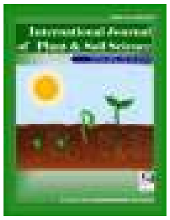

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Comparative Effects of Lime and Phosphorus Sources on Nutrients Uptake and Yield of Maize in a Tropical Ultisol

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Authors' contributions

This work was carried out in collaboration between all authors. Author EAA designed the study. Author MOA performed the statistical analysis and wrote the protocol as well as the first draft of the manuscript. Author BOO managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Ultisols are acid forest soils of low fertility status formed from intense weathering and leaching processes in the humid temperate and tropical regions. Sustainable crop production on these soils where phosphorus (P) deficiency is a main constraint aims at maintaining high crop yields by enhancing nutrients availability and uptake efficiency. This study was carried out at the Faculty of Agriculture, University of Ibadan to compare nutrients uptake and yield among maize plants grown from an ultisol with either sole or combined amendments of lime (L), rock phosphate (RP) and organomineral fertilizer (OMF). Eight treatment combinations: control, L, RP, OMF, L+ RP, L+OMF, RP+OMF and L+RP+OMF, each supplying 200kg P/ha and/or 1.0t/ha of L were replicated three times in a Complete Randomized Design. Crops grown in the RP+OMF amended soil (AMS) took up the highest concentrations of Ca, Zn, Mn and Fe. These were followed by the uptake of Ca and Mn from the L+RP AMS with the highest uptake of Mg. Next were those produced from the OMF AMS for Mg, Ca, Mn with the uptake of Zn and Fe only second to those in the RP+OMF AMS. Maize produced at 4 weeks after sowing from the OMF and L+RP AMS took up relatively higher

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concentrations of P, and together with those raised in the RP+OMF AMS which had the heaviest significant ($P \leq 0.05$) fresh root weight, produced the most significant height, leaf area and fresh shoot weight. The concentrations (1.10g/kg) of the dried shoot weight of the OMF and L+RP AMS were significantly higher than those of the other AMS, besides that of the RP+OMF (0.98g/kg). Tropical ultisols could be amended with OMF, RP+OMF or L+RP for effective nutrient uptake and maize yield.

Keywords: Lime; organomineral fertilizer; phosphorus; rock phosphate; nutrient uptake.

1. INTRODUCTION

Phosphorus (P) deficiency is a major constraint of crop production in the tropics [1]. The acid nutrient-poor oxisols and ultisols which dominate the forest, savannas and uplands of these regions [2] are infertile due to the complex interactions of pH, toxicities of Al and Mn as well as deficiencies of Ca and Mg, in addition to P [3]. These soils cover about 17 million hectares [4] of the total land area of 92.4 million hectares in Nigeria [5].

The poor growth of crops on such soils is associated with low pH values; therefore lime is usually applied to raise such values by adding Ca or Mg elements. Liming increases the uptake of nutrients, stimulates biological activity and reduces the toxicity of heavy metals [6]. However, for most efficient crop production on acid soils, the application of suitable amounts of both lime and P fertilizers has been in use [7]. It has been reported [8] that ultisols due to their high sorption capacity may require over 200kg P/ha to raise the soil solution concentration of the plough layer to 0.3kg P/ha in order to alleviate the limitation of P to crop yields.

Over the years, the direct application of rock phosphate (RP) to soil as an alternative to the more expensive soluble P fertilizers in tropical cropping systems has received much attention because of their relatively lower costs, coupled with their utilization potential, with or without amendments [9]. Thus, attempts have been made to utilize the indigenous RP deposits in Nigeria [10].

However, the cost, scarcity and inability of chemical fertilizers to substantially redress the physical fragility and chemical deterioration of the soil in these regions [11] have led to the formulation of Pacesetter organomineral fertilizer (OMF) by the Oyo State Government of Nigeria which is relatively cheap, readily available and environmentally friendly [12]. The fertilizer is composed of animal and plant wastes, assorted city refuse and fortified with N and P [13]. Analysis of the OMF [14] showed the concentrations (g/kg) of the nutrient contents of N, available P, exchangeable K and Ca as 28.8, 10.8, 6.8 and 6.8 respectively. Besides improving soil physical properties, they release relatively more nutrients, control soil acidity, and have residual effect on soil fertility as well as crop performances [11,15].

Phosphorus is the second most important plant nutrient after nitrogen that is critical for plant growth. The element is an integral component of key molecules such as nucleic acids, phospholipids and ATP [16] which provide compounds for photosynthesis in plants and respiration in animals. Adequate P in soils results in early crop maturity, greater stalk strength, improved crop quality, increased root growth and higher grain production [17].

