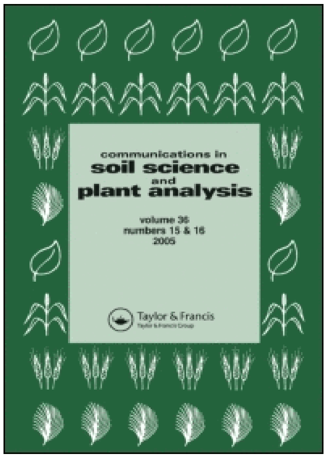

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Yield, Nutrient Uptake, and Soil Chemical Properties as Influenced by Liming and Boron Application in Common Bean in a No-Tillage System

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Abstract: In Oxisols, acidity is the principal limiting factor for crop production. In recent years, because of intensive cropping on these soils, deficiency of micronutrients is increasing. A field experiment was conducted on an Oxisol during three consecutive years to assess the response of common bean (*Phaseolus vulgaris L.*) under a no-tillage system to varying rates of lime (0, 12, and 24 Mg ha^{-1}) and boron (0, 2, 4, 8, 12, 16, and 24 kg ha^{-1}) application. Both time and boron (B) were applied as broadcast and incorporated into the soil at the beginning of the study. Changes in selected soil chemical properties in the soil profile (0- to 10- and 10- to 20-cm depths) with liming were also determined. During all three years, gain yields increased significantly with the application of lime. However, B application significantly increased common bean yield in only the first crop. Only lime application significantly affected the soil chemical properties [pH; calcium (Ca^{2+}); magnesium (Mg^{2+}); hydrogen (H^+) + aluminum (Al^{3+}); base saturation; acidity saturation; cation exchange capacity

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(CEC); percent saturation of Ca^{2+}, Mg^{2+}, and potassium (K^+); and ratios of exchangeable Ca/Mg, Ca/K, and Mg/K] at both soil depths (0–10 cm and 10–20 cm). A positive significant association was observed between grain yield and soil chemical properties. Averaged across two depths and three crops, common bean produced maximum grain yield at soil pH_w of 6.7, exchangeable ($cmol_c\,kg^{-1}$) of Ca^{2+} 4.9, Mg^{2+} 2.2, $H^+ + Al^{3+}$ 2.6, acidity saturation of 27.6%, CEC of 4.1 $cmol_c\,kg^{-1}$, base saturation of 72%, Ca saturation of 53.2%, Mg saturation of 17.6%, K saturation of 2.7%, Ca/Mg ratio of 2.8, Ca/K ratio of 25.7, and Mg/K ratio of 8.6. Soil organic matter did not change significantly with addition of lime.

Keywords: Base saturation, nutrient-use efficiency, Oxisol, *Phaseolus vulgaris*, soil pH

INTRODUCTION

Common bean is an important legume crop for a large percentage of the world's population. Bean is a principal component in the diet of the people of Central and South America, Africa, and Asia. Yield of common bean is quite low in most of the regions where this crop is grown. Both biotic and abiotic constraints are responsible for reduced yields. Low soil fertility is the major yield-limiting factor in most of the bean-producing regions (Fageria 2002; Fageria and Baligar 2003). Moreover, soil used for bean cultivation are mostly acidic, and soil acidity constraints contribute to the low yields. It is estimated that in tropical South America alone, 85% of the soils are acidic, and approximately 850 million ha of such land area is underutilized (Fageria and Baligar 2001). Liming is still a dominant practice in reducing soil acidity and improving yields of annual crops.

In recent years, the incidence of micronutrient deficiencies in crops has increased markedly because of intensive cropping, loss of topsoil by erosion, losses of micronutrients through leaching, liming of acid soils, decreased proportions of farmyard manure compared to chemical fertilizer use, increased purity of chemical fertilizers, and use of marginal lands for crop production (Fageria, Baligar, and Clark 2002). Among micronutrients, boron (B) deficiency is widespread, and it has been reported in at least 80 countries on 132 crop species (Fageria, Baligar, and Clark 2002). It is estimated that worldwide about 15 million hectares of agricultural land are annually treated with B fertilizers (Shorrocks 1997). Boron plays an important role in normal growth and development of crop plants (Marschner 1995). Availability of B is reported to be reduced with the application of lime because of adsorption with increasing soil pH (Barber 1995).

In central part of Brazil in recent years, the no-tillage system is emerging as an important soil management practice. This system of planting reduces cost of production and helps in soil conservation (Lyon, Stroup, and Brown 1998). Tillage and cropping system also affect soil physical and chemical characteristics (Karlen, Berry, and Colvin 1991; Kettler et al. 2000). It is widely reported that frequent use of the moldboard plow causes declines in soil organic carbon, decreases in soil structure and aggregation, reductions in water infiltration rates, and increases in soil erosion by wind and water (Karlen, Berry, and Colvin 1991). Information of liming on boron nutrition of common bean in no-tillage system in Brazilian Oxisols is limited. The objectives of this study were to i) evaluate yield response of common bean to liming and B fertilization in a no-tillage system, ii) to determine the uptake of nutrients by bean crop at optimal yield level, and iii) to assess changes in soil chemical properties with the application of lime.

