
Total N (gkg ⁻¹)	0.30	0.40	0.35
Available P (mgkg ⁻¹)	8.23	8.97	8.60
Zn (mgkg ⁻¹)	6.92	7.57	7.25
Organic carbon (gkg ⁻¹)	0.95	0.88	0.92
Exchangeable Cations (cmolk⁻¹)			
Ca ²⁺	0.25	0.27	0.26
Mg ²⁺	0.23	0.31	0.27
K ⁺	1.88	1.78	1.83
Na ⁺	0.86	0.84	0.85
Cations Exchange Capacity (CEC)	5.21	5.43	5.32
Electrical Conductivity (ds/m)	0.37	0.35	0.36

The total N was found to be 0.13 gkg⁻¹ in 2018 and 0.14% in 2019 with a mean value of 0.135%. The total nitrogen content of the soils of the study area ranges from low to moderate (0.13 - 0.14%). Available P values was 8.23 mgkg⁻¹ in 2018 and 8.97 mgkg⁻¹ in 2019. The mean was 8.60mgkg⁻¹ considered within the moderate range. Zinc contents of soils were 6.92 mgkg⁻¹ in 2018 and 7.57 mgkg⁻¹ in 2019 dictating low values. Zinc content of the experimental site indicated low values with an average mean of (7.25 mgkg⁻¹) while the organic carbon contents of 8.9 gkg⁻¹ and 9.5 gkg⁻¹ were recorded in 2018 and 2019 having a mean value of 9.2gkg⁻¹ respectively. Organic matter of the soil was low in both 2018 and 2019 which slightly decreases in 2019 (0.95 gkg⁻¹ and 0.88 gkg⁻¹). The Exchangeable calcium (Ca²⁺) of soil was found to be 0.25cmol kg⁻¹ and 0.27cmol kg⁻¹ in 2005 and 2006 respectively with a mean of 0.26 cmol kg⁻¹. Similarly, exchangeable magnesium (Mg²⁺) was found to be low in 2018 being 0.23 cmol kg⁻¹ while in 2019 the value obtained was 0.31cmol kg⁻¹ with their mean being 0.27 cmol kg⁻¹. Exchangeable magnesium content of soil of the study area showed similar behaviour as calcium content having low values ranging between 0.23 to 0.31 with mean value of 0.27 respectively. The exchangeable potassium (K⁺) content of the soils of study area is low and was 1.88 cmol kg⁻¹ in 2018 and 1.87 cmol kg⁻¹ in 2019 with the mean value of 1.83 cmol kg⁻¹. Exchangeable sodium (Na⁺) shows a value of 0.86cmol kg⁻¹ in 2018 and 0.84cmol kg⁻¹ in 2019 with their mean as 0.85cmol kg⁻¹. The cation exchange capacity CEC (cmol kg⁻¹) was found to be 5.21 in 2018 and 5.42 in 2019 with 5.32 as their mean.

3.2 Effects of P and Zn Application on Plants Heights

The result presented on Table 2 shows that, the main effects of P and Zn did not show any significant difference in plants height in both years of experimentation except at harvest where main effect of P showed slightly taller plants at P₃ level in 2018 with values of 202.11 cm and P₃ level in 2019 with values of 206.11 cm having a corresponding mean value of 204.11cm respectively. Conversely, at P₀ level the plant heights were shorter in both 2018 and 2019 having a corresponding values of 35.00 cm and 39.00 cm with a mean value of 37.00 cm respectively. Similarly, at Zn levels the plant heights was relatively taller at Zn₁ (202.33 cm) in 2018 and at Zn₂ level (206.00 cm) at harvest stage accordingly.

3.3 Effects of P and Zn Application on Leaf Area and Leaf Area Index (LAI)

Results of the leaf area and leaf area index LAI (Table 3) shows that there was no significant differences in the leaf area, however, highest leaf area was observed at P₃ in both 2018 and 2019 seasons (250.8cm² and 236.1cm²) with a mean value of 243.5cm² respectively. While at Zn levels in 2018 the leaf area was highest at Zn₂ level (210.1cm²) and in 2019 with Zn₁ (227.6cm²). In addition, the leaf Area Index LAI shows highest values of 2.95 and 3.28at P₃in 2018 and 2019 seasons with corresponding mean value of 2.98 while for the Zn levels the zn₂ treatments was observed with 2.47

Table 2. Effects of P and Zn application on maize plant height at different days after planting

