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Comparative effects of lime and organic materials on selected soil chemical properties and nutrient uptake by maize in an acid soil

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ABSTRACT

The use of phosphate fertilizers and lime to mitigate P deficiencies and Al toxicities in Kenya has not been effective due to their high cost. Organic materials (OMs) are therefore being tested as cheaper alternatives but there are knowledge gaps on how they interact with soil to increase crop yields in acid soils. The effect of two OMs; farmyard manure (FYM) and Tithonia diversifolia (tithonia) green manure, and agricultural lime, each when applied alone or in combination with triple superphosphate (TSP), on selected soil chemical properties related to fertility and nutrient uptake by maize, was tested in a greenhouse experiment. Only the lime and FYM treatments significantly increased the soil pH. Lime was the most effective amendment in reducing the exchangeable Al followed by tithonia and FYM but TSP when applied alone did not reduce exchangeable acidity. The OMs and lime, when applied alone or in combination with TSP reduced the P sorption capacity of the soil but TSP on its own did not. Although TSP when applied alone gave the highest amounts of plant available P, this did not translate to the highest nutrient uptakes implying that some other factor, likely Al toxicity, was limiting their uptake. A reduction in exchangeable Al by application of OMs or lime led to higher nutrient uptakes compared to TSP. It is concluded that OMs can play the dual role of providing nutrients and mitigating the deleterious effects of soil acidity and in this respect are, therefore, likely to be more cost effective than lime.

Key words: Farmyard manure, Lime, phosphorus, soil acidity, *Tithonia diversifolia*

INTRODCUTION

Phosphorus deficiencies and aluminum toxicities often occur simultaneously in many acid soils in Kenya and are thought to be responsible for poor crop yields in such soils [1]. Soil acidity can be ameliorated with application of lime while inorganic fertilizers are commonly used to mitigate P deficiencies. However, due to increasing costs of lime and fertilizers, smallholder farmers cannot afford them and there is, therefore, an increasing interest in the use of cheaper locally available organic nutrient inputs to replace them. Thus, in eastern Africa, several organic materials (OMs) have been tested as alternatives. In recent years, *Tithonia diversifolia* green manure (tithonia), in particular, has attracted great research attention due to its ability to effect dramatic increases in maize yields compared to inorganic P fertilizers and other OMs commonly available on smalholder farms [2,3]. The reasons as to why tithonia is able to give large yield increases compared to inorganic fertilizers and other OMs remain a subject of intense debate.

[4] and [5] suggested that the superior ability of tithonia to reduce the P sorption capacity of the soil and hence increase plant available P was the main cause of higher yields recorded for tithonia compared to other P nutrient inputs. [6], however, observed higher maize yields with tithonia than FYM although the latter was more effective in reducing the P sorption capacity of the soil and increasing available soil P. Other possible reasons that have been given for the generally superior performance of OMs such as tithonia in acid soils compared to use of inorganic P fertilizers include their ability to reduce Al toxicity [7], provision of other nutrients not present in inorganic fertilizers and improvement in soil physical properties [8]. The objective of this study was, therefore, to contribute to the understanding of the effects of OMs on soil chemical properties and subsequent crop growth. This paper is organized into four main parts. After this introduction, the methodology of the study is described. The results and discussion are presented next followed by a brief conclusion.

MATERIALS AND METHODS

A greenhouse pot experiment was conducted with maize as the test crop at Bukura Agricultural College (BAC), in western Kenya, from April to May 2009. The top soil (0-20 cm) was collected randomly from various spots at the BAC farm and bulked. The soil was an orthic Ferralsol with the following properties: pH (H_2O) = 4.8; exchangeable acidity = 0.9 cmol kg^{-1}; total soil organic carbon = 34.9 g kg^{-1}; exchangeable Mg = 1.8 cmol$_c$ kg^{-1} and exchangeable Ca = 1.7 cmol kg^{-1}. The soil had a moderate P-fixing capacity with a soil P concentration of 0.2 mg l^{-1} corresponding to 260 mg P kg^{-1} adsorbed by the soil.

The bulked soil was air-dried, sieved through a 4 mm mesh and applied in all the pots at a rate 4 kg of soil pot^{-1}. A randomised complete block design with three replications was used and the imposed treatments are shown below.

