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Lime-phosphate relation and soybean growth in an oxisol from no-tillage system

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Abstract

Phosphorus (P) accumulation can be observed in the surface no-tilled soil layer, that can cause aluminium (Al^{+3}) inactivation. Lime-phosphate interaction may, in this situation, explain the lower crop response to liming. The objective of this research was to evaluate the effect of different soil acidity and P combinations on soybean growth in undeformed soil in columns, collected in the no-tillage system. An experiment was conducted in a clayey Rhodic Hapludox (Oxisol) which has been seven years under no-tillage after the application of 1 (1/24 lime recommendation), 6 (1/4 lime recommendation) and 24 (lime recommendation pH 6.0) t ha^{-1} of lime. Phosphorus was applied in the surface columns, in equivalent rates of 0, 40 and 80 kg ha^{-1} of P_2O_5 as triple phosphate. After 25 days of soybean cultivation, relationships between soil acidity and P attributes and plant parameters were established. The relation of substitution between lime and phosphate was characterized by aluminium content and saturation decrease with soil phosphorus increase, that determined a higher soybean response to this nutrient under low acidity conditions.

Key words: Soil acidity indexes, soil phosphorus content, plant parameters.

Introduction

The maintenance of a permanent soil cover by plants or their residues and surface application of lime, fertilizer in no tillage system (NTS), alter the dynamics of nutrients, particularly phosphorus (P) and calcium (Ca), causing an increase in nutrient concentrations in the soil surface [9, 18, 22, 30, 31]. This accumulation can be contributing to decrease the deleterious effect of soil acidity due to the high chemical affinity between Ca and P [19] and by the Ca physiological protection. Furthermore, the rise in soil pH by liming increases the negative charges in the exchangeable complex and decreases the activity of aluminium (Al^{+3}), thus increasing the P concentration in soil solution [8, 9, 29, 30]. This increase, caused by fertilization, by tillage (NT) or by liming, which raises the soil pH (reducing solubility of Al and Fe compounds) may be contributing to inactivate a part of the Al^{+3} in soil solution, forming stable compounds [$AlPO_4$; $Al(OH)_2H_2PO_4$] with low solubility, that precipitate [18, 19].

The increase in the soil phosphorus resulted in interaction with liming, determining different combinations for the same soybean [28] and wheat [5] yield in conventional tillage. It is expected that this interaction can be important to explain the lower crop response to liming in NTS [1, 3]. Moreover, in soils with higher pH (> 6.5), high concentration of exchangeable calcium, from the high application of lime rates, especially on the soil surface in NTS may also occur, the reaction between P (accumulated or added to soil) and calcium [19, 23, 29], decreasing its solubility. This occurs by the phosphate precipitation in the tricalcium form [$Ca_3(PO_4)_2$] in the phenomenon known as retrogradation [19].

The interaction between lime and P [10, 16, 29, 30] inactivates part of the Al^{+3} due to increasing pH [17, 19, 29] and also provides a reduction in P retention, increasing the availability in solution [8]. In addition, the higher concentration of P present in solution, may be contributing to inactivate part of Al^{+3} in solution, reducing the toxic effect of this element to plants.

It was observed both on crops and in experiments under conventional tillage, higher responses to P than the liming and lime-phosphorus interaction in lower rates [1, 3, 28]. However, information to evaluate the effects of lime and phosphorus application in the crop development under NTS is still necessary. The objective of this work was to verify the effect of different combinations of lime and phosphorus in the soybean growth under NTS.

Material and Methods

An experiment was conducted in enclosed greenhouse, outdoors, in undeformed soil in columns from a field experiment installed by EMBRAPA Trigo, in a clayey Rhodic Hapludox (Oxisol) [27] located in Passo Fundo, Rio Grande do Sul, Brazil. This area was natural pasture until 1988, when it began to be cultivated in the conventional system with corn (*Zea mays*) and soybean (*Glycine max*) in summer, and oat (*Avena strigosa*) in winter, until 1994. In this year, the experiment was installed in NTS with incorporation (0-20 cm) of 1 (1/24 lime requirement), 6 (1/4 lime requirement) and 24 t ha^{-1} (lime requirement - 1 SMP - pH 6.0) of lime in a randomized block design with four replicates. The area was cultivated until the soil sampling for this work, in the succession oat/soybean/ wheat (*Triticum vulgare*)/corn, receiving by broadcasting the fertilizer recommended by Soil Fertility Commission [6, 7].