MATERIALS AND METHODS

A field experiment was conducted on Oxisol (clay, isothermic, mesic Typic Haplustox) with common bean (*Phaseolus vulgaris* L.) The experiment was conducted during three consecutive years at the EMBRAPA National Rice and Bean Research Center experimental station, Capivara, state of Goiás, in the central part of Brazil. To determine the initial soil properties, two composite soil samples were collected from the entire experimental area at two depths (0–10 and 10–20 cm) prior to treatment establishment, and properties are reported in Table 1. Soil pH was measured in a 1:2.5 soil–water suspension. Phosphorus (P), potassium (K), copper (Cu), zinc (Zn), iron (Fe), and

Table 1. Soil chemical and textural properties of the experimental site (0- to 10- and 10- to 20-cm soil depths) before application of lime and boron treatments

Soil property	0–10 cm	10–20 cm
pH (1:2.5 soil water ratio)	5.8	5.8
Ca ($\text{cmol}_c\ \text{kg}^{-1}$)	2.2	2.4
Mg ($\text{cmol}_c\ \text{kg}^{-1}$)	1.1	1.3
Al ($\text{cmol}_c\ \text{kg}^{-1}$)	0.1	0.1
H + Al ($\text{cmol}_c\ \text{kg}^{-1}$)	5.9	5.7
P (mg kg^{-1})	29.6	9.4
K (mg kg^{-1})	129	84
Cu (mg kg^{-1})	2.3	2.6
Zn (mg kg^{-1})	7.2	6.7
Fe (mg kg^{-1})	59	88
Mn (mg kg^{-1})	15	16
B (mg kg^{-1})	0.8	0.8
Organic matter (g kg^{-1})	19	19
Clay (g kg^{-1})	485	460
Silt (g kg^{-1})	235	230
Sand (g kg^{-1})	280	310

manganese (Mn) were extracted by the Mehlich 1 extracting solution [0.05 M hydrochloric acid (HCl) + 0.0125 M sulfuric acid (H_2SO_4)]. Phosphorus was determined colorimetrically and K, Cu, Zn, Fe, and Mn by atomic absorption spectroscopy. Calcium (Ca), magnesium (Mg), and aluminum (Al) were extracted with 1 M potassium chloride (KCl). Aluminum was determined by titration with sodium hydroxide (NaOH), and Ca and Mg were determined by titration with ethylenediamine tetraacetic acid (EDTA). Organic matter was determined by the Walkley–Black method, and B was extracted by hot water and determined colorimetrically. Soil texture was determined by the pipette method. Soil analysis methods used in this study are described in a soil analysis manual published by EMBRAPA (1997).

Treatments consisted of three levels of dolomitic lime (0, 12, and 20 Mg ha^{-1}) and six levels of B(0, 2, 4, 8, 16, and 24 kg ha^{-1}). Liming material that had calcium oxide (Cao) 32.5%, magnesium oxide (MgO) 13.3%, and neutralizing power 88.3% was applied as broadcast on 21 December 1998 and incorporated by disking into soil. Boron (borax with 11% B) was applied as broadcast and incorporated by disking before sowing. A randomized completed block design with a split-plot arrangement was adapted, with three replications. Lime treatments were in the main plots and B treatments in the subplots. Main plot size was 42 × 42 m and subplot 7 × 7 m. There was spacing of 2 m between each main plot and 1 m between each subplot. Lime and boron treatments were applied only once before sowing the first bean crop. The first crop of common bean (cv. Perola) was seeds with drill in the last week of May 1999 at a spacing 40 cm between rows using 19 seeds per meter row. At the time of sowing, 400 kg ha^{-1} of mixed fertilizer (4–30–16) was applied through combined sowing drill. Weeds were controlled by postemergence application of herbicide Fusiflex (Fluazilop-p-butil + Fomesafen). Fifty kg N as urea was top-dressed 27 days after sowing, and a second level of N, at 50 kg ha^{-1}, was applied 41 days after sowing. Beans were planted during the dry season; therefore, a pivot system was used for irrigation. Seven central rows each of 4 m were harvested for grain yield determination in the first week of September 1999. One meter row was also harvested from each plot for determination of dry-matter yield.

In sequence, second and third bean crops were planted in the last week of May 2000 and 2001, respectively. Cultural practices for these succeeding bean crops were similar to those adopted for the first crop. A no-tillage system was established after sowing the first bean crop, and a burndown application of herbicide Roundup (Glyphosate) was applied about 4 weeks before planting of succeeding bean crops to control weeds.