Treatment	30DAP			60DAP			At harvest		
	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
P ₀	35.00	39.00	37.00	156.33	164.76	160.55	107.75	200.92	199.34
P ₁	37.00	41.00	39.00	166.25	166.25	166.25	200.67	203.74	202.21
P ₂	36.00	40.00	38.00	166.25	165.45	165.85	201.95	202.08	202.02
P ₃	38.00	42.00	40.00	164.78	163.78	164.28	202.11	206.11	204.11
SE ₊	3.50	3.50	3.50	3.85	3.88	3.87	2.89	3.09	2.99
Zinc									
Zn ₀	34.00	41.00	37.50	167.56	166.56	167.06	189.78	193.78	191.78
Zn ₁	38.00	38.00	38.00	163.00	162.00	162.50	202.33	203.00	202.67
Zn ₂	34.00	37.00	35.50	169.78	168.33	169.06	200.89	206.00	203.45
SE ₊	7.40	7.40	7.40	4.09	4.36	4.23	3.51	3.90	3.71
Interaction									
(Zn&P)		NS	NS	NS	NS	NS	NS	NS	NS
LSD(0.05)									

DAP=Days after Planting; NS = non-significant at P= (0.05 %)

value in 2018 and 2.68 value in 2019 at Zn1 treatment. Generally, mean values of 2.98 and 2.54 cm² observed at P₃Zn₁ respectively.

3.4 Effects of P and Zn Application on Plant Dry Weight (g/plant)

Results on the effects of P and Zn application on plant dry weight (g/plant) were presented on Table 4. The main effect of P treatment on plant dry weight did not show any significant effect but however, at 30 days after planting the P₃treatment has the highest plant dry weight per stand in 2018 and 2019 (22.11g and 31.44 g) having a corresponding values of 24.34g while the least (18.67 g and 30.00 g) with mean values of 26.78 g was recorded from P₀ treatment.

Also, result shows that, in 2018 the plant dry weight at Zn₂ on 30 days after planting was highest 21.17 g and 30.75 g (mean value of 25.96 g) as against the lowest 19.92 g and 30.58 g (mean value of 25.25 g) from the Zn₁ treatment indicating, that Zn₂ was not significantly different from Zn₀ treatment in both 2018 and 2019 respectively. The trends changes at 60 days after planting where the plant dry weight was highest at P₂ treatment with the values of 54.36g in 2018 and 56.41 g in 2019 having the mean value of 55.39 g while at Zn₂ treatment expressed highest dry weight of 52.82 g and 55.19g in both 2018 and 2019 with mean value of 54.01 and the lowest values were recorded with Zn₁ treatment (49.87 g) in 2018 and with Zn₀ treatment (53.23 g) in 2019 correspondingly.

Table 3. Effects of P and Zn application on leaf area (cm²) per plan and leaf area index

Treatment	Leaf area (cm ²)			Leaf area index (LAI)		
	2018	2019	Mean	2018	2019	Mean
P ₀	235.1	289.0	262.05	2.77	2.92	2.85
P ₁	146.0	168.0	157.0	1.72	1.98	1.85
P ₂	163.5	180.0	171.8	1.92	2.12	2.02
P ₃	250.8	236.1	243.5	2.95	3.28	2.98
SE _t	28.2	30.4	28.3	0.13	3.14	0.14
Zinc						
Zn ₀	182.9	210.3	196.6	2.15	2.47	2.31
Zn ₁	203.6	227.6	215.6	2.40	2.68	2.54
Zn ₂	210.1	201.6	205.9	2.47	2.37	2.43
SE _t	27.9	33.5	30.7	0.12	0.12	0.12
Interaction						
(Zn&P)	NS	NS	NS	0.2 [*]	0.2 [*]	0.2 [*]
LSD(0.05)						

* Significant different P = (0.05), NS= non-significant

Table 4. Effect of P and Zn application on plant dry weight (g/plant) at different days after planting

Treatment	30DAP			60DAP			At harvest		
	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
P ₀	18.67	30.00	24.34	50.54	54.16	52.35	88.11	93.33	90.72
P ₁	20.11	30.67	25.39	51.73	55.34	53.54	87.67	93.33	90.50
P ₂	21.00	30.56	25.78	54.36	56.41	55.39	88.44	94.44	91.44
P ₃	22.10	31.44	26.77	50.47	54.68	52.58	87.89	93.56	90.73
SE _t	0.71	1.23	0.97	1.03	1.85	1.44	1.45	2.28	1.86
Zinc									
Zn ₀	20.33	30.07	25.20	50.30	53.23	51.77	87.17	90.42	88.80
Zn ₁	19.92	30.58	25.25	49.87	55.16	52.52	97.33	93.08	95.21
Zn ₂	21.17	30.75	25.96	52.82	55.19	54.01	87.58	93.50	90.54
SE _t	0.95	1.40	1.17	1.20	2.01	1.61	1.34	2.71	2.03
Interaction									
(Zn & P)	NS	NS	NS	NS	NS	NS	NS	NS	NS
LSD(0.05)									

