Effects of Lime and Phosphorus Applications on Soil Chemical Composition, Growth and Nutrient Uptake of Maize (*Zea mays* L.) in an Acid Soil of Gununo, Southern Ethiopia

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Abstract

Soil acidity and phosphorus deficiency are some of the constraints affecting crop production in highlands of Ethiopia. A pot experiment was conducted with maize (*Zea mays* L. ACV 6) to determine the effects of lime ($CaCO_3$) and phosphorus (P) application on highly acidic and P-deficient clayey soil from Gununo area in southern Ethiopia. The experiment consisted application of lime at three rates (0, 3, and 6 g $CaCO_3$ kg^{-1} soil) and P at four rates (0, 50, 100 and 150 mg P kg^{-1} soil), each quadruplicated in a completely randomized design (CRD). Plants harvested at 60 days after plating were partitioned into roots and shoots to record dry matter yields. Changes in soil properties and macronutrient concentrations in roots and shoots were determined. Application of the lime at the highest tested rate (6 g $CaCO_3$ kg^{-1} soil) increased the soil pH by 1.73 units over control, and increased the concentrations of Ca and Mg in the soil and plants. Liming, when applied with P, also improved dry matter production and P concentration in shoots. However, liming alone did not influence available P in the experimental soil, and increasing rates of lime resulted in a slight decline in plant growth and biomass production. On the other hand, P application significantly enhanced available P and exchangeable Ca in the soil; plant heights, root and shoot dry weights, and uptake and concentration of nutrients in shoots and roots. Interestingly, application of 50 g P kg^{-1} soil improved root and shoot dry weights by 1332 and 4184%, respectively, as compared to controls (P omitted pots) demonstrating that P was a more important limiting nutrient for maize growth in the study soils. The results demonstrated that 3 g $CaCO_3$ kg^{-1} together with 50 g P kg^{-1} soil could be recommended for maize growth on the acidic soils of the Gununo area, Boloso Sore district of southern Ethiopia.

Key words: acid soil; dry weight; nutrient concentration; plant height; soil characteristics

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INTRODUCTION

Soil acidity and fertility depletion are among the major constraints limiting agricultural production in high rainfall areas of sub-Saharan Africa (Sanchez et al., 1997; Kisinyo et al., 2014). Soil acidification is one of the major environmental factors emerging as an important land degradation issue. Acid soils constitute about 40% of the cultivated land in Ethiopia and the problem of soil acidity in the country is apparently increasing both in area and severity (Mesfin, 2007). It has become a serious threat to crop production in highlands of the country in general and in the southern region in particular (Desta, 1987; Abdena et al., 2007).

In acid soils, the availability of certain nutrients like aluminum, iron and manganese increases due to high dissolution rates (Upjohn et al., 2005; Sarker et al., 2014). This has been one of the main factors limiting agricultural productivity. Consequently, some barley and wheat growing farmers in southern highland areas have shifted to producing oats, a crop more tolerant to soil acidity. In addition, 70 to 75% of the agricultural soils of the highland regions of Ethiopia are P deficient (Desta 1982; Tekalign and Haque 1991). Phosphorus is therefore considered to be the most limiting nutrient for food production in the soils of Ethiopian highlands (Tekalign and Haque, 1991; Sanchez et al., 1997; Solomon et al., 2002).