Plant samples were taken from a 1-m long row from 12 Mg lime ha^{-1} treatment plots at harvest of first and second crops to determine dry-matter production and nutrient analysis. Dried plant material was ground and digested with a 2:1 mixture of nitric acid (HNO_3) and perchloric acid ($HClO_4$). Phosphorus was determined colorimetrically, and all other nutrients were determined by atomic absorption spectroscopy (Moraes and Rabelo 1986). Total nitrogen (N) in the plant tissue was determined with a Tecator 1016 digester and 1004 distilling unit. After harvest of each bean crop, soil samples were taken and 0- to 10-and 10- to 20-cm soil depths from each plot to determine chemical properties. About 50 cores were taken from each plot to make one composite sample. Soil samples were dried and ground, and chemical properties were determined using standard methods (EMBRAPA 1997). The cation exchange capacity (CEC); base saturation; acidity saturation; and Ca, Mg, and K saturation were calculated with the help of following equations:

$$\text{CEC}\ (\text{cmol}_\text{c}\text{kg}^{-1}) = \sum(\text{Ca, Mg, K, H, Al}),$$

where, Ca, Mg, K, H, and Al are in $\text{cmol}_\text{c}\text{kg}^{-1}$.

$$\text{Base saturation}\ (\%) = \frac{\Sigma(\text{Ca, Mg, K})}{\text{CEC}} \times 100.$$

$$\text{Acidity saturation}\ (\%) = \frac{(\text{H} + \text{Al})}{\text{CEC}} \times 100.$$

$$\text{Saturation of Ca, Mg, or K}\ (\%) = \frac{(\text{Ca})}{(\text{CEC})} \times 100, \quad \frac{(\text{Mg})}{(\text{CEC})} \times 100, \quad \text{or} \quad \frac{(\text{K})}{\text{CEC}} \times 100.$$

All the data were analyzed by analysis of variance, and treatment means were compared by Tukey's test at the 5% probability level. Regression analysis was also performed to evaluate the relationship between soil chemical properties and grain yield.

RESULTS AND DISCUSSION

Grain Yield

The crop year × lime × boron interaction for grain yield was significant. Hence, grain yield data for 3 years are presented (Table 2). With the exceptions of the third year, increasing levels of lime increased grain yield. Under different lime treatments, average grain yield of the first bean crop varied from 3102 to 4075 kg ha^{-1}, second crop yield varied from 2822 to 3778 kg ha^{-1}, and the third crop yield varied from 1841 to 2510 kg ha^{-1}. Average yield of three bean crops at an adequate lime rate of 12 Mg ha^{-1} produced 3409 kg ha^{-1} bean grain yield. This represents an average increase of about 32% in bean yield as compared to no lime application. Bean yield improvement with liming in Brazilian Oxisols has been reported by Fageria (2001a, 2002), Caires, Banzatto, and Fonseca (2000), and Fageria and Baligar (2003). On a similar type of soil, Fageria (2001a)

Table 2. Grain yield (kg ha^{-1}) of common bean under different lime and boron treatments during three cropping years

Lime rate (Mg ha^{-1})	1st year	2nd year	3rd year	Average
Parameter				
0	3102b	2822b	1841b	2588b
12	3977a	3740a	2510a	3409a
24	4075a	3778a	2400a	3416a
B rate (kg ha^{-1})				
0	3852ab	3295	2185	3111abc
2	4024ab	3432	2151	3202ab
4	4140a	3556	2364	3353a
8	3979ab	3475	2250	3232ab
16	3488b	3448	2185	3041bc
24	2825c	3472	2368	2888c
F-Test				
Year (Y)		**		
Lime (L)		**		
Y × L		NS		
Boron (B)		**		
Y × B		**		
L × B		*		
Y × L × B		*		
CV (%)		9.8		

*, **, NSSignificant at the 5 and 1% probability levels and nonsignificant, respectively.

Note. Means within same column, followed by same letter, do not differ significantly at the 5% probability level by Tukey's test.

achieved maximum grain yield of bean with the application of 10 Mg lime ha^{-1}. The higher lime requirements needed to produce good bean yields in this study may be due to different bean cultivars planted and differences in the clay content of the soils. Soil used in this experiment had 43% higher clay content in the surface (0- to 20-cm) horizon than the soil used in the earlier study (Fageria 2001a). Farina, Channon, and Thibaud (2000) suggested that clay mineralogical properties should be taken into consideration in correcting soil acidity by liming.

The increase in grain yield of bean with liming was associated with increase in shoot dry-matter yield and number of pods m^{-2} (Table 3). At 12 Mg lime ha^{-1} application, shoot weight increased by 47% and pods m^{-2} increased by 26% compared to the control. Grain yield was highly correlated ($P > 0.01$) with shoot dry weight and pod number (Table 3). The shoot dry-matter yield contributed 58% of the variation in grain yield, whereas pods m^{-2} contributed 43% of the variation in grain yield (Table 3). Fageria (1989) reported a highly significant correlation between bean yield and

Table 3. Shoot dry weight, pod number, and 100 grain-weight of common bean under different lime and boron treatments (values are across three years)

Lime rate (Mg ha^{-1})	Shoot dry wt. (kg ha^{-1})	Pod number (m^{-2})	100 grain wt. (g)
Parameter			
0	1497.8b	266.8b	26.5
12	2200.3a	336.1a	26.7
24	2000.0a	319.0a	26.4
B rate (kg ha^{-1})			
0	1899.9	310.4	26.4
2	1868.2	305.4	26.9
4	2032.4	314.5	26.2
8	1952.9	314.4	26.5
16	1853.0	302.0	26.7
24	1789.9	297.2	26.4
F-Test			
Year (Y)	**	**	**
Lime (L)	**	**	NS
Boro (B)	NS	NS	NS
Y × L	NS	NS	NS
Y × B	NS	NS	NS
L × B	NS	NS	NS
Y × L × B	NS	NS	*
CV (%)	21.4	16.7	4.8

$^{*, **, NS}$Significant at the 1% probability level and nonsignificant, respectively.