DAP = Days After Planting, NS= non-significant at P = (0.05%)

At harvest stage under P treatments, dry weight was observed to be highest at P₁ in 2018 and 2019 (87.67g and 93.33 g) with a mean value of 90.50 g respectively. Moreover, at Zn levels, Zn₀ treatments shows the lowest dry weight values in 2018 with the value of 87.17 g and in 2019 with 90.42 g having a mean value of 88.80 g recorded.

3.5 Effects of P and Zn Application on Available P and Zinc Changes in Soil after Crop Harvest

The result of available phosphorus and Zinc content in soil was presented on Table 5. Available P in soil after the harvest of 2018 and 2019 showed that, the available P is significantly affected where the highest values of P content was observed at P₃ with the values of 13.14 mgkg⁻¹ and 14.97 mgkg⁻¹ having a mean value of 14.06 mgkg⁻¹ while the least values of P content 10.76 mgkg⁻¹ was from P₁ treatments in 2018 and P₂ treatment (13.72 mgkg⁻¹) in 2019. However, the available P in the soil was 8.23 mgkg⁻¹ and 8.97 mgkg⁻¹ (Table 1) in 2018 and 2019 and increased to 11.38 mgkg⁻¹ and 14.23 mgkg⁻¹ at P₀ treatment (Table 5) which indicated that P in soil could increase without fertilizer respectively. Also, there was no significant difference in the main effect of the Zinc treatments on available Zn in the soil in 2019. The highest values in both 2018 and 2019 were recorded at Zn₀ with 2.34 mgkg⁻¹ and 4.03 mgkg⁻¹ having a mean value of 3.19 mgkg⁻¹ respectively.

4. DISCUSSION

4.1 Physico-chemical Properties of Soils of Experimental Site

The result of the particle size analysis of the soils of study area reveals that, the soil is sandy loam in texture in both 2018 and 2019 cropping years as depicted on Table 1. This result is in conformity with the findings of [29] who reported that, the soils of University Research Farm are mostly sandy loam underlined by sand to silt clay. The low water holding capacity of the soil might be due to sandy loam nature of the soil. The soil pH was slightly acidic to near neutral which indicated that the soils might have possessed a net negative charge in the colloidal complex. This assertion is in conformity with the findings of [41] in Yamaltu-Deba area of Gombe State Northern part of Nigeria that the soils were generally acidic with soil pH varying widely from 4.77 (very strongly acid) to 5.93 (moderately acid) between the locations. The total nitrogen content of the soils of the study area ranges from low to moderate (0.13 - 0.14%). Since the nitrogen content of the study area is low, application of nitrogen fertilizer at required rates for hybrid maize cultivation will be necessary. An available P value was considered within the moderate range. Phosphorus in soil for the two years of the study is moderate and also corresponds to the distribution of organic carbon. This indicates that, most of the available P of the study area is from decomposed organic matter as ascertained by [42]. However, in order to obtain desirable

Table 5. Effect of P and Zn application on available phosphorus and Zinc content in soil (mg/kg) harvesting

Treatments	Available P in soil			Zinc in soil		
	2018	2019	Mean	2018	2019	Mean
P ₀	11.38	14.23	12.81	1.70	3.83	2.77
P ₁	10.76	13.92	12.34	2.21	3.23	2.72
P ₂	11.39	13.72	12.56	2.38	4.43	3.41
P ₃	13.14	14.97	14.06	2.19	2.01	2.10
SE ₊	0.97	2.31	1.64	0.12	0.20	0.16
Zinc						
Zn ₀	6.92	13.58	10.25	2.34	4.03	3.19
Zn ₁	13.19	15.32	14.26	1.99	3.06	2.53
Zn ₂	15.23	13.73	14.48	2.03	3.04	2.54
SE ₊	1.18	1.39	1.29	0.22	0.33	0.28
Interaction						
(Zn&P)	4.49*	4.47*	4.49*	0.26*	NS	0.74
LSD(0.05)						