For the testing, undeformed soil samples were collected in PVC (polyvinyl chloride) columns of 10 cm (diameter) x 15 cm (height), totaling three columns for plot, between the soybean lines in the field experiment, and were submitted to surface application of equivalent to 0, 40 and 80 kg ha^{-1} P_2O_5 as triple superphosphate. The phosphate fertilizer was ground and sieved (grain size between 1 and 2 mm) to provide a higher reactivity. In the columns ten soybean seeds of variety BR-16, susceptible to Al^{+3} [14], were seeded, and four plants remained in columns after thinning. During the cultivation of plants, the humidity was maintained near to field capacity. The plant harvest was done at 25 days after sowing, when the most developed roots reached the column background.

After cultivation the shoots were collected, and the dry matter was obtained after drying at 65°C for 72 hours. The columns were maintained in a greenhouse under constant temperature (5°C) with the objective of preserve soil and roots until evaluations. Subsequently, the soil was separated from the roots, that were washed, weighed (fresh matter), stored in plastic bags and frozen (-18°C) for later determination of radius, according to equation (r = [mass/length x)π1/2, described by Barber [4]. The root length was determined by Tennant [26] method. In parallel, the soybean yield was obtained from the field plots (data obtained by EMBRAPA Trigo, Passo Fundo, RS).

In soil collected for the characterization of field experiments (0-20 cm) and column (0-15 cm) cultivated with soybeans in a screenhouse total organic carbon, pH-H_2O and exchangeable Ca, Mg and Al (1 M KCl) were determined. The Ca^{+2} and Mg^{+2} were determined with atomic absorption spectrophotometry, Al^{+3} by titration with 0.0125 M NaOH and potassium was extracted by Mehlich-1 and determined with flame photometry [25]. Phosphorus was extracted by Mehlich-1 and determined by colorimetry [15]. The potential acidity, used to calculate base saturation and Al^{+3}, was obtained by the SMP method with the equation proposed by Kaminski *et al.* [13].

Relations were established between soil acidity attributes of the columns, grown under NTS, and the soybean characteristics under different levels of available P. The results were submitted to variance and regression analysis by SANEST program, and means were compared by Tukey test at 5% error.

Results and Discussion

After seven years of liming and cultivation in NTS, there was a wide range in values of soil acidity and concentration of exchangeable calcium, magnesium and aluminium still occurred maintaining the same levels of available P (Mehlich 1) and organic carbon (Table 1). The residual effect of liming was also manifested in soybeans cropped in field, whose yields were affected by the levels of soil acidity (Table 1). The application of P doses in the columns topsoil provided a quadratic increase in concentration of available phosphorus regardless of soil acidity level (Fig. 1a); however, there was a tendency for higher P concentration with the decreasing soil acidity. The P addition, in turn, only resulted in a trend of pH increasing under conditions of high soil acidity and a declining trend for the lower acidity condition (Fig. 1b). Simultaneously there was a reduction in the Al^{+3} concentration and saturation (Fig. 1c-d) and a trend of increasing Ca saturation (Fig. 1f) and exchangeable Ca (Fig. 1e) in condition of more acidity (pH 4.0 , 1 t ha^{-1} of lime).

Addition of phosphate fertilizers to soil, in NTS, dislodges the other adsorbed anions and a higher P adsorption on the soil exchange sites, and thus P remains in available form for more time in the soil. The surface accumulation of P can result in formation of low solubility compounds [$AlPO_4$; $Al(OH)\cdot 2H_2PO_4$] that

Table 1. Chemical attributes in soil layer (0 - 20 cm) and soybean grain yield in a Rhodic Hapludox (Oxisol) cultivated under no-tillage for seven years after application of lime rates (EMBRAPA Trigo, Passo Fundo, RS).