Maize (*Zea mays* L.) is the third most important cereal crop in the world after wheat and rice with respect to area of coverage and productivity [18]. It has great significance as human food, animal feed and raw material for large number of industrial products [19]. Maize varieties are known to vary in P uptake and utilization efficiencies, as well as in adaptability to different soil types [20]. The need to assess the sources of P for the crop nutrient uptake so as to maximize the yield cannot be over emphasized.

Thus, the objective of this study was to evaluate the effectiveness of lime and P sources in a tropical ultisol in enhancing nutrients uptake and yield of maize.

2. MATERIALS AND METHODS

2.1 Study Area

Soil samples (0 -15cm) were collected from the Teaching and Research Farm of Ambrose Alli University, Ekpoma, in a forest, savanna transition zone of Nigeria (Lat 6°45'N and long

6°08'E). The samples were analyzed prior to the conduc t of the experiments (Table 1). The soil was used to conduct two incubation studies and a screen house experiment at the Plant Nutrition Unit of the Agronomy Department, University of Ibadan, Nigeria (Latitude 07º 22'N; longitude 03°58'E). Lime (L), Ogun RP (28.3–32.0% P_2O_5) and Pacesetter organomineral (OMF) fertilizer were obtained from Oyo State Pacesetter Fertilizer Plant, Ibadan.

2.2 Experimental Design

During the first incubation study, 50g of soil samples were weighed into 45 plastic containers and mixed with lime ($Ca(OH)_2$ at 5 levels (0, 1, 2, 3, 4 t/ha). The treatments were replicated three times in a Completely Randomized Design (CRD) and incubated for 1, 2 and 3 weeks to give a total of 5x3x3 (lime application levels x replication x incubation periods) experimental units. The soil samples were moistened to 60% field capacity (FC) and the 15 samples involved at the end of each incubation period were analyzed for pH and available P. Thereafter, the quantities of lime applied were plotted against soil pH values and the optimum liming rate for maize production on the soil type was determined to be 1.0t/ha (Table 2).

During the 2^{nd} incubation study, 50g soils were weighed into 72 plastic containers and mixed thoroughly with 8 sole and treatment combinations: control, L, RP, OMF, L+RP, L+OMF, RP+OMF and L+RP+OMF at 200kg P/ha. These combinations were replicated 3 times in a CRD such that a total of 24 cups were used for each incubating period of 1, 2 and 3 weeks to give a total of 8x3x3 (treatments x replication x incubation periods) experimental unit. Once again, the soil samples were moistened to 60% FC and at the end of each incubation period the 15 samples involved were analyzed for pH and available P.

2.3 Screen House Trial

Evaluation of the effectiveness of lime, P sources and their combinations on the growth of maize was assessed in a screen house. Soil samples of 1kg each were weighed into 24 experimental pots (poly bags) and mixed with the same 8 sole and treatment combinations which were replicated three times in a CRD. Lime was applied at 1.0t/ha which was obtained as the optimum liming rate in the 1^{st} incubation study while the P sources were applied at 200kg P/ha [6] as a single treatment and at 100kg P/ha during combinations.

2.4 Determination of Plant Growth and Yield Parameters

One week after amending the soils, seeds of the maize variety 95TZEE-WI, purchased from the International Institute of Tropical Agriculture (IITA), Ibadan, were sown in the amended soils. Three seeds were sown per pot and thinned to one, one week after germination. Growth parameters were measured at four weeks after sowing (WAS). These include plant height (cm) (taken by the use of a meter rule to measure from the base to the tip of the flag leaf), leaf area (cm^2) (determined by using the formula L x B x 0.75 (L is leaf length and B is broadest part of the leaf), stem girth was measured with a vernier caliper. The yield parameters were measured by carefully uprooting the three plants in each treatment at 5 WAS and washed gently with distilled water to remove soil particles. They were cut into shoots and roots and weighed with a weighing balance to determine the fresh shoot weight (FSW) and fresh root weight (FRW) (g/kg) respectively. The dry shoot weight (DSW) and fresh shoot weight (FSW) were also recorded (g/kg) after drying the plant samples to a constant weight at 75°C for 48h. Thereafter, the plants were ground and used for the analysis and determination of nutrients uptake as detailed by Cottenie et al. [21].

2.5 Soil Analysis

Soil pH was measured (soil: water ratio, 1:2) using a glass electrode. Organic carbon was determined using the modified Walkley – Black method [22] while total N content was determined by micro - Kjeldahl method [23]. Available P was determined following Bray No 1 (1 N NH4F + 0.5N) HCl extractant by vanadomolybdophosphoric acid method [24]. Exchangeable bases were determined by extraction with ammonium acetate, after which Ca and Mg were determined with an atomic absorption spectrophotometer (AAS) [25]. Concentrations of the micronutrients were determined by extracting of soil samples with 100mls of 0.1N HCl by using an AAS. Particle size analysis was done by the hydrometer method [26] and the corresponding textural class was determined from the USDA textural class triangle.