Soil acidity adversely affects crop yields, seedling emergence and survival, legume nodulation and root growth, as well as microbial growth, especially if soil pH ($CaCl_2$) is less than 4.5. In strongly acidic soil (pH < 5) aluminum and manganese become more soluble and toxic in most soils, and deficiencies of essential plant nutrients such as P, Ca, K, Mg, and Mo arise (Wang et al., 2006). Correcting soil acidity and nutrient deficiencies, especially P deficiency, by lime and P fertilizer applications, respectively, are the general practices (Fageria et al., 1995; Jibrin et al., 2002). Liming improves the physical, chemical and biological properties of soils and increases crop production on acid soils by raising the pH, Ca and Mg concentrations, and P availability by improving nutrient uptake by plants (Haynes and Ludecke, 1981; Naidu et al., 1990; Oguntoyinbo et al., 1996; Oluwantoyinbo et al., 2005; Loncaric et al., 2007; Uzoho et al., 2010). Liming is more effective in increasing dry matter yields and changing soil properties when combined with phosphorus fertilization (Oluwantoyinbo et al., 2005; Uzoho et al., 2010). Lime materials applied as calcium hydroxide [$Ca(OH)_2$], calcium oxide (CaO) or calcium carbonate ($CaCO_3$) have been found to effectively counteract soil acidity by raising the pH of acidic soils, providing Ca^{2+} and decreasing Al-toxicity, hence stimulating crop growth (Kamprath, 1984; Kanyanjua et al., 2002; Omenyo et al., 2010). Increases in the available P in soil and resultant high maize production have been reported in acid soils of western Kenya due to P fertilizer application (Kisinyo et al., 2014).

At Gununo, Wolaita Zone of southern Ethiopia, agricultural soils are P deficient due to continuous mining, poor external nutrient return, and soil acidity. This suggests that P availability is the most commonly limiting factor for crop production in the area (Gifole et al., 2011; Sheleme, 2011; Wondwosen and Sheleme, 2011). Further works have also confirmed that most soils in the region are poor in available P and addition of fertilizer is a must for optimum crop production (Ashenafi et al., 2010; Mulugeta and Sheleme, 2010). Application of lime is also one of the important practices, to enhance P availability in acidic soils. However, detailed studies are scanty regarding pH levels, liming requirements and P fertilizer application rates for profitable crop production. In view of this, a lath house experiment was designed to evaluate the effects of lime and P fertilizer application on soil properties, growth, dry matter production and nutrient uptake of maize on acidic soil from Gununo, Wolaita Zone, Southern Ethiopia.

MATERIALS AND METHODS

Site description and soil sampling

Twelve random surface soil samples (0-20 cm) were collected from a farmer's field with known acidity in Gununo (06º 56.316' N, 37º 39.503' E and altitude 1920 meters above sea level) Boloso Sore district, Wolaita Zone in southern Ethiopia. The area is characterized by undulating topography with well-drained Alfisols formed from basaltic parent material. The main crops grown in the area include cereals such as maize (*Zea mays*), wheat (*Triticum aestivum*), pulses such as haricot bean (*Phaseolus vulgaris*), root and tuber crops such as sweet potato (*Ipomea batatas*) and enset (*Ensete ventricosum*).

Soil sample preparation and experimental setting

Soils were homogenized and each pot (10 L capacity) was filled with 5 kg soil and set in a Lath house. Pot experiment was conducted in 2013 with treatment combinations of three lime (0, 3 and 6 g lime kg^{-1} soil) and four phosphorus (0, 50, 100 and 150 mg P kg^{-1} soil) levels, each quadruplicated in a completely randomized design. A recommended rate of N was uniformly applied at 200 mg N kg^{-1} soil using urea (46-0-0) as a fertilizer source, while P (as per the treatment) was applied as triple superphosphate (0-46-0). Four seeds of maize (*Zea mays* L. cv ACV 6) per pot were sown and thinned to two plants per pot 10 days after germination.

Collection of plant data and soil samples from the pot experiment

The pots were kept in a Lath house that was protected from incoming dust and watered regularly using deionized water to maintain the moisture level at about field capacity. Under each pot, a saucer was placed to prevent drainage loss of nutrients. Plant heights were measured at harvest (60 days after planting). Roots and shoots were carefully harvested and their dry weights recorded after oven drying the samples at 80^{0}C to constant weights (until the same weights were obtained in three consecutive measurements). Soil samples were also collected from each pot at the time of harvest.