1.Control
2. Lime (2 t ha^{-1})
3. Tithonia (20 kg P ha^{-1})
4. FYM (20 kg P ha^{-1})
5. TSP (60 kg P ha^{-1})
6. TSP (60 kg P ha^{-1}) + Lime
7. Tithonia (20 kg P ha^{-1}) + TSP (40 kg P ha^{-1})
8. FYM (20 kg P ha^{-1}) + TSP (40 kg P ha^{-1})
9. Citric acid (3 µg g^{-1} soil) + TSP (60 kg P ha^{-1})

The highest total P rate in this study (60 kg ha^{-1}) was chosen based on earlier observations [9] which showed that this rate gave maximum net benefits to maize crops in most soils in western

Kenya. In addition, three other treatments with lower P application rates, i.e., a control with no P input, FYM and tithonia applied alone at P rate of 20 kg P ha^{-1}, were included to test the degree of response to applied P inputs. The combination of inorganic P fertilizer with organic materials, i.e., 40 kg P ha^{-1} from the inorganics and 20 kg P ha^{-1} from the organic materials was included to test the effect of combining organic and inorganic sources of P on soil chemical properties and nutrient uptake. Lime, as $CaCO_3$, was applied at a rate of 2 t ha^{-1}, which was determined as the approximate liming requirement of this soil in a laboratory experiment. This treatment was included to test the effects of increasing soil pH on maize shoot biomass and nutrient uptake. This is important in acid soils, where maize growth may be inhibited by Al toxicity. Citric acid was included to mimic organic acids which are produced by decompositon of OMs such as tithonia and applied at a rate of 3 µg g^{-1} to test whether such acids are responsible for the reduction in the P sorption capacity of the soils. A control with no P input was also included.

All the treatments with no tithonia or FYM application received muriate of potash (60 kg K ha^{-1}) and urea (60 kg N ha^{-1}) to ensure that all the major nutrients (except P) were non-limiting. Lime was applied to the appropriate pots receiving lime treatment and incubated for 30 days at approximately field water holding capacity to allow reaction before planting maize. The other treatments were applied on the day of planting after which 4 maize seeds were planted per pot at a depth of approximately 2 cm. The maize plants were thinned to 2 per pot one week after emergence from the soil. Soil water was maintained at almost equal levels for all treatments by regular watering and weeds were regularly removed by hand. Each treatment was destructively harvested at 6 weeks after planting by cutting the maize tops at soil level. The harvested plants were oven dried at 70^{o}C to a constant weight. The dried samples were cut into small pieces and ground to pass through a 0.5 mm sieve and subsequently analysed for total N and P. Maize N and P uptakes were calculated as the N and P concentrations multiplied by the shoot dry weight. At harvest time, soils were sampled from each pot and analysed for pH, exchangeable acidity and Al, Olsen P, and P sorption characteristics.

Characterization of soils and the OMs was performed using the following laboratory analyses as described by [10]; organic C was determined by Walkley and Black sulphuric acid-dichromate digestion followed by back titration with ferrous ammonium sulphate. Total N and P in the soils were determined by digesting 0.3 g of the soil sample in a mixture of Se, $LiSO_4$, H_2O_2 and concentrated H_2SO_4. The N and P contents in the digests were determined colorimetrically. Total soluble polyphenols in tithonia and FYM were determined by the Folin-Ciocalteau method, while the lignin content was determined using the acid detergent fibre (ADF) method. Soil pH was determined using a glass electrode pH meter at 1: 2.5 soil: water ratio. The basic cations (Ca, Mg and K) were extracted using ammonium acetate at pH 7. Exchangeable Ca and Mg in the extract were determined using the atomic absorption spectrophotometry and exchangeable K by flame photometry. Given the soils' low pH, it was assumed that Na^+ ions were not present in sufficient amounts on the exchange complex and were, therefore, not measured. Exchangeable acidity and exchangeable Al were extracted using unbuffered 1 M KCl.

The available P was determined at all sampling dates by the Olsen method as described by [10] while the method of [11] was used to determine the P sorption characteristics of the soils. Non-linear regression using the Genstat statistical package [12] was used to fit the adsorption data obtained to the non-linear form of the Langmuir equation;

$$q = kbc/(1+ kc),$$

where c (mg P L^{-1}) is the equilibrium concentration, q (mg P kg^{-1}) is the amount of P adsorbed per unit mass of adsorbent, b (mg P kg^{-1}) is the P adsorption maximum and k (mg L^{-1}) is the constant related to the energy of adsorption.