2.6 Statistical Analysis

The results were expressed as mean values. The whole data were subjected to analysis of variance (ANOVA) procedure and significant differences among the means were determined by Duncan's Multiple Range Test (DMRT) at 5% ($P \leq 0.05$) level of probability. Correlation matrices were determined to examine the relationship between nutrients uptake and some growth and yield parameters. The analyses were done using a Statistical Analysis System [27] package.

3. RESULTS AND DISCUSSION

The soil texture was loamy sand and the pH (4.6) was very strongly acidic (Table 1). Organic C, available P, Ca and Mg contents of the soil were very low, the N content was low while the value of K was moderate based on Landon [28] guidelines.

Soil pH values increased with increase in the level of lime applied to the soils (Table 2). The values decline with increase in the period of incubation. Lime applied at 1.0 t/ha produced the most favourable pH range (6.18) for maize production as well as the highest available P of 8.28mg/kg and 8.36 mg/kg at both the 2nd and 3rd week of incubation respectively.

Generally, the application of the various soil amendments resulted to increase in soil pH values (Table 3). These values were highest at the 1st week of incubation and decreased from the 2nd week of incubation which suggests that available P can be easily sorbed or fixed. The order in which available P was produced based on the material used in soil amendments was RP+OMF > L > OMF > RP > L+RP+OMF > L+OMF > L+RP > Control at the 3rd week of incubation. The addition of lime to RP and/or OMF produced concentrations of available P that were lower than the singular use of these amendments; due to an interaction effect. The primary reason for increasing the soil pH through liming is to reduce the aluminum toxicity to plant but the process also reduces the dissolution of RP due to increased Ca concentration (the common ion effect) [29]

Nutrients uptake of P from the amended soil measured at 4 weeks after sowing (WAS) were in the order: OMF > L+RP > L+OMF > RP+ OMF > L+RP +OMF > RP > L > control (Table 4). The highest uptake of P from OMF amended soil suggests that adequate supply of other nutrients tends to increase the absorption of P from the soil as observed by Grant et al. [30]. It was observed that the use of lime alone resulted in a relatively substantial available P (12.43mg/kg) but in P uptake (0.79 mg/kg) higher than that of only the control. This limitation due to the low availability of P in the bulk soil [16]. The P content (mg/g) of maize was quite to some extent a reflection of the uptake of P.

Table 1. Physico-chemical properties of test soil

Soil Properties	Values
pH	4.6
Organic C (g/kg)	1.1
Available P (mg/kg)	3.4
Total N (g/kg)	0.97
Exchangeable bases (cmol/kg)	
Mg	0.2
Na	0.31
K	0.57
Ca	0.36
Al	0.4
Micronutrients (mg/kg)	
Cu	1.3
Fe	26
Mn	37
Zn	7.9
Soil Texture (g/kg)	
Sand	888
Silt	45
Clay	67

Higher Ca, Zn, Mn and Fe were obtained from the RP+OMF amended soil (Table 4) followed by the L+RP amended soil which took up the highest Mg. Next to these are the OMF and L+RP+OMF amended soils followed by L+OMF and then L in the uptake of Mg, Ca, Zn, Mn and Fe, relative to RP and control. The result is in agreement with Ojeniyi et al. [31] who reported that pacesetter OMF alone or combined with poultry manure increased soil exchangeable cations, uptake and tissue P, K, Ca, Mg and Zn in maize. Nevertheless, significant and positive correlation has been reported [32] between 30 days old, dry matter yield of maize and soil available P (0.851**) and P uptake (0.981**) as well as between 60 days old dry matter yield of maize and soil available P (0.514**) and P uptake (0.860**).