Notes. Means within same column followed by the same letter do not differ significantly at the 5% probability level.

Regression: Dry matter yield (X) vs. grain yield $(Y) = -169.3782 + 2.6383X - 0.00045X^2$, $R^2 = 0.58^{**}$. Number of pods (X) vs. grain yield $(Y) = 689.0368 + 8.7109X - 0.00236X^2$, $R^2 = 0.43^{**}$.

shoot dry weight at different growth stages. Sarafi (1978) and Nienhuis and Singh (1989) reported that bean yield was having highly significant ($P < 0.01$) association with pods m^{-2}. Sarafi (1978) and Bennet, Adams, and Burga (1977) reported that pods per plant or per unit area has often been recommended as an indirect plant selection criterion in breeding programs for selecting plant types that are capable of producing high bean yield, primarily because of its higher and more consistent correlation with yield.

Grain yield was significantly affected by levels of soil applied B in the first year, however, applied B had no significant effects in the second and third years (Table 2). Increasing B application, up to 4 kg B ha^{-1}, increased grain yield but further increasing B reduced grain yields. Average increase in bean grain yield with the application of 4 kg B ha^{-1} was about 8% over control.

The lime × B interaction was significant. Hence, regression analysis was performed relating grain yield (Y) and B rate (X) at each lime rate, and the equations were as follows: at 0 Mg lime ha^{-1} $(Y) = 3636.03 + 17.89X - 4.62X^2$, $R^2 = 0.95^{**}$; at 12 Mg lime ha^{-1} $(Y) = 4099.87 + 9.91X - 1.39X^2$, $R^2 = 0.69^{**}$; and at 24 Mg lime ha^{-1} $(Y) = 4117.51 + 55.13X - 3.53X^2$, $R^2 = 0.76^{**}$. Based on these regressing equations, the needed B application to achieve maximum yield was 1.9 kg B ha^{-1} at 0 Mg lime ha^{-1}, 3.6 kg B ha^{-1} at 12 Mg lime ha^{-1}, and 7.8 kg B ha^{-1} at 24 Mg lime ha^{-1}. These results indicate that with increasing lime rate, higher levels of B applications are needed to achieve yield potentials. Such increased B requirement may be due to higher adsorption of B by iron and aluminum hydroxides with increased soil pH by liming, and such reaction leads to reduced B availability (Barber 1995). Sakal and Singh (1995) reported that an increase in exchangeable Ca^{2+} and Mg^{2+} increased the B fixation from 46 to 60% and 47 to 57% respectively.

The regression equation was also adjusted for average grain yield of 3 years across three lime rates to define average B requirements rate for bean crop. The relationship between grain yield (Y) and B application rate (X) was highly significant and quadratic ($Y = 3184.66 + 15.20X - 1.20X^2$, $R^2 = 0.53^{**}$). Based on the equation, maximum bean yield was obtained with the application of 6.3 kg of ha^{-1}. Even though data on bean response to B fertilization are limited in the Brazilian Oxisols, in a greenhouse study, Fageria (2000) reported positive effects of B fertilization on the growth of common bean crop grown on Oxisol.

Nutrient Uptake and Use Efficiency

Concentration (content per unit dry weight) and uptake (concentration × dry weight) of nutrients for the first-and second-year bean crops were determined across B levels at 12 Mg lime ha^{-1} application (Table 4). Concentrations of N, P, K, Zn, Cu, and Mn were higher in grain compared with shoot. Fageria (1989) reported a similar trend in nutrient concentrations in shoot and grain of common bean plants under greenhouse conditions Average shoot dry weight and grain yield of bean were near maximal at 12 Mg lime rate ha^{-1}, and hence nutrient concentrations values presented in Table 4 can be considered adequate for bean crop. Piggott (1986) reported adequate concentration values of macro-and micronutrients in a similar range for bean crop. Total nutrient uptake (shoot plus grain) order was $N > K > Ca > p > Mg > Fe > Zn > Mn > Cu$. Bean crop requires high N followed by K, Ca, and Mg for good yield in Oxisols. Among micronutrients in shoot and grain the Fe requirement was maximal and the Cu was minimal. These uptake values can be taken as references for maintaining soil fertility for bean production in Oxisols.