RESULTS AND DISCUSSION

Characteristics of the organic materials used in the study

Tithonia contained higher amounts of C, N, Ca, Mg and K than FYM but its total P content and pH were lower FYM (Table 1). The C:N ratios of tithonia and FYM were 13.5 and 20 respectively while the C:P ratios were 140 for tithonia and 90 for FYM. Tithonia had low lignin (< 15%) while FYM had high (> 15%) lignin content. Both OMs had low polyphenol content (< 4%). According to the classification scheme of [13], both the tithonia and FYM are of high quality and would therefore readily mineralize to release nutrients.

Table 1. Chemical composition of tithonia and farmyard manure used in the study

OM	m.c.	%N	%P	%Ca	%Mg	%K	%C	pH	%Lig	%Poly
Tithonia	80%	3.1	0.30	2.0	0.6	4.1	42	6.5	13	3.17
FYM	30%	1.8	0.40	0.9	0.5	2.2	36	7.7	21	0.84

OM = organic material, FYM = Farmyard manure, Lig. = Lignin, Poly. = Polyphenol, m.c. = moisture content.

Soil pH

Whereas the application of lime or FYM resulted in a significant increase in soil pH compared to the control, the application of tithonia alone, TSP alone or citric acid combined with TSP led to a slight decrease in soil pH, but this was not significant (Table 2). Lime combined with TSP gave the highest soil pH (5.61) while TSP applied alone had the least (4.57). The observed increase in pH due to lime application was expected and is well documented. The increase in soil pH due to application of FYM is consistent with results reported by other workers [14,15] and can partly be attributed to the high pH of the FYM (7.7) at the time of its application. It may also be partly explained by proton exchange between the soil and the added FYM which contains some phenolic, humic-like material [16]. Another mechanism that has been proposed to explain the increase in soil pH by such materials as FYM is the specific adsorption of humic material and/or organic acids (the products of decomposition of organic materials) onto hydrous surfaces of Al and Fe oxides by ligand exchange with corresponding release of OH^- as suggested by [17]. The failure of tithonia to significantly increase the soil pH in the present study appears to contradict findings by [18] who reported an increase in pH due to application of tithonia in an incubation experiment. The rates of tithonia used in their study (88 t ha^{-1}) were, however, much higher compared to 5 t ha^{-1} in the present study.

Exchangeable acidity and exchangeable aluminum

Addition of tithonia, FYM or lime had the effect of reducing both the exchangeable acidity and exchangeable Al but the magnitude of the reduction varied among these materials (Table 2). The effect was extremely marked with the lime treatments where the exchangeable Al was reduced by 100%. Tithonia appeared to be more effective in reducing exchangeable Al, but not exchangeable acidity, compared to FYM. The reduction in exchangeable acidity and exchangeable Al can partially be attributed to increase in soil pH that was observed when FYM or lime was applied to the soil. Several other workers have measured an increase in soil pH with concomitant decrease in exchangeable Al during decomposition of organic residues in soils [e.g. 15,16]. An increase in soil pH results in precipitation of exchangeable and soluble Al as insoluble Al hydroxides [19] thus reducing concentration of Al in soil solution.

While the decrease in exchangeable Al by lime is mainly a function of the rise of soil pH, the same is not always true for all OMs. There are other mechanisms involved in the reactions of Al with OMs which are intricate and according [19], probably involve complex formation with low molecular weight organic acids, such as citric, oxalic and malic acids, and humic material produced during the decomposition of the OMs and adsorption of Al onto the decomposing organic residues. Complexation by soluble organic matter may partially explain why the tithonia treatments were able to significantly reduce exchangeable acidity and Al relative to the control treatment, despite the fact that they had at times low pH that was comparable to that of TSP, which failed to reduce exchangeable acidity.