* Significant difference $P = (0.05)$, NS = non-significant

effect on maize performance, additional P input is highly important, although care must be taken in the application of phosphorus to soils with moderate P because increase in P rates beyond what is required would further depress yield and lead to low economic return. Zinc content of the experimental site indicated low values with an average mean of (7.25mgkg⁻¹). This could be as a result of Zn uptake by plants or by increased retention of the Zn by the soils, it can also be related to the texture of the soil of experimental site since it was sandy loam in texture and such soils are generally low in Zn concentration. Similarly, having a mean value of 9.2gkg⁻¹ was low in both 2018 and 2019 which slightly decreases in 2019 (0.95 gkg⁻¹ and 0.88 gkg⁻¹). The Exchangeable calcium (Ca²⁺) of soil was low. Similarly, exchangeable magnesium (Mg²⁺) was found to be low. Exchangeable magnesium content of soil of the study area showed similar behaviour as calcium content having low values respectively. Ca/Mg ratio of soil ranging from 1.0 to 2.8 indicated very narrow to moderated content, a Ca/Mg ratio of less than 1:1 is used to indicate the possibility of calcium deficiency in soils [43,44]. The exchangeable potassium (K⁺) content was also low. The low content in study area is in line with the observation made by [41] who reported that exchangeable K content of Yamaltu-Deba area of Gombe State soils are generally low (0.2188cmol kg⁻¹). The low sodium content (Mean 0.85cmol kg⁻¹) of the soils indicated that Salinity could not be a problem to crop cultivation. The low sodium of this soil are also similar with results obtained by [41] on savannah soils. The low cation exchange capacity values observed (5.32) for the two years of experiment could be due to low organic carbon/organic matter content coupled with low to moderate clay minerals in the soil.

4.2 Effects of P and Zn Application on Plants Heights

The result presented on Table 2 shows that, the main effects of P and Zn did not show any significant difference in plants height in both years of experimentation except at harvest where main effect of P showed slightly taller plants at P₃ level in 2018 and 2019. Generally the mean values of plant heights at various P levels are higher than that at the Zn levels. This may be due to the fact that, phosphorus and Zinc are absorbed by the maize plants, as they are absolutely essential or needed for the normal healthy growth and reproduction. This finding is in conformity with the result of [45] at the Agricultural Research Institute, Tarnab (Peshawar) for

the maize crop reported that the value of plant height, increased with a rise in P level up to 100 kg ha⁻¹ at all growth stages. Similarly, Ref. [46] reported that maize plant height increased with increase in P level. Ref. [47] also reported that the growth parameters of maize increased with a rise in zinc application but not in all growth stages. The low plants height (stunted growth), and reduced stem in untreated treatments (P₀Zn₀) followed by P₁Zn₁ treatments may be due to the absence or low zinc and phosphorus content of the soil of study area. Plants heights are higher where there is higher P than Zn levels in both 2018 and 2019 growing season and at all the stage of growth. Contrary to the findings of [48] who reported that phosphorus fertilization treatment decreased plant height and increase plant stalk diameter.

4.3 Effects of P and Zn Application on Leaf Area and Leaf Area Index (LAI)

Results of the leaf area LAI (Table 3) shows that there were no significant differences in the leaf area in both 2018 and 2019 seasons. However, the highest values were observed at P₃ and Zn₂ and Zn₁ in both 2018 and 2019 cropping years. This might be connected to the interactive or dilution effect of applied phosphorus and Zinc as they are absolutely essential for the normal healthy growth and reproduction of maize. It has been reported that various levels of phosphorus (50, 75, 100, 125 and 150 kg ha⁻¹) at a constant dose of N increased plant height, leaf area index, ear length, grain numbers per ear and 1000-grain weight significantly over control [49]. Similarly, the higher leaf area index observed on (Table 3) which is the total one-sided area of the leaf tissue per unit ground surface area and which has great influence on the rate of photosynthesis, canopy, atmospheric interface and growth that shows significant differences at P = 0.05 % with Zn₂ and Zn₁ treatments may be due to the interactive effects of P and Zn as observed in leaf area. Thus, LAI is a dimensionless quantity characterizing the canopy of all ecosystems. Ref. [50] observed the same trend with higher values of LAI and leaf area with higher level of P. Leaf area (LA) and LAI was significantly affected by P, Zn applied with upper level of P (120 kg ha⁻¹) and Zn (15kg ha⁻¹) as reported by [51] respectively.