Soil and plant tissue analyses

Soil samples (pre-sowing and post-harvest) were analyzed following standard procedures for soil analysis (Sparks, 1996). Accordingly, determinations of pH (0.01 M $CaCl_2$) in 1:2.5 soil: liquid, available P (Bray and Kurtz method), exchangeable Ca, Mg and K (using 1M NH_4OAc extract) and organic carbon content (following the method of Walkley and Black, 1934) were made. In addition, particle size (in accordance with the pipette method of Gee and Bauder, 1986), total nitrogen (Kjeldahal method), NH_4-N and NO_3-N (using ion-selective electrodes), total P, dithionite extractable Fe and Al, pyrophosphate extractable Fe and Al, and oxalate extractable Fe, Al and Si of the test soil were also determined. Plant samples were analyzed for N by a modified Kjeldahal procedure (Nelson and Sommers, 1973), and P, K, Ca and Mg were measured following dry ashing method (Wolf, 1982).

Data analyses

Data from post-harvest soil analysis, plant height, root and shoot dry weights, and nutrient uptakes and concentrations in the plants were subjected to analysis of variance (ANOVA) using SAS version 9.2 (SAS, 2007). Mean comparisons were made using Least Significant Difference (LSD), and a PROC CORR option of ANOVA was used to determine the relationships between nutrient availability, growth parameters and nutrient uptake.

RESULTS

Soil characteristics before lime and P application

The experimental soil was clayey in texture, highly acidic (pH 4.01) and very low in available phosphorus (Table 1). It also demonstrated low levels of organic carbon and total nitrogen concentrations. The C:N ratio (13:1) however suggests a dominance of mineralization in the soil even with the acidic conditions of the soil. Nevertheless, this does not guarantee sufficient N availability for plants, as soil microbes often out-compete plants. Out of 1300 mg kg^{-1} total N (0.13 per cent), only

0.32% (4.10 mg kg^{-1}) was NH_4-N and 0.80% (10.4 mg kg^{-1}) NO_3-N, while the remaining 98.9% of the total nitrogen was present in soil as organic N (NH_2-N). The low level of total N coupled with the acidic soil reaction are causes of deficiencies of N in these soils. Furthermore, the very low mineral forms of N show that N availability is extremely low, which might be due to poor microbial activity in the acidic conditions. Additionally, the available P content of the soil (1.07 mg kg^{-1} soil) was also very low (Landon, 1991) indicating that an external supply of N and P would be required for optimum plant growth.

Table 1. Some selected physical and chemical properties of the experimental soil

Sand (%)	8.94	**Dithionite-citrate-bicarbonate (DCB) extractable**	
Clay (%)	65.03	Fe (%)	0.35
pH (0.01M $CaCl_2$)	4.01	Al (%)	0.37
Organic C (%)	1.70	**Sodium pyrophosphate extractable**	
Total N (%)	0.13	Fe (%)	0.24
Total P (mg kg^{-1})	381	Al (%)	0.09
Avail. P (mg kg^{-1})	1.07	**Ammonium oxalate extractable**	
Exch. K (mg kg^{-1})	300	Fe (%)	7.3
Exch. Ca (mg kg^{-1})	456	Al (%)	0.65
Exch. Mg (mg kg^{-1})	58	Si (%)	0.70
Mineral Nitrogen			
NH_4-N (mg kg^{-1})	4.10	NO_3-N (mg kg^{-1})	10.44

The soil, being acidic, demonstrated appreciable amount of exchangeable Ca, followed by K and, less yet, by Mg. With such inherent properties, the effects of liming as well as P application on some selected soil properties and growth parameters of maize appeared to be specific and selective. The concentrations of Ca (2.28 cmol kg^{-1}), Mg (0.48 cmol kg^{-1}) and K (0.77 cmol kg^{-1}) in the experimental soil could be considered low, medium and high, respectively, in accordance with the ratings of Landon (1991). These results indicate that the Ca:Mg ratio (4.75:1) was in an adequate range, whereas the K:Mg ratio (1.6:1) was high in the experimental soil. Although the absolute Mg concentration (0.48 cmol kg^{-1}) is about optimum threshold for clay soils, deficiencies of Mg could result from its imbalance with K (Landon, 1991). A potassium-to-magnesium ratio of 0.7:1 was suggested as optimum (Loide, 2004) and values higher than 1:1 may affect Mg uptake in clayey soils.