Many studies have reported that the low molecular organic acids can complex aluminum and reduce its activity in soil solution [e.g. 17,20]. Though there is little direct evidence for the complexation mechanism, an attempt is made here to demonstrate that the mechanism may indeed exist. In this experiment, tithonia when applied alone gave a soil pH of 4.58 which was comparable to 4.57 for TSP and lower than 4.67 recorded for the control. The exchangeable acidity was 0.49 cmol kg^{-1} for tithonia and 0.60 cmol kg^{-1} for both TSP and the control while the exchangeable Al was 0.31, 0.40 and 0.41 cmol kg^{-1} for tithonia, TSP and the control, respectively. The soil pH measures the H^+ concentration in soil solution and, therefore the H^+ concentrations for tithonia and TSP were similar because their pH values were comparable. Since exchangeable acidity is comprised of $H^+ + Al^{3+}$, and given that TSP and tithonia had similar levels of H^+ concentration, it is logical to conclude that the resultant depression of exchangeable acidity relative to the control as a result of treating the soil with tithonia was because tithonia was able to remove one component of exchangeable acidity, i.e. Al which TSP could not. This was confirmed by the lower levels of exchangeable Al by tithonia treated soils compared to those treated with TSP. Since soil pH was unaffected by the application of tithonia in the example cited, precipitation of Al as Al hydroxide due to a rise in pH, is not likely to be the dominant mechanism for reducing the exchangeable Al. This leaves complexation as the most probable mechanism by which tithonia reduced exchangeable Al in the soil. The Al complexing effect of tithonia is likely to have been stronger than that of FYM given that FYM gave higher soil pH (5.17) than tithonia but still ended up with a higher level of exchangeable Al (0.35 cmol kg^{-1}). Tithonia was applied as a green manure and was thus likely to produce large quantities of organic acids, which would be involved in complexation reactions [5]. On the other hand, FYM had been exposed to the weather elements for a long time (one year) before its collection for use in this study. It was well rotten and hence likely to be at an advanced stage of decomposition and is therefore unlikely to have had substantial amounts of organic acids.

Table 2. Effect of treatments on selected soil properties and P and N concentration in maize in the green house pot experiment

Treatment	pH	Exch‡ acidity (cmol kg^{-1})	Exch‡. Al (cmol kg^{-1})	Olsen P (mg kg^{-1})	% P in plant	% N in plant
Control (0 P)	4.67	0.60	0.41	6.1	0.08	1.34
Lime (0 P)	5.49	0.28	0.00	7.8	0.09	1.12
Tithonia (20 kg P ha^{-1})	4.58	0.49	0.31	10.5	0.11	1.43
FYM (20 kg P ha^{-1})	5.17	0.48	0.35	10.2	0.11	1.33
TSP(60 kg P ha^{-1})	4.57	0.60	0.40	23.5	0.10	1.30
Tithonia (20 kg P ha^{-1}) + TSP (40 kg P ha^{-1})	4.93	0.48	0.18	16.5	0.12	1.36
FYM (20 kg P ha^{-1}) + TSP (40 kg P ha^{-1})	5.27	0.45	0.26	18.9	0.10	1.43
Citric acid + TSP (60 kg P ha^{-1})	4.60	0.56	0.38	19.9	0.10	1.41
Lime + TSP (60 kg P ha^{-1})	5.61	0.34	0.00	21.2	0.11	1.29
SED	0.1	0.07	0.07	1.5	NS	NS
CV%	2.5	18.4	32	12	13	6.6

FYM= Farmyard manure; TSP= triple superphosphate; ‡ exchangeable; NS = not significant SED = standard error of difference between means.

Soil Olsen P changes as affected by application of organic and inorganic materials

Addition of P from both organic and inorganic sources generally resulted in an increase in the Olsen P relative to the control (Table 2). The magnitude of the increase, however, depended on P source and rate of P application. Comparison among the treatments where P was applied at the same rate of 60 kg ha^{-1} revealed that TSP, when applied alone had the highest Olsen P value (23.5 mg kg^{-1}) while Tithonia (20 kg P ha^{-1}) + TSP (40 kg P ha^{-1}) had the least (16.5 mg kg^{-1}). FYM (20 kg P ha^{-1}) + TSP (40 kg P ha^{-1}), Citric acid + TSP (60 kg P ha^{-1}) and Lime + TSP (60 kg P ha^{-1}) gave Olsen P values that were not significantly different from each other. This finding does not support the commonly held view that combining OMs with inorganic P sources results in synergism in terms of P availability [9].