Chemical attributes and soybean grain yield	Lime rates applied in 1994 (t ha^{-1}) 1.0		6.0		24[(3)]	
pH – H_2O	4.0	C	4.6	B	6.4	A
Exchangeable Ca ($cmol_c$ kg^{-1})	0.64	C	2.58	B	6.98	A
Exchangeable Mg ($cmol_c$ kg^{-1})	0,22	C	1.78	B	4.64	A
Available K - Mehlich 1 (mg kg^{-1})	55	A	49	A	46	A
Exchangeable Al ($cmol_c$ kg^{-1})	3.4	A	1.3	B	0.0	C
CEC [(1)] ($cmol_c$ kg^{-1})	24.93	A	16.11	B	14.20	C
Bases saturation (%)	4	C	28	B	83	A
Al saturation (%)	78	A	22	B	0.1	C
Available P - Mehlich 1 (mg kg^{-1})	27	A	27	A	24	A
Organic carbon (g kg^{-1})	30	A	29	A	29	A
Soybean grain yield [(2)] (t ha^{-1})	1.51	C	3.67	B	4.49	A

(1) cation exchange capacity, based on the potential acidity given by the equation proposed by Kaminski *et al.* [13].
(2) Means followed by the same letter in row are not statistically different (Tukey P <0.05).
(3) Lime requirement – 1 SMP – pH 6.0

precipitate [19], based on their chemical activity [12] and thus contribute to inactivate part of soil solution aluminium [17, 29, 31]. Furthermore, increasing P can promote the displacement of hydroxide (OH^-) ions to solution, due to the phosphorus preference on the surface of hydrated oxides of iron and aluminium which also contribute to the Al^{+3} neutralization in soil solution [20, 29]. This may be one reason for the low or even lack of response to liming in NTS in soils with low water pH (≤5.0) in classes with high [3] or very high [2] available P. Higher concentration of exchangeable calcium on the soil surface in NTS (Table 1) can also reduce the Al^{+3} phytotoxic effect for its physiological protective action and also may remove P solution by forming calcium phosphate as $CaHPO_4$ and CaH_2PO_4 [19], as suggested in Fig. 1c, under high calcium and pH conditions.

The decrease in soil acidity (Table 1), due to the residual liming effect, and the P increase (Fig. 1a), due to P addition, increases (simple effects) the shoots and roots dry matter production and the soybean root length and a decreasing trend of radius (Table 2). The effects of phosphorus-lime interactions occurred in shoot dry matter production and in the root length (Table 3), with very similar behavior. The root system, particularly its morphology, is the plant part that best reflects, in a short-term, the effects of soil acidity [18, 21], but also be very important in P bioavailability [4], the root length was used as a referential parameter for interpreting the lime-phosphorus relations in this work.

In the most acid treatments (1 t ha^{-1} of lime) and 80 kg P_2O_5 ha^{-1}, the root length was similar to that obtained in treatment of intermediate acidity (6 t ha^{-1} of lime) and 40 kg P_2O_5 ha^{-1} (Table 3). This indicates that P fertilization can neutralize part of the Al^{+3} [19]. Moreover, it was observed that the higher root length response to P addition occurred at higher acidity (1 t ha^{-1} of lime), while in lower acidity treatments, the P response was lower. According to Goepfert and Freire [11], the lower plant response to P under conditions of low acidity, characterizes replacement ratio between the two inputs. Silva *et al.* [24] observed the phosphorus applied on seedling stage increased oil content and a thousand grain mass and consequently also increased crambe yield in two cropping years.