Table 4. Nutrient concentration and uptake in the shoot and grain of common bean crop at harvest (values are averages of 1st and 2nd crops across boron level at 12 Mg ha^{-1} lime level)

	Concentration (g kg^{-1} or mg kg^{-1})[a]		Uptake (kg ha^{-1} or g ha^{-1})[a]	
Nutrient	Shoot	Grain	Shoot	Grain
N	6.3	32.0	16.9	124.1
P	0.6	3.8	1.6	14.6
K	15.5	16.8	41.2	63.8
Ca	7.3	2.2	22.0	8.5
Mg	3.0	1.6	8.9	6.2
Zn	23.8	32.0	61.7	123.3
Cu	3.6	9.0	9.2	34.6
Mn	11.8	12.6	31.1	48.7
Fe	349.4	71.1	1010.3	274.9

[a] Concentration values for macronutrients are in g kg^{-1} and micronutrients in mg kg^{-1}. Similarly, values of uptake of macronutrients are in kg ha^{-1} and micronutrients in g ha^{-1}.

Nutrients exported to grain, nutrient-use efficiency, and amount of nutrient required to produce 1 Mg grain were evaluated for bean crop grown at 12 Mg ha^{-1} lime and across the B levels (Table 5). Phosphorus and N were exported to grain in the highest amounts, followed by Cu, Zn, Mn, and K. Transport of Fe and Ca was minimal. Fageria, Baligar, and Jones (1997) and Fageria (2001b) reported similar trends in transport of nutrients to grains of bean grown on Oxisols. Nutrient-use efficiency (grain yield per unit of nutrient accumulated) was most for Mg and least for N among macronutrients. Whereas among micronutrients, Cu-use efficiency was highest, and Fe-use efficiency was the lowest. Demand for N was highest and Mg was lowest to produce 1 Mg grain in bean. Similarly, demand for Fe was highest and Cu was lowest among micronutrients to produce 1 Mg grain yield. Fageria (2001b) reported a similar nutrient requirement by bean crop to produce 1 Mg of bean yield. To produce high bean yields in Oxisols, it is essential to maintain high levels of available soil N.

Changes in Soil Chemical Properties with Liming

Because B application did not have any significant effect on soil chemical properties (data not shown), results related to lime application on soil chemical properties are presented (Tables 6 and 7). Liming significantly ($P < 0.01$) modified the soil chemical properties at two soil depths (0–10 and 10–20 cm) with the exception of organic matter at both the depths and

Table 5. Nutrient exported to grain, nutrient-use efficiency, and nutrient requirement per Mg of grain production of common bean (values are averaged of 1st and 2nd crops across six boron level at 12 Mg ha^{-1} lime level at harvest)

Nutrient	Exported to grain (% of total uptake)	Use efficiency (kg kg^{-1} or kg g^{-1})[a]	Required per Mg grain yield (kg or g)[b]
N	88	27.4	36.5
P	90	238.2	4.2
K	61	36.7	27.2
Ca	28	126.5	7.9
Mg	41	255.5	3.9
Zn	67	20.9	48.0
Cu	79	88.1	11.4
Mn	61	48.4	20.7
Fe	21	3.0	333.1

[a] Nutrient use efficiency = (Grain yield in kg)/(Nutrient uptake in shoot plus grain in kg or g). Macronutrient uptake is in kg, and micronutrient uptake is in g. Macronutrients are in kg kg^{-1}, and micronutrients are in kg g^{-1}.

[b] Similarly, macronutrients are in kg, and micronutrients are in g.

CEC in the 10- to 20-cm depth. Increase in soil pH with liming was significant ($P < 0.01$) at both the soil depths; however, values were higher in the 0- to 10-cm layer. Such higher soil pH in this layer is due to a higher amount of exchangeable Ca. Average soil Ca in the top soil layer was 2.1 $cmol_c\ kg^{-1}$ compared with 1.6 $cmol_c\ kg^{-1}$ in the 10- to 20-cm soil layer. Hussain, Olson, and Ebelhar (1999) reported higher pH in the top 0- to 5-cm soil layer compared the to 5- to 15-cm soil layer in the no-tillage system.

Base saturation significantly increased with increasing lime rate, and values were higher in the top 0- to 10-cm soil layer compared with the subsoil layer, probably because of higher exchangeable Ca^{2+} and Mg^{2+} in this layer. Base saturation was having a highly significant positive relationship with yield of bean (Table 8). Values of base saturation for maximum yield of bean were 82.6% in the 0- to 10-cm soil layer, 62.8% in the 10- to 20-cm soil layer, and 72% across two layers. In Brazilian Oxisols, adequate values of base saturation required for most of the crops reported in the literature varied from 53 to 70% (Fageria 2001b). This variation may be due to adoption of different soil-and plant-management practices.