Amongst the OMs, FYM was more effective in increasing the Olsen P than tithonia, likely due to the fact that FYM was applied when it had partially decomposed and hence was likely to provide more inorganic P in the short-term than tithonia which was applied as a green manure. The significant increase in Olsen P, above the control, by application of OMs alone reflects the large percentage of soluble P in both the tithonia tissues and the FYM. High levels of water soluble P in plant tissues (50 – 80%) have also been reported by [4]. Immediate net P mineralization would also be expected to occur because both OMs had a higher P concentration (0.3% in tithonia and 0.4% in FYM) than the critical level of 0.25% required for net P mineralization [4].

Application of TSP in combination with lime slightly depressed the availability of P compared to application of TSP alone at the same P rate. When applied alone, lime did not significantly increase the Olsen P above that of the control implying that lime was not able to mobilize or prime the P already fixed in the soil. Many other studies have investigated the effects of lime application on P retention and extractability, but consistent improvements in the availability of soil P have not been obtained [21,22]. Liming with the sole aim of increasing available soil P should, therefore, be treated with caution as it may not always produce the desired effect. Liming is, however, often successfully applied to remedy other soil constraints such as soil acidity.

There was no advantage in combining citric acid and TSP in terms of increased Olsen P. This is contrary to several other studies which have reported an organic acid mediated increase in available soil P through a variety of mechanisms [23,24]. The inability of citric acid to enhance P availability in the present study is likely due to rapid microbial degradation of this organic acid which rendered it ineffective [25] or the low concentration of citric applied.

Phosphorus sorption by soils

The amount of P adsorbed in equilibrium (q) with a solution P of 0.2 mg P L^{-1} as determined from the Langmuir equation, ranged from 162 mg kg^{-1} (Lime + TSP (60 kg P ha^{-1})) to 285 mg kg^{-1} (control) (Table 3). All the treatments, apart from TSP applied alone or in combination with citric acid, significantly lowered the P adsorption capacity of the soil compared to the control. This reduction in P adsorption was accompanied by a reduction in adsorption affinity, k, but not the adsorption maxima which were not significantly influenced by the treatments (Table 3). Figure 1 depicts the P sorption behavior of the soil in response to the different amendments. The P sorption isotherms show that lime applied in combination with TSP exhibited the greatest displacement to the right and change in slope of the sorption curve relative to the control and therefore was the most effective amendment in reducing P sorption. In addition, a shift to the right and change in slope relative to the control was observed for all the other amendments indicating that all reduced P sorption but with varying levels of effectiveness. These observations were in agreement with calculated sorption parameters by the Langmuir equation (Table 3).

As mentioned earlier, lime applied in combination with TSP gave the lowest P sorption capacity and was more effective than lime when applied alone (Table 3). Similarly, FYM and tithonia when applied in combination with TSP were generally more effective than when they were applied alone. This suggests that the part of the observed reduction in q was due to the blocking of the P sorption sites by inorganic P. As observed previously by others [26], addition of P to soils decreases the soil's capacity to bind P. However, the failure of the inorganic P sources when applied alone to significantly reduce P sorption at similar P rates with lime or OM treatments point to other additional mechanisms of reduction in P sorption that were not significantly affected by inorganic P sources. These mechanisms may include complexation and competition for sorption sites by the products of OM decomposition such as the low molecular weight organic acids [4].

Table 3. The Langmuir estimates i.e. adsorption affinity (k), adsorption maxima (b), and P adsorbed at 0.2 mg P L^{-1} (q) obtained from the Langmuir equation for the various treatments in the pot experiment.

Treatment	k (mg L^{-1})	b (mg kg^{-1})	q (mg kg^{-1})
Control (0 P)	3.51	691	285
Lime (0 P)	2.85	670	243
Tithonia (20 kg P ha^{-1})	2.64	690	238
FYM (20 kg P ha^{-1})	2.80	689	209
TSP(60 kg P ha^{-1})	3.27	676	272
Tithonia (20 kg P ha^{-1}) + TSP (40 kg P ha^{-1})	1.98	750	210
FYM (20 kg P ha^{-1}) + TSP (40 kg P ha^{-1})	2.13	703	247
Citric acid + TSP (60 kg P ha^{-1})	3.17	658	254
Lime + TSP (60 kg P ha^{-1})	1.54	697	162
SED	0.35	NS	17
CV%	13.1	5.5	6.3

FYM is farmyard manure, TSP is triple superphosphate. SED = standard error of difference between means.