The interaction effects of liming-phosphorus in soybean root length, to the main indicators of acidity affected by liming, are characterized by a lack of parallelism between the adjusted curves

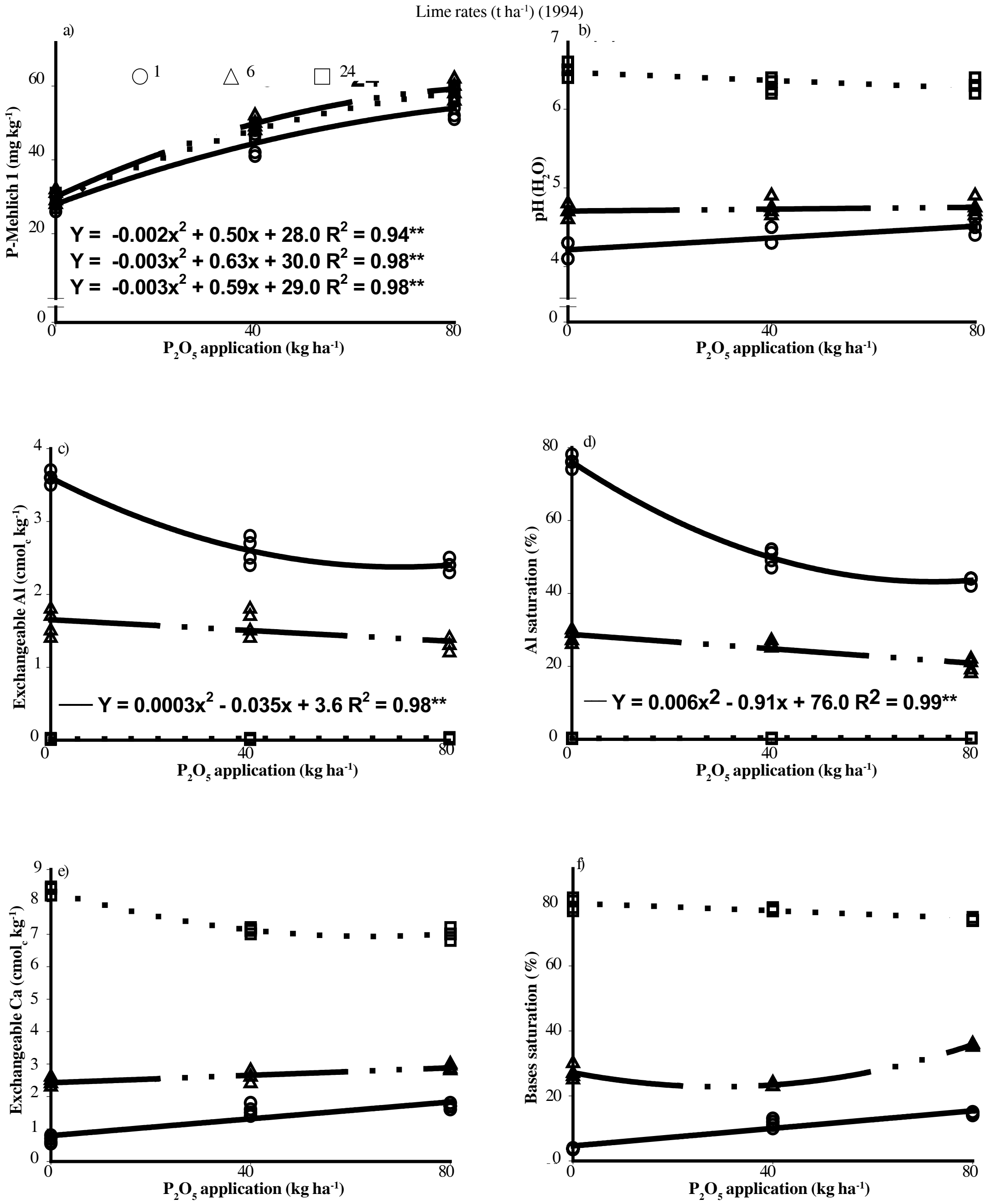

Figure 1. Chemical attributes affected by P addition in a Rhodic Hapludox (Oxisol) columns, previously cultivated under no-tillage for seven years after application of lime rates: a) Available phosphorus, b) pH-H_2O, c) exchangeable aluminium, d) Al saturation, e) exchangeable calcium, f) bases saturation.