The amounts of Fe and Al extracted from the soils increased in the order following: pyrophosphate-, dithionite-citrate-bicarbonate (DCB-) and oxalate-extractable Fe and Al. Higher values of oxalate-extractable Fe than DCB-extractable Fe might be due to the dissolution of minerals such as magnetite by acid oxalate (Evans and Wilson, 1985; Loepprt and Inskeep, 1996). Furthermore, Fe-oxalate/Fe-DCB ratios (about 21) suggested a high amount of extractable Fe in the soils in the form of active iron oxides. The ratio of Al:Si [(Al-oxalate – Al-pyrophosphate)/Si-oxalate] of about 0.8 indicated dominance of 1:1 clay minerals and the experimental soils being at advanced stages of weathering.

Selected properties of the soils after liming and P application

Soil pH ($CaCl_2$) was raised significantly ($P \leq 0.05$) with increasing doses of lime indicating the usefulness of adding liming material for amelioration of acidity in soils, and corroborating previous findings (Ernani et al., 2006; Torkashvand et al., 2010; Uzoho et al., 2010; Kisinyo et al., 2014; Muindi et al., 2015). Addition of P with lime has also resulted in significant ($P \leq 0.05$) pH increments, although much variation was not recorded among the different levels of applied P (Table 2). However, it did significantly correlate ($P \leq 0.001$) with exchangeable Ca and Mg (Table 6) showing that the release of these basic cations from liming material altered soil reactions. Increases in soil pH after P application without lime might be attributed to contribution of Ca from TSP [Ca $(H_2PO_4)_2$].

Table 2. Soil pH, available P, and exchangeable Ca, Mg and K as influenced by increasing levels of lime and P application

Treatment		pH ($CaCl_2$)	Avail. P	Exch. Ca	Exch. Mg	Exch. K
Lime ($g\ kg^{-1}$ soil)	P ($mg\ kg^{-1}$ soil)		($mg\ kg^{-1}$ soil)			
0	0	4.43d	1.10f	486.75c	73.50d	279.25a
	50	4.72d	3.54f	503.00c	71.25d	158.75bc
	100	4.64d	12.05cd	523.25c	74.25d	134.50c
	150	4.79cd	17.67a	549.50c	99.00d	174.00bc
3	0	4.87cd	1.03f	1028.75b	209.50bc	292.25a
	50	5.37bc	3.29f	1046.25b	213.25bc	154.00bc
	100	5.82ab	9.45de	1065.75b	206.25c	163.00bc
	150	5.59ab	15.88ab	1086.50b	234.00bc	171.25bc
6	0	5.56ab	1.22f	1427.00a	328.75a	297.00a
	50	6.16a	3.77f	1431.75a	280.00ab	180.50bc
	100	5.87ab	8.38e	1448.00a	278.50ab	166.75bc
	150	5.93ab	13.87bc	1446.00a	278.75ab	193.25b
LSD *(0.05)*		0.63	3.26	199.69	70.72	51.49

Means followed by the same letter(s) within a column are not significantly different at $P \leq 0.05$.