The failure of any of the treatments to provide enough equilibrium P concentration at the point of zero added P to attain 0.2 mg P L^{-1} (Figure 1) indicates that these soils, even after application of the treatments, were P-deficient and would, therefore, respond to application of P. The superiority of lime compared to the OMs in reducing q is attributed to its stronger ability to reduce the exchangeable Al and increase soil pH. The effect of liming on P sorption in acid soils, just like its effect on P availability, is controversial, with some studies reporting increased P sorption with liming [21].

Maize dry matter yield and nutrient uptake

The results for maize dry matter (dm) yield, as affected by nutrient inputs, are shown in Figure 2. The yields ranged from 4.7 g pot^{-1} (Control) to 12.7 g pot^{-1} (Lime + TSP). All the treatments with P inputs significantly increased the dm yield compared to the control or lime applied with no P input. There were no significant treatment effects on the P and N contents in the maize biomass (Table 2) and, therefore, the P and N uptake trends (Figures 3 and 4) closely followed those of dm accumulation. Lime when applied without P (but with N and K applied at non-limiting rates) did not significantly increase the dm above the control thus confirming that P was a limiting factor in this soil.

FYM and tithonia when applied alone at P rate of 20 kg P ha^{-1} gave dm yields and nutrient uptakes that were not significantly different from those of TSP applied alone at 60 kg P ha^{-1}. However, at the same P rate of 60 kg P ha^{-1}, TSP when combined with lime, tithonia or FYM gave dm yields that were not significantly different from each other but they significantly out-yielded TSP when applied alone, which gave higher Olsen P values in the soil. This implies that some other factor was likely to be more important in governing the nutrient uptake in these soils than availability of P. This is confirmed by the correlation coefficients (Table 4) which show that when all the treatments were included in the correlation analysis, there was no correlation between the Olsen P and P uptakes or any of the other measured soil parameters. However, excluding the treatments with no P inputs, i.e. the control and Lime alone treatments, from the analysis greatly improved the correlation between the pH, exchangeable acidity and exchangeable Al with P uptake, but that of Olsen P with P uptake declined (Table 4). In general, the P uptake increased with declining exchangeable Al as indicated by a high negative correlation ($r = -0.96$) between exchangeable Al and P uptake when only treatments with P inputs were included in the regression analysis. This suggests that Al toxicity may have contributed to the lower nutrient uptakes in treatments without lime or OMs as the Al saturation (22%) of these soils was above the critical value of 20% for maize [27]. The application of lime and OMs (with TSP) reduced the exchangeable Al levels in the soils and thus gave higher nutrient uptakes than TSP (applied alone), which was unable to reduce exchangeable Al, at comparable P application rates.

Although N was applied at non-limiting rates to all the treatments, uptakes for N by the control and the lime applied without TSP treatment were significantly lower than those for the other treatments with P inputs confirming that P must be applied to these soils for maize production, even after elimination of Al toxicity.