Table 2. Effect of lime on soil pH and available P at successive incubation periods

$Ca(OH)_2$ (t/ha)	Soil pH			Available P (mg/kg)		
	Incubation period (weeks)			Incubation period (weeks)		
	1	2	3	1	2	3
0	4.65	4.57	4.41	6.46	5.97	5.53
1	6.02	6.22	6.18	6.64	8.28	8.36
2	7.12	7.17	7.29	7.27	7.28	6.80
3	7.44	7.54	7.58	5.61	6.32	6.52
4	7.79	7.69	7.73	5.72	6.59	6.28
SE	0.28	0.31	0.33	0.26	0.43	0.28

Table 3. Soil pH and available P from the incubation of lime and P sources

Treatment	Soil pH			Available P (mg/kg)		
	Incubation period (week)			Incubation period (week)		
	1	2	3	1	2	3
Control	5.82	5.05	5.29	5.62	4.18	5.23
L	7.55	7.48	7.30	14.18	15.63	12.43
RP	6.68	4.86	4.88	4.95	11.01	10.04
OMF	6.09	5.55	5.47	15.33	16.14	10.22
L+RP	7.39	7.33	7.21	5.62	5.61	5.11
L+OMF	7.27	7.52	7.50	4.91	4.34	6.81
RP+OMF	5.84	5.38	5.28	11.11	20.04	15.86
L+RP+OMF	5.53	5.20	4.83	8.96	6.69	7.81

Table 4. Nutrients uptake and P content of maize at 4 WAS from soil amended with lime and P source fertilizers

Treatment	Nutrient uptake (mg/kg)						P content (mg/g)
	Mg	Ca	Zn	Mn	Fe	P	
Control	7.7	4.8	0.37	0.25	0.22	0.16	1.9
L	11.3	8.2	0.33	0.31	0.37	0.79	1.6
RP	11.3	7.6	0.49	0.19	0.32	0.99	2.0
OMF	12.3	10.9	0.89	0.69	0.69	3.45	3.8
L+RP	15.3	13.1	0.66	0.74	0.60	3.22	3.6
L+OMF	9.5	10.9	0.38	0.33	0.28	1.88	3.3
RP+OMF	13.5	15.4	0.93	0.83	0.71	1.36	1.2
L+RP+OMF	13.1	11.2	0.76	0.48	0.48	1.04	1.7

WAS= weeks after sowing

The application of the various materials to soil increased the growth parameters at 4 WAS (Table 5). The tallest (23.1cm) maize crops were obtained from the L+RP treated soils. These were statistically similar (P=0.05) to plants that received OMF (22.8cm) and RP +OMF (22.4cm). These were followed by the crop plants grown in the soil amended with L+RP+OMF but this was not significantly (P≤0.05) different from those of L+ OMF, L and RP respectively. The widest leaf area was significantly (P≤0.05) produced from RP + OMF (76.53cm) and OMF (76.17cm) amended soils but these are significantly (p≤0.05) the same as those of L + RP (65.18cm). These were followed by the leaf area of the maize plants grown from the use of L+OMF, L+RP+OMF, RP and L. Bigger stem girth (0.76cm) was significantly (P≤0.05) produced by the OMF amended soil. Next were those grown in the L+RP and RP+OMF treated soils with the same value (0.68cm). These were significantly higher than the smaller stem girth (0.56, 0.54, 0.54, 0.57 and 0.53 cm) of L+RP+OMF, L+OMF, RP, L and control respectively.

The use of L+RP, OMF and RP+OMF produced significantly (P ≤0.05) higher FSW (9.7, 9.1, and 8.5 g/kg) respectively. These were followed by the FSW of 5.8g/kg obtained from the L+RP+OMF amended soil which was significantly higher than those obtained from the other AMS. The use of RP + OMF significantly

($P \leq 0.05$) produced more FRW (5.1g/kg) followed by that of L+RP+OMF (4.6 g/kg) relative to other AMS and control. The L+RP, OMF and RP+OMF AMS produced significant higher DSW of 1.10, 1.10 and 0.98 (g/kg) respectively compared to the DSW from the other amended soils. However, higher DRW produced are in the order L+RP+OMF > RP+OMF > L+RP > OMF and these were significantly ($P \leq 0.05$) higher relative to other treatments.

Statistical correlation coefficients were established between plant nutrient uptake and growth parameter of maize at ($P \leq 0.05$) and ($P \leq 0.01$) levels of probability (Table 6). There was positive relationship between the yield parameters and nutrients uptake. The fresh shoot weight significantly correlated with Mg (r=0.83**), Ca (r=0.81**), Mn (r=0.94**) and Fe (r=0.94**). The correlation between FRW and Ca uptake (r=0.77*) was significant while that between FRW and other elements (Mg, Zn, Mn and Fe) were not. The correlation between DSW and nutrients uptake of Mg (r=0.76*), Ca (r=0.77*), Mn (r=0.96**) and Fe (r=0.94**) was also found to be significant. Significant correlation was also observed between DRW and Mn (r=0.75*), Ca (r=0.76*), Mn (r=0.76*) and Fe (r=0.78*) nutrient elements. Generally, Zn uptake had no significant correlation with any of the maize yield parameter tested.