Tremendous increases in available P in soils were observed with increasing doses of P, particularly at high P rates (Table 2), whereas increasing levels of lime resulted in a trend of decreasing available P in soil, perhaps due to P fixation as calcium phosphate. Previous studies revealed that a reducing effect on available P was pronounced with high rates of lime application owing to complexation of P (Oluwatoyinbo et al., 2005; Torkashvand et al., 2010; Kisinyo et al., 2014). Additionally, insignificant changes in the levels of available P might also be attributed to the low level of total P and precipitation of phosphate with Fe as structural parts of clay minerals that would not be easily dissociated in acid soil (Mengel and Kirkby, 2001).

Exchangeable Ca significantly ($P \leq 0.05$) increased with increasing doses of lime, whereas its increments with increasing P application rates were not significant (Table 2). The increase in exchangeable Ca was due to its release from the liming material and its slight increase with P rates could be attributed to the release of Ca from the TSP [$Ca\ (H_2PO_4)_2$] fertilizer. Liming has also significantly enhanced the amount of Mg^{2+} in the soil, whereas the influence of added P on exchangeable Mg was slightly suppressed when combined with the highest lime level (Table 2). The results are in line with previous findings (Torkashvand et al., 2010; Uzoho et al., 2010), and confirmed increments in soil pH, Ca and Mg contents with combined application of P fertilizer and lime. On the other hand, liming had no significant influence on the exchangeable K while P application reduced its content in the soil, which might be attributed to improved K uptake by plants due to synergistic effect of P. Exchangeable K was also negatively correlated ($P \leq 0.001$) with all growth parameters and nutrients' uptake (Table 6) indicating its removal by plants was the cause for the decline in the post-harvest soil.

Plant height and dry matter production

Plant height increased significantly by application of P alone or in combination with lime, although lime alone had no effect (Table 3). Maize plants were vigorously grown with successive increase in P rates when combined with lime. Application of P alone increased root dry weight up to 100 mg P kg^{-1} soil, and root dry weight significantly decreased at the highest P rate indicating declining response of root growth to high P level. Liming combined with P enhanced root dry weights and the highest value was obtained at 3 g kg^{-1} lime and 50 mg P kg^{-1} soil, but further increase in P levels reduced root yields (Table 3). On the other hand, no significant effect of lime alone was observed on root dry weights.

Similarly, shoot dry weight was significantly ($P \leq 0.05$) increased by application of P alone and lime in combination with P application. The highest shoot dry weight (53.5 g pot^{-1}) was recorded at application of 3 g and 150 mg kg^{-1} soil lime and P, respectively (Table 3). This was followed by the treatment combination having the highest rate of lime (6 g kg^{-1} soil) and 100 mg P kg^{-1} soil, whereas the lowest dry weight of shoots was obtained from the pots that received the highest rate of lime without P. There was a slight, reduction in shoot dry weight when increasing levels of lime applied alone indicating that increased rates of lime without P negatively affects plant growth. In contrast, the application of P alone tremendously increased the shoot dry weight. The shoot dry weight was also reduced by combining the highest rates of both lime and P. The yield obtained from this treatment was significantly lower compared to that of the highest level of P and 3 g lime kg^{-1} soil (Table 3).

Generally, the results show that P rates higher than 50 mg kg^{-1} soil did not significantly increase plant height, and dry weights of roots and shoots when applied in combination with lime. Thus, low level of lime combined with low level of P enhanced maize yield showing that P fertilizer utilization efficiency was enhanced at low level of liming. This is consonant with previous reports showing the presence of low amount of lime reduces the amount of fertilizer P required for optimum crop performance (Oluwatoyinbo et al., 2005; Ernani et al., 2006). Sarker et al. (2014) also reported that shoot and root dry weights were boosted by combining lime with P application. Control plants were remarkably shorter and weighed less than plants treated with lime and/or phosphorus fertilizer. The increments in plant height and dry weights could be attributed to enhanced nutrient uptake, which in turn were influenced by P availability following application of the fertilizer. This was also confirmed by the correlation between the nutrient uptakes and available P in the soil (Tables 2 & 6), showing the essentiality of P, and its deficiency limiting plant growth (Schactman et al., 1998). Previous studies revealed that P deficiency highly limits good crop growth and development in the soils of the study area, and as a result 70, 56 and 76% reductions in plant height, root and shoot dry weights, respectively, were recorded due to P-omission as compared to the optimum treatment with adequate P supply (Wondwosen and Sheleme, 2011).