The H + Al and acidity saturation were significantly reduced with liming as expected. Values of these two acidity indices were higher in the lower soil depth (10–20 cm) compared with upper soil layer (0–10 cm). The higher concentration of H + Al and acidity saturation in the lower soil layer was the result of lower concentrations of exchangeable Ca^{2+} and Mg^{2+} in the deeper soil layer. The values of H + Al for maximum bean yield were

Table 6. Selected soil chemical properties after harvest of 1st and 2nd common bean crops at two soil depths as influenced by liming treatments across six B levels

	Lime rate (Mg ha^{-1})				
Soil property	0	12	24	F-test	CV (%)
1st crop (0- to 10-cm depth)					
pH	5.6c	6.5b	6.9a	**	2
Base saturation (%)	35.4c	78.7b	86.2a	**	5
H + Al (cmol$_c$ kg^{-1})	5.5a	1.6b	1.0c	**	16
Acidity saturation (%)	65.2a	21.3b	13.8c	**	17
Ca (cmol$_c$ kg^{-1})	2.0c	4.2b	4.8a	**	7
Mg (cmol$_c$ kg^{-1})	0.7b	1.5a	1.3a	**	18
CEC (cmol$_c$ kg^{-1})	8.4	7.6	7.4	**	6
1st crop (10- to 20-cm depth)					
pH	5.4c	5.9b	6.3a	**	2
Base saturation (%)	28.9c	49.9b	65.9a	**	14
H + Al (cmol$_c$ kg^{-1})	6.2a	4.1b	2.7c	**	14
Acidity saturation (%)	71.2a	50.1b	34.1c	**	16
Ca (cmol$_c$ kg^{-1})	1.8c	3.0b	3.9a	**	16
Mg (cmol$_c$ kg^{-1})	0.6b	1.1a	1.3a	**	25
CEC (cmol$_c$ kg^{-1})	8.7	8.4	8.2	NS	10
2nd crop (0- to 10-cm depth)					
pH	5.4c	6.4b	6.9a	**	3
Base saturation (%)	33.0c	71.8b	85.9a	**	11
H + Al (cmol$_c$ kg^{-1})	6.3a	2.2b	1.1c	**	20
Acidity saturation (%)	66.9a	28.2b	14.0c	**	20
Ca (cmol$_c$ kg^{-1})	2.3c	4.1b	4.9a	**	13
Mg (cmol$_c$ kg^{-1})	0.6b	1.3a	1.4a	**	15
CEC (cmol$_c$ kg^{-1})	9.5a	7.9b	7.7b	**	10
2nd crop (10- to 20-cm depth)					
pH	5.2c	6.1b	6.4a	**	3
Base saturation (%)	22.4c	49.5b	57.6a	**	13
H + Al (cmol$_c$ kg^{-1})	7.1a	4.4b	3.6c	**	12
Acidity saturation (%)	77.6a	50.5b	42.4c	**	10
Ca (cmol$_c$ kg^{-1})	0.4c	1.1b	1.1a	**	17
Mg (cmol$_c$ kg^{-1})	1.5b	3.1a	3.7a	**	18
CEC (cmol$_c$ kg^{-1})	9.1	8.8	8.6	NS	9

$^{*,**,\,NS}$Significant at the 5 and 1% probability level and nonsignificant, respectively. Means followed by the same letter in the same line under different lime treatments are statistically not significant at the 5% probability level by Tukey's test.

1.7 cmol$_c$ kg^{-1} in the 0- to 10-cm soil layer, 3.2 in the 10- to 20-cm soil layer, and 2.6 across two soil layers. This means if values of H + Al increased beyond these limits, bean yield may decrease because of the toxicity of H + Al. Similarly, acidity saturation values for maximum bean yield were

Table 7. Selected soil chemical properties after harvest of three common bean crop and averages of three common bean crops at two soil depths as influenced by liming treatments across six B levels[a]

	Lime rate (Mg ha^{-1})				
Soil property	0	12	24	F-test	CV (%)
3rd crop (0- to 10-cm depth)					
pH	5.4c	6.7b	7.2a	**	3
Base saturation (%)	29.3c	68.9b	84.6a	**	11
H + Al (cmol$_c$ kg^{-1})	6.9a	2.7b	1.2c	**	15
Acidity saturation (%)	70.7a	31.1b	15.4c	**	18
Ca (cmol$_c$ kg^{-1})	2.1c	4.3b	4.9a	**	15
Mg (cmol$_c$ kg^{-1})	0.6b	1.5a	1.5a	**	113
CEC (cmol$_c$ kg^{-1})	9.9a	8.8b	7.8c	**	8
3rd crop (10- to 20-cm depth)					
pH	5.3c	6.3b	6.9a	**	4
Base saturation (%)	21.3c	54.3b	74.5a	**	9
H + Al (cmol$_c$ kg^{-1})	7.1a	3.6b	1.9c	**	11
Acidity saturation (%)	78.7a	45.6b	25.5c	**	9
Ca (cmol$_c$ kg^{-1})	1.5c	3.1b	4.2a	**	15
Mg (cmol$_c$ kg^{-1})	0.3b	1.1a	1.3a	**	13
CEC (cmol$_c$ kg^{-1})	9.0a	7.9b	7.5b	**	9
Average of 3 crops (0- to 10-cm depth)					
pH	5.5c	6.5b	7.0a	**	2
Base saturation (%)	32.6c	73.1b	85.6c	**	8
H + Al (cmol$_c$ kg^{-1})	6.2a	2.1b	1.1c	**	12
Acidity saturation (%)	67.6a	26.9b	14.4c	**	14
Ca (cmol$_c$ kg^{-1})	2.1c	4.2b	4.9a	**	12
Mg (cmol$_c$ kg^{-1})	0.6b	1.4a	1.4a	**	12
CEC (cmol$_c$ kg^{-1})	9.3a	8.1b	7.6b	**	7
Average of 3 crops (10- to 20-cm depth)					
pH	5.3c	6.1b	6.5a	**	3
Base saturation (%)	24.2c	51.3b	66.0a	**	10
H + Al (cmol$_c$ kg^{-1})	6.8a	4.1b	2.8c	**	8
Acidity saturation (%)	75.8a	48.7a	33.9c	**	9
Ca (cmol$_c$ kg^{-1})	1.6c	3.1b	3.9a	**	15
Mg (cmol$_c$ kg^{-1})	0.4b	1.1a	1.2a	**	15
CEC (cmol$_c$ kg^{-1})	8.9	8.4b	8.1b	**	7