4.4 Effects of P and Zn Application on Plant Dry Weight (g/plant)

Results on the effects of P and Zn application on plant dry weight (g/plant) is presented on

Table 4. The main effect of P treatment on plant dry weight did not show any significant effect. However, at P₃ treatment has the highest plant dry weight per stand at 30 DAP and at P₂ treatment at 60 DAP and at harvest. Also the highest plant dry weight at Zn₂ treatment on 30 days and at harvest in both 2018 and 2019 respectively. It can be deduced from the values obtained from dry matter weight at different stages of plant growth (Table 4) that, the dry matter production is more a function of phosphorus increasing rates of application than increasing rate of Zn application. This is because, the pattern of responses of plants height to different rate of P/Zn application are similar to that of dry weight per plant. This study observed that plants dry weights have higher values with P levels application compared to Zn levels application. According to Ref. [52] reported that the dry matter production also increased significantly with increasing phosphorus levels. The possible reason for increase in dry matter production could be correlated with the increased number of tillers. Ref. [45] also conducted a research at the Agricultural Research Institute, Tarnab (Peshawar) for the maize crop where he found that dry matter increased with a rise in P level up to 100 kg ha⁻¹. At the highest Zn rates, most of the maize crop showed reduction in dry matter production in all stages of growth (Table 4). Therefore, phosphorus deficiency affects nearly all the plant growth stages and plant dry matter weight. However, the dry weight response depends on the rate of P application and their exposure to sunshine. In this concern, it can be stated that, dry matter were more sensitive to P application rather than Zn application since it causes an increase in values of the dry matter parameter.

4.5 Effects of P and Zn Application on Available P and Zinc Changes in Soil after Crop Harvest

The result of available phosphorus and Zinc content in soil was presented on Table 5. Available P in soil after the harvest of 2018 showed that, the available P is significantly affected. Highest mean values of P content 13.14 mgkg⁻¹ was recorded at P₃ while the least mean values of P content 10.76mgkg⁻¹ were from P₁ treatments in 2018. Similarly, in 2019, the highest phosphorus content in soil was 14.97mgkg⁻¹ with P₃ treatment while the lowest value of P 13.72mgkg⁻¹ was recorded at P₂ respectively. This signifies the supplemental increase of phosphorous content in the inherent

soil status due to residual amount derived from the added amount of P fertilizer. Conversely, the increased in the soil P level in both 2018 and 2019 at P₀ might be attributed to the biochemical mineralization processes of some residual non-humic ligand compound exchange over a long period which subsequently releases the phosphorus in the soil complex. Similarly, there was significant difference in the main effect of the Zinc treatments on available Zn in the soil in 2018. Thus, according to Ref. [53] carried an experiment to study the effect of inorganic fertilizers on yield and nutrient uptake of maize (*Zea mays* L.) in Peelamedu soil series at Tamil Nadu Agricultural University, Coimbatore also showed the similar kind of findings in relation with the post harvest status of soil in relation with the Nitrogen, Phosphorus, Potassium and Zinc. It is also interesting to note that as the mean concentration of zinc increases, the mean concentration of P decreases and vice versa (Table 5). This study also observed that, the addition of P fertilizer to the 'existing available P in the soil, further increases the P content of the soil and the ability of the plants to absorb the essential elements under ideal agro-ecological conditions depends on Zinc concentration in the soil. Regardless of the moderate P content in the soil of area of study, the ZnSO₄ application may result in significant increase in soil zinc content.

5. CONCLUSIONS

Profitable farming among small scale farmers depends on the farming system and management that requires appropriate utilization of inorganic fertilizers towards improving plant growth and in turn sustaining the inherent nutrients status of the soil for future use. However, due to intensive agricultural activities on the marginal farmlands coupled with inappropriate used of inorganic fertilizers have led to poor growth of crop and subsequently declining the soil fertility most especially among the maize farmers in Yola and environs. Maize required optimum amount of Phosphorous and zinc nutrients for it proper vegetative growth which are very low in most of the Savannah soils which led to low crop performance and decline in soil nutrients. Therefore, this study saddled to study the efficacious response of maize (*Zea mays* L.) growth and soil changes to phosphorous and zinc application on chromic luvisols in North-eastern part of Nigeria. The results indicated that revealed that, there was an effective vegetative responses of plant height, leaf area, leaf area index and dry weight of maize

crop to the treatments tested and improved the soil P and Zn contents respectively. Therefore, application of 30 kg Pha⁻¹ and 10 kg Zn ha⁻¹ was evident in improving the maize growth and maintained the soil nutrients. Thus should be employed by the farmers for sustainable maize production in the area.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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