Nutrient concentrations and uptake in maize plant parts

Applying lime alone had significantly increased Ca and Mg concentrations in the plant material, whereas the concentrations of the other macronutrients in roots and shoots were not affected (Table 4). The highest concentrations of Ca and Mg in the shoot were recorded at the highest lime rate without P, while addition of P significantly suppressed the Ca concentration in shoots at the highest lime rate. On the other hand, increasing P levels significantly improved root Ca concentration. Highest rates of both lime and P together showed the highest concentrations of Ca and Mg in the roots, indicating a synergistic effect of lime with applied P. In contrast, the least concentration of leaf Ca was obtained from the highest rates of P and $CaCO_3$, owing to low soil reaction that might have reduced its uptake by plants (Oluwatoyinbo et al., 2005).

Table 3. Influence of lime and P levels on maize plant height, and root and shoot dry weights

Treatments		Plant height (cm)	Root dry weight (g pot^{-1})	Shoot dry weight (g pot^{-1})
Lime (g kg^{-1} soil)	P (mg kg^{-1} soil)			
0	0	14.9c	1.08d	1.30d
	50	66.8b	11.43bc	34.68c
	100	75.1ab	12.75ab	42.53bc
	150	74.0ab	8.15c	33.58c
3	0	13.1c	0.83d	0.93d
	50	73.3ab	15.30a	48.38ab
	100	75.8ab	13.40ab	45.43ab
	150	79.8a	14.23ab	53.53a
6	0	13.8c	0.95d	0.83d
	50	77.1ab	14.08ab	48.13ab
	100	80.5a	13.78ab	50.10ab
	150	80.5a	13.88ab	41.83bc
LSD (0.05)		10.51	3.57	9.72

Means followed by the same letter(s) within a column are not significantly different at $P \leq 0.05$.

Table 4. Nutrient concentrations in maize roots and shoots as influenced by increasing levels of lime and P applications on acidic soils of Gununo area, southern Ethiopia

Treatment		**Concentration in Roots (%)**					**Concentration in Shoots (%)**				
Lime (g kg^{-1})	**P (mg kg^{-1})**	**N**	**P**	**K**	**Ca**	**Mg**	**N**	**P**	**K**	**Ca**	**Mg**
0	0	2.58a-c	0.13f	0.62	0.14d	0.06c	3.58a-d	0.13f	2.18a	0.34de	0.15d
	50	2.63a-c	0.19d-f	0.57	0.16d	0.07c	3.54a-d	0.27de	1.69bc	0.30e	0.10e
	100	2.35bc	0.23c-e	0.52	0.18cd	0.08bc	3.62a-d	0.37bc	1.72bc	0.37c-e	0.11de
	150	3.23a	0.38a	0.67	0.21bc	0.09bc	4.03a	0.45a	1.70bc	0.39b-d	0.12de
3	0	2.16bc	0.14f	0.52	0.21bc	0.09bc	3.24b-d	0.13f	2.06ab	0.45bc	0.23bc
	50	2.18bc	0.16ef	0.58	0.22bc	0.11ab	3.24b-d	0.24e	1.68bc	0.39b-d	0.20c
	100	2.46bc	0.26b-d	0.65	0.24b	0.12a	3.45a-d	0.35bc	1.37c	0.40b-d	0.22bc
	150	2.84ab	0.34ab	0.61	0.25ab	0.12a	3.82ab	0.40ab	1.33c	0.42b-d	0.24a-c
6	0	2.08c	0.15f	0.76	0.25ab	0.12a	3.08d	0.13f	2.25a	0.59a	0.28a
	50	2.45bc	0.16ef	0.57	0.23bc	0.12a	3.16dc	0.22e	1.44c	0.46b	0.26ab
	100	2.57a-c	0.26b-d	0.62	0.24b	0.13a	3.58a-d	0.33cd	1.44c	0.42b-d	0.28a
	150	2.80a-c	0.30bc	0.63	0.29a	0.13a	3.76a-c	0.35bc	1.31c	0.46b	0.25ab
LSD (0.05)		0.748	0.082	NS*	0.048	0.029	0.616	0.059	0.425	0.093	0.041