$^{*,\,**,\,\mathrm{NS}}$Significant at the 5 and 1% probability level and nonsignificant, respectively. Means followed by the same letter in the same line under different lime treatments are statistically not significant at the 5% probability level by Tukey's test.

[a] Values are averages of two crops.

Table 8. Relationship between some soil chemical properties (X) at two soil depths and averages of two depths and grain yield (Y) of common bean values are averages of three crops

Soil chemical property	Regression equation	R^2	Value for maximum yield
0- to 10-cm depth			
pH	$Y = -16406.7900 + 5804.2400 - 424.4457X^2$	0.6728**	6.8
Ca (cmol$_c$ kg^{-1})	$Y = 1433.2580 + 679.9645X - 54.1826X^2$	0.6578**	6.3
Mg (cmol$_c$ kg^{-1}	$Y = 1821.3900 + 1469.9430X - 255.9889X^2$	0.6630**	2.9
H + Al (cmol$_c$ kg^{-1}	$Y = 3311.7010 + 137.1801X - 39.9073X^2$	0.7240**	1.7
Acidity saturation (%)	$Y = 3330.8820 + 1.3513X - 0.3264X^2$	0.6998**	17.4
CEC (cmol$_c$ kg^{-1})	$Y = 4473.1480 + 33.5894X - 22.8829X^2$	0.4327**	0.7
Base saturation (%)	$Y = 1201.4690 + 53.9413X - 0.3264X^2$	0.6998**	82.6
Ca saturation (%)	$Y = 1304.9590 + 69.6064X - 0.5668X^2$	0.6991**	61.4
Mg saturation (%)	$Y = 1504.9600 + 205.4451X - 5.5374X^2$	0.6885**	18.6
K saturation (%)	$Y = -740.0040 + 2120.3950X - 275.1728X^2$	0.1345*	3.8
Ca/Mg ratio	$Y = 302.3003 + 2225.5070X - 407.0294X^2$	0.1676*	2.7
Ca/K ratio	$Y = 1533.8650 + 152.2764X - 2.7710X^2$	0.6943**	27.5
Mg/K ratio	$Y = 1619.6390 + 503.5037X - 33.2781X^2$	0.6802**	7.6
10- to 20-cm depth			
pH	$Y = -21481.8100 + 7706.4490X - 595.4493X^2$	0.6698**	6.5
Ca (cmol$_c$ kg^{-1})	$Y = 1229.7610 + 1105.7270X - 135.7863X^2$	0.6384**	4.1
Mg (cmol$_c$ kg^{-1})	$Y = 1751.6950 + 2412.9520X - 848.3736X^2$	0.6701**	1.4
H + Al (cmol$_c$ kg^{-1})	$Y = 2800.4890 + 408.6895X - 64.2835X^2$	0.6874**	3.2
Acidity saturation (%)	$Y = 2663.8750 + 42.7892X - 0.5745X^2$	0.6849**	37.2
CEC (cmol$_c$ kg^{-1})	$Y = 211.9102 + 997.9102X - 76.4744X^2$	0.1888*	6.5
Base saturation (%)	$Y = 1197.1740 + 72.1336X - 0.5747X^2$	0.6849**	62.8

(*continued*)