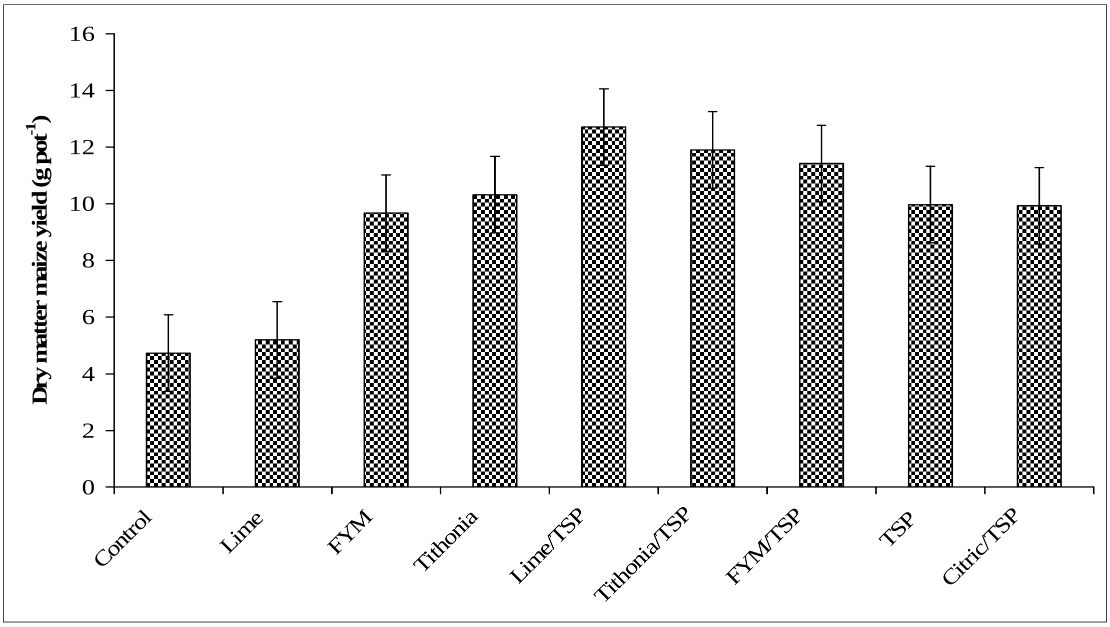

Figure 2. Dry matter yields of maize as influenced by organic and inorganic inputs

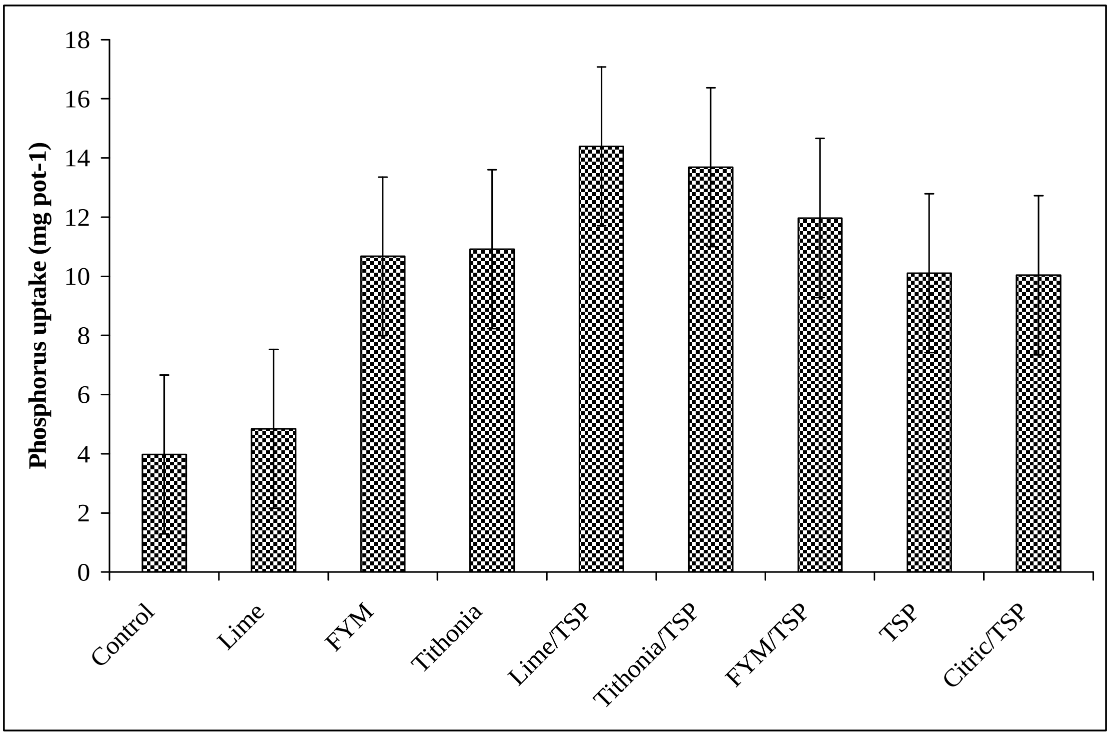

Figure 3. Phosphorus uptake by maize as influenced by organic and inorganic inputs