Means followed by the same letter(s) within a column are not significantly different at P≤0.05. *NS= Non-significant

The concentrations of P in roots and shoots increased significantly and linearly with increasing levels of applied P; though increasing lime rates suppressed its influence (Table 4). Despite the pronounced increments in concentrations of P, the dry weights of the plant parts did not significantly increase after the first level of applied P, indicating luxury consumption of the nutrient at higher P levels. In contrast to many previous findings (Ivoilov et al., 1990; Oluwatoyinbo et al., 2005; Torkashvand et al., 2010), liming neither increased the concentration of P nor its uptake by plants in the present study, which may be due to the absence of a solubilizing effect of lime on soil P. Generally, N concentrations in both shoots and roots were not significantly affected by liming or applied P; however, the highest P dose indicated appreciable increases in concentrations of N in roots and shoots (Table 4). The K concentration of shoots declined with added P due to the dilution effect.

Table 5. Nutrient uptake by maize root and shoots as influenced by increasing levels of lime and P applications on acidic soils of Gununo area, southern Ethiopia

Treatment		**Uptake by Roots (mg pot^{-1})**					**Uptake by Shoots (mg pot^{-1})**				
Lime (g kg^{-1})	**P (mg kg^{-1})**	**N**	**P**	**K**	**Ca**	**Mg**	**N**	**P**	**K**	**Ca**	**Mg**
0	0	27.6c	1.4f	6.7c	1.5d	0.7c	47.0d	1.7e	28.5d	4.4e	2.0e
	50	294.6ab	21.0e	64.2ab	17.6c	8.4b	1236.3c	92.7d	584.3bc	102.8d	33.3d
	100	288.5b	29.3c-e	65.4ab	22.3bc	10.5b	1577.5a-c	154.0bc	710.1a-c	153.4bc	47.0d
	150	264.6b	30.7dc	54.2b	17.0c	7.0b	1356.3bc	149.3bc	561.7bc	132.6cd	41.8d
3	0	17.9c	1.1f	4.3c	1.8d	0.7c	29.6d	1.2e	19.6d	4.2e	2.2e
	50	333.7ab	23.5de	85.0a	33.0a	16.0a	1551.2bc	117.2b-d	819.1a	187.4ab	96.7c
	100	328.9ab	34.4bc	87.6a	31.6ab	15.7a	1574.0a-c	158.8b	613.2bc	179.9a-c	99.3c
	150	386.2a	46.0a	83.6a	36.5a	17.1a	2025.4a	218.2a	736.4ab	228.7a	129.4ab
6	0	20.8c	1.5f	6.5c	2.4d	1.1c	25.4d	1.0e	16.8d	4.6e	2.3e
	50	348.2ab	22.0e	81.4ab	31.6ab	16.4a	1532.8bc	108.5cd	685.0a-c	223.6a	124.6a-c
	100	343.9ab	34.2bc	83.7a	33.9a	17.2a	1802.8ab	164.6b	722.4a-c	211.8a	139.3a
	150	383.8a	39.9ab	86.4a	39.9a	17.9a	1577.8a-c	147.6bc	546.1c	189.5ab	105.1bc
LSD *(0.05)*		94.6	8.4	27.6	10.6	4.5	468.2	48.4	186.6	49.0	28.4

Means followed by the same letter(s) within a column are not significantly different at P≤0.05.