Table 8. Continued

Soil chemical property	Regression equation	R^2	Value for maximum yield
Ca saturation (%)	$Y = 1198.0030 + 98.8195X - 1.0721X^2$	0.6774**	46.1
Mg saturation (%)	$Y = 1708.7540 + 223.7970X - 7.2423X^2$	0.6941**	15.5
K saturation (%)[a]	$Y = 3386.1450 - 570.8961X + 233.4323X^2$	0.0239^{NS}	2.1
Ca/Mg ratio[a]	$Y = 4388.0920 - 164.7107X - 62.8794X^2$	0.4852**	3.3
Ca/K ratio	$Y = 1229.5330 + 170.7049X - 3.2282X^2$	0.6743**	26.4
Mg/K ratio	$Y = 1726.6610 + 401.2852X - 23.1486X^2$	0.6829**	8.7
Average 0- to 10-and 10- to 20-cm depths			
pH	$Y = 118351.6100 + 6524.7040X - 488.3252X^2$	0.6722**	6.7
Ca ($\text{cmol}_c\ \text{kg}^{-1}$)	$Y = 1266.1050 + 907.8640X - 92.7547X^2$	0.6570**	4.9
Mg ($\text{cmol}_c\ \text{kg}^{-1}$	$Y = 1831.5330 + 1719.9810X - 393.8950X^2$	0.6745**	2.2
H + Al ($\text{cmol}_c\ \text{kg}^{-1}$)	$Y = 3030.4910 + 279.2087X - 54.1334X^2$	0.7225**	2.6
Acidity saturation (%)	$Y = 3110.2420 + 23.9056X - 0.4323X^2$	0.6995**	27.6
CEC ($\text{cmol}_c\ \text{kg}^{-1}$)	$Y = 3274.6200 + 346.6924X - 42.7200X^2$	0.3404**	4.1
Base saturation (%)	$Y = 1177.5470 + 62.5517X - 0.4322X^2$	0.6995**	72
Ca saturation (%)	$Y = 1223.4700 + 83.7798X - 0.7869X^2$	0.6971**	53.2
Mg saturation (%)	$Y = 1644.9820 + 202.4027X - 5.7518X^2$	0.6933**	17.6
K saturation (%)	$Y = -8934.5270 + 8984.4080X - 1644.1740X^2$	0.1847**	2.7
Ca/Mg ratio[a]	$Y = -1519.1560 + 3484.7980X - 616.6482X^2$	0.4275**	2.8
Ca/K ratio	$Y = 1323.2420 + 169.9053X - 3.3052X^2$	0.6925**	25.7
Mg/K ratio	$Y = 1725.1990 + 416.4390X - 24.3172X^2$	0.6927**	8.6

^{*,**,NS}Significant at the 5 and 1% probability levels and nosignificant, respectively.

[a] Because of negative β_1 regression coefficient or nosignificant R^2, average value of the determined soil property at harvest was considered for maximum yield.

17.4% in the top 0- to 10-cm soil layer, 37.2% in the 10- to 20-cm layer, and 27.6% across two soil layers. This indicates that if values of acidity saturation increased beyond these limits, bean yield may decrease as a result of acidity toxicity.

The Ca and Mg values increased with liming in the two soil layers. However, values of these two cations were higher in the surface layer compared with subsoil layer. Lack of tillage and higher concentration of crop residues at the soil surface in no-tillage system contributed to its higher concentrations of exchangeable Ca and Mg in the 0- to 10-cm layer. Values of exchangeable Ca and Mg and percent of their saturation had a significant positive association with bean yield (Table 8). Potassium saturation also had significant positive association with grain yield of bean. Positive association between potassium saturation and yield of bean has been reported by Fageria (2001b).

The basic cation saturation ratio philosophy promotes that maximum yields can be achieved by creating an ideal ratio of Ca, Mg, and K in the soil (Eckert 1987). Graham (1959) proposed that for production of annual crops, saturation ranges of 65 to 85% Ca, 6 to 12% for Mg, and 2 to 5% for K in soils are needed. Average values across two soil layers for base saturation was 72%, Ca saturation was 53.2%, Mg saturation was 17.6%, and K saturation was 2.7%. Fageria and Baligar (2001) and Fageria (2001a) reported similar values for K and Mg saturation in Brazilian Oxisols for optimum bean grain yields. However, base saturation and Ca saturation values reported by these authors were lower than reported in this study. This difference may be related to the system of cultivation used in these studies as earlier studies pertained to conventional tillage system and not the no-tillage system as in the present study.

CONCLUSIONS

Production potentials of common bean could be increased significantly by liming the Oxisol. Application of B also improved bean yield on limed Oxisol. The effects of liming were particularly significant for improving bean production. On average, the increase in bean yield was about 32% with the application of 12 Mg ha^{-1} lime compared with no lime application treatment. The quantity of lime required in this study (12 Mg ha^{-1}) was much greater than those typically reported for maximum yield of bean crop in Brazilian Oxisols (5 to 9 Mg ha^{-1}) (Fageria 2001a). Such difference may be associated with soil mineralogical properties, especially with amount of clay content. Most of the earlier studies were conducted in Oxisols having clay content of about 200 to 300 g kg^{-1}. In the present study, clay content of the experimental site was 485 and 460 g kg^{-1} at 0- to 10- and 10- to 20-cm soil depths, respectively. This suggests that clay mineralogical properties deserve much more attention than they customarily receive in correcting acidity of Oxisols.

Another reason may be the different cultivars planted with higher yield potential. The results obtained in this study unquestionably give evidence that use of adequate rate of liming for Brazilian Oxisols is a very effective soil-management practice in amelioration of soil acidity and consequently increasing bean yields. Some soil acidity parameters such as pH, base saturation, and acidity saturation can be used for liming Oxisols for bean production.

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