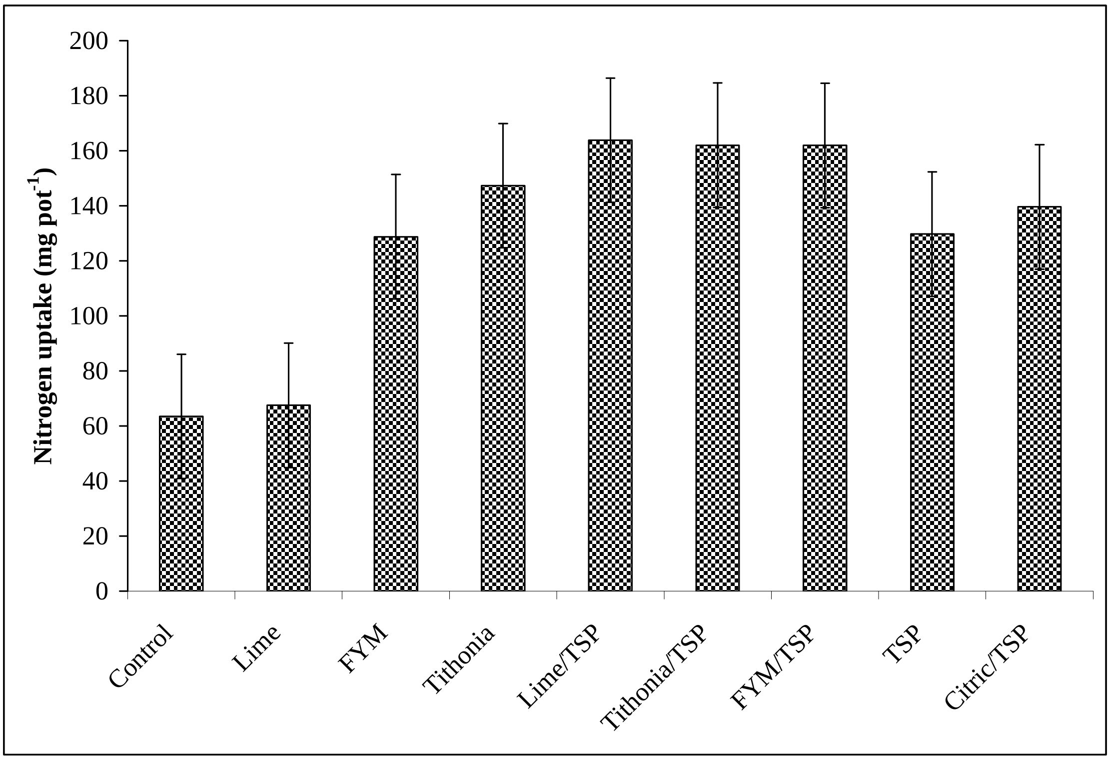

Figure 4. Nitrogen uptake by maize as influenced by organic and inorganic inputs

Note: The error bars represents the LSD.

Table 4. Coefficients of determination (r^2) and regression equations relating dry matter yield of maize in the pot experiment to measures of selected soil properties

Variable	(r^2)	Regression equation
pH (all treatments)	0.03	P uptake = 1.55 x pH + 2.33
pH (only treatments with P inputs)	0.52	P uptake = 3.11 x pH + 3.73
Olsen P (all treatments)	0.47	P uptake = 0.38 x Olsen P + 4.34
Olsen P (treatments with P inputs only)	0.02	P uptake = 0.05 x Olsen P + 10.84
Exch. acidity (all treatments)	0.09	P uptake = -9.52 x exch. acidity + 14.59
Exch. acidity (treatments with P inputs only)	0.69	P uptake = -14.23 x exch. acidity +
Exch. Al (all treatments)	0.04	118.47
Exch. Al (treatments with P inputs only)	0.92	P uptake = -4.18 x exch. Al + 11.12
Soil organic carbon (all treatments)	0.03	P uptake = -11.95 x exch. Al + 14.89
		P uptake = -11.95 x exch. Al + 14.89

Note: Exch. is exchangeable

CONCLUSIONS

Application of FYM increased the soil pH but tithonia did not. However, tithonia was more effective in reducing the exchangeable Al than FYM likely due to its stronger ability to complex Al. TSP when applied alone gave the highest amounts of available P, but it did not give the highest P uptakes implying that some other factor, possibly Al toxicity, was preventing proper utilization of P by the maize plants. A reduction in exchangeable Al by application of OMs or lime led to increased nutrient uptakes. It is concluded that OMs can play the dual role of providing nutrients and mitigating the deleterious effects of soil acidity and in this respect are therefore likely to be more cost effective than lime, which controls mainly only the soil acidity.

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