Increasing levels of lime had no significant influence on the uptake of the macronutrients (N, K, Ca and Mg) by roots and shoots of maize (Table 5), whereas the uptakes of these nutrients were increased in both plant parts by applying P alone; but with no significant difference between the rates of applied P. Combined use of lime and

P had a pronounced effect on the uptake of the nutrients, being maximum at 3 g lime and 150 mg P kg^{-1} soil (Table 5). However, the results of plant growth and yields indicated that application of lime and P above 3 and 50 mg kg^{-1} soil, respectively, was not necessary (Table 3). Increased nutrient uptake with application of P fertilizer was due to high plant growth as was evident by strong correlations between these parameters and corroborates with previous findings (Torkashvand et al., 2010). In addition, very high correlations between nutrient uptakes (Table 6) indicated that their supply should be balanced by adequate availability of other nutrients for optimum growth and development (Wondwosen and Sheleme, 2011).

Table 6. Correlations between soil pH, available P, exchangeable cations, nutrients' uptake and growth parameters

	SDW	RDW	PH	N-UP	P-UP	K-UP	Ca-UP	Mg-UP	AvP	Ex.Ca	Ex.Mg	Ex.K
RDW	0.89***											
PH	0.92***	0.87***										
N-UP	0.97***	0.85***	0.92***									
P-UP	0.91***	0.79***	0.84***	0.91***								
K-UP	0.96***	0.90***	0.89***	0.90***	0.89***							
Ca-UP	0.96***	0.89***	0.87***	0.91***	0.90***	0.93***						
Mg-UP	0.89***	0.80***	0.78***	0.85***	0.81***	0.82***	0.94***					
AvP	0.50***	0.44**	0.64***	0.57***	0.70***	0.47***	0.50***	0.39**				
Ex.Ca	0.45**	0.44**	0.42**	0.43**	0.47***	0.39**	0.56***	0.64***	0.39**			
Ex.Mg	0.11	0.13	0.02	0.09	0.08	0.05	0.25	0.40**	-0.09	0.84***		
Ex.K	0.81***	-0.70***	0.79***	0.79***	0.74***	0.82***	0.71***	0.60***	0.49***	-0.16	0.21	
S-pH	0.40**	0.40**	0.37*	0.41**	0.26	0.25	0.46***	0.60***	0.11	0.70***	0.69***	-0.01

*, **, *** = significant at $P \leq 0.05, 0.01, 0.001$, respectively

SDW=Shoot dry weight; RDW=Root dry weight; PH=Plant height; N-UP=N uptake; P-UP=P uptake; K-UP=K uptake; Ca-UP=Ca uptake; Mg-UP=Mg uptake; AvP=Available P; Ex.Ca=Exchangeable Ca; Ex.Mg=Exchangeable Mg; Ex.K=Exchangeable K; S-pH=Soil pH

CONCLUSION

The study showed that increasing rates of lime increased soil pH and concentrations of nutrients in soil and plants. Liming also had positive effects on dry weights of maize roots and shoots and P concentrations in shoots, when applied with P. However, liming alone did not influence available P in soil, and an increasing rate of lime application without P resulted in a slight decrease in growth and biomass production of the plants. On the other hand, P application significantly enhanced available P and exchangeable Ca in the soil; plant height, root and shoot dry weights and; concentration and uptake of the nutrients in maize shoots and roots. The results demonstrate that P is the most important limiting nutrient; more important than liming for maize growth on the acid soil of the study area. Furthermore, the findings indicate that liming should be used with appropriate level of P to improve plant growth and production. However, the experiment should be repeated in the field to draw a sound conclusion.

Acknowledgements

The study was conducted with the financial support of the government of Canada, International Development Research Center and Global Affairs Canada, through the Canadian International Food Security Research Fund. The support provided by the Research Assistants and Laboratory Staff of the College of Agriculture at Hawassa University was highly appreciated.

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