The findings of this study can be compared to the results presented by Onwuka et al. [33] where highly significant ($P<0.001$) correlation was reported between soil pH and maize plant height (r=0.64), root number (r =0.56) and root length (r=0.61). The authors also observed the highly significant ($P<0.001$) but negative correlation between exchangeable acidity and root number (r = - 0.70) and root length (r=-0.62) as well as significant ($P<0.01$) negative correlation between exchangeable acidity and plant height (r = -0.52) and dry matter yield (r = -0.54) of maize. Also, in a related study [34], the effect of elemental sulphur and nitrogen fertilizer in a sandy calcareous soil revealed that the total dry matter accumulation of maize plants showed strong positive significant ($P<0.01$) correlation with N (r=0.84), Fe (r = 0.87), P (r=0.84), S (r= 0.82), Zn (r=0.96) and Mn (r=0.84) uptake.

Table 5. Growth parameters at 4WAS and yield components of maize at 5WAS from soil amended with lime and P source fertilizers

Treatment	Height (cm)	Leaf area (cm^2)	Stem girth (cm)	FSW (g/kg)	FRW (g/kg)	DSW (g/kg)	DRW (g/kg)
Control	12.5d	39.61c	0.53c	2.3d	0.9d	0.35c	0.20c
L	15.4bc	45.32c	0.57c	2.9cd	1.3cd	0.45bc	0.18c
RP	15.4bc	48.22bc	0.54c	3.8c	2.5cd	0.33c	0.30bc
OMF	22.8a	76.17a	0.76a	9.1a	1.9cd	1.10a	0.42ab
L+RP	23.1a	65.18ab	0.68b	9.7a	2.9bc	1.10a	0.45ab
L+OMF	17.1bc	50.71bc	0.54c	3.8c	1.7cd	0.47bc	0.22c
RP+OMF	22.4a	76.53a	0.68b	8.5a	5.1a	0.98a	0.58a
L+RP+OMF	17.9b	48.31bc	0.56c	5.8b	4.6ab	0.63b	0.60a

Mean in the same column with different letter are significantly different ($P \leq 0.05$); FSW= Fresh shoot weight; FRW= Fresh root weight; DSW= Dry shoot weight; DRW= Dry root weight

Table 6. Correlation between yield of maize and plant nutrient uptake

Yield parameter	Mg	Ca	Zn	Mn	Fe
FSW	0.83**	0.81**	0.24	0.94**	0.94**
FRW	0.68	0.77*	0.42	0.63	0.64
DSW	0.76*	0.77*	0.23	0.96**	0.94**
DRW	0.75*	0.76*	0.51	0.76*	0.78*

** significant ($P \leq 0.05$); ** highly significant ($P \leq 0.01$); FSW= Fresh shoot weight; FRW= Fresh root weight; DSW= Dry shoot weight; DRW= Dry root weight*

The present study agrees with earlier ones that the application of lime alone although contributes in releasing some amount of fixed P but does not significantly (P≤0.05) increase maize production [6] and that the use of RP alone is not a cost effective way of increasing crop production [35]. Thus, the general practice for correcting soil acidity and nutrient deficiency especially of P is by lime and P fertilizer application respectively [5] because as revealed in this present study the combination produced the highest yield of the FSW. The composting of rock phosphates with agricultural wastes or organic materials has been well recognized to increase the solubility of rock phosphates and subsequent availability of P [32,36]. During the decomposition of organic materials, intense microbial activities produce organic acids which enhance dissolution of RP to release P and the chelating effect of such acids on Ca, Fe and Al also reduces their fixation effect on soil P [36].

4. CONCLUSIONS

The study revealed the test soil to be very strongly acidic and of low fertility status. The optimum liming rate for the soil was determined at 1.0 t/ha. The uptake of P by the maize crop plant from the amended soils was in the order: OMF > L+RP > L+OMF > RP+ OMF > L+RP+OMF > RP > L > control while the uptake of the other nutrients was as follows: RP+OMF > L + RP > OMF > L+RP+OMF > L+OMF > L > RP > control. Lime+RP provided the highest FSW of maize which was not significantly ($P > 0.05$) different from the use of OMF alone and that of OMF+RP at 5WAS. Again, the use of L+RP and OMF produced the same concentration of DSW (1.10 g/kg) which were significantly higher ($P \leq 0.05$) than those produced from the other amended soils besides that (0.98 g/pot) of RP+OMF. There was positive relationship between the yield parameters and nutrients uptake. The FSW and DSW significantly correlated with Mg, Ca, Mn, and Fe. Tropical ultisols should be amended with L+RP, RP+OMF and especially OMF, as it is more eco-friendly, for effective maize crop production.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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