Table 2. Growth attributes of soybean cultivated in soil columns, affected by liming (1994) and by phosphorus application, in a Rhodic Hapludox (Oxisol) cultivated under no-tillage for seven years after application of lime rates.

Soybean attributes	pH-H_2O			P_2O_5 application, kg ha^{-1}		
	4.0	4.6	6.4 [(1)]	0	40	80
Shoot: Dry matter, g plant^{-1}	0.46b	0.67a	0.68a	0.52c	0.61b	0.69[a]
Root: Dry matter, g plant^{-1}	0.21c	0.30b	0.33a	0.23c	0.28b	0.32a
Length, m plant^{-1}	13.2b	17.2b	19.0a	12.5c	16.6b	20.4a
Radius, mm	0.16a	0.13a	0.14a	0.15a	0.14a	0.13a

[1] Lime requirement – 1 SMP – pH 6.0.
Means followed by the same letter in row, within the pH and P_2O_5 levels, are not statistically different (Tukey P <0.05).

Table 3. Dry matter production and soybean root length, affected by liming (1994) and by phosphorus application, in a Rhodic Hapludox (Oxisol) cultivated under no-tillage for seven years after application of lime rates.

P_2O_5 application	pH – H_2O 4.0	4.6	6.4 (1 SMP –pH 6.0)
kg ha^{-1}		Shoot dry matter, g plant^{-1}	
0	0.34 Cb	0.61Ba	0.61Ca
40	0.47 Bb	0.66 Ba	0.69 Ba
80	0.57 Ab	0.74 Aa	0.75Aa
		Root length, m plant^{-1}	
0	8.6 Bb	14.9 Ba	14.0 Ca
40	13.9 Ab	15.5 ABa	19.2 Ba
80	17.1 Ab	20.2 Aa	23.81 Aa

Means followed by the same letter in row, are not statistically different (Tukey P <0.05) for phosphorus rates in pH-H_2O levels; means followed by the same letter in column, are not statistically different (Tukey P <0.05) for pH-H_2O rates in phosphorus levels.

(Fig. 2). Thus, it is possible to establish different combinations of chemical attributes related to acidity and P added, resulting in similar root growth. For example, it is possible to obtain like root length in treatment with intermediate acidity (6 t ha^{-1}), when the exhangeable aluminium, Al^{+3} saturation and base saturation were around 1.5 kg cmol$_c$kg^{-1}, 28% and 30%, respectively, and at higher acidity (1 t ha^{-1}) combined with 40 kg P_2O_5 ha^{-1} when the exhangeable aluminium, Al^{+3} saturation and base saturation were around 2.5 cmol$_c$ kg^{-1}, 50% and 15%, respectively (Fig. 2).

Moreover, the largest effect of P application occurred at lower acidity conditions, that is, with high water pH, low exchangeable aluminium and Al^{+3} saturation and high base saturation (Fig. 2). This ocurred by the stimulating effect of phosphorus on soybean root growth [4], under this acidity conditions. Major effect of different levels of acidity, in turn, occurred when phosphorus was not applied; and decreased with increasing P doses. The P interference, neutralizing the effect of Al^{+3}, characterizes the relation between the residual effect of lime and recent P addition, where high doses of one input reduce the efficiency of another.

The reduction of exchangeable aluminium and Al^{+3} saturation, due to P application (Fig. 1), may have occurred, as previously shown, by complexation between Al^{+3} and a part of phosphorus, from fertilization [28, 30], leading to the formation of $Al(OH)_2H_2PO_4$, which precipitates, decreasing the Al^{+3} activity in solution [9]. In addition, in NTS, there is a surface accumulation of organic material and nutrients, which can also reduce the Al^{+3} activity, due to its complex and/or precipitation, improving conditions for plant growth.

Conclusions

Phosphorus available increased with decreasing soil acidity by liming. A higher soybean growth was obtained with P application in low acidity conditions. The relation of substitution between lime and phosphate was characterized, in a Rhodic Hapludox under no tillage system, by decreasing of exchangeable aluminum and aluminum saturation when P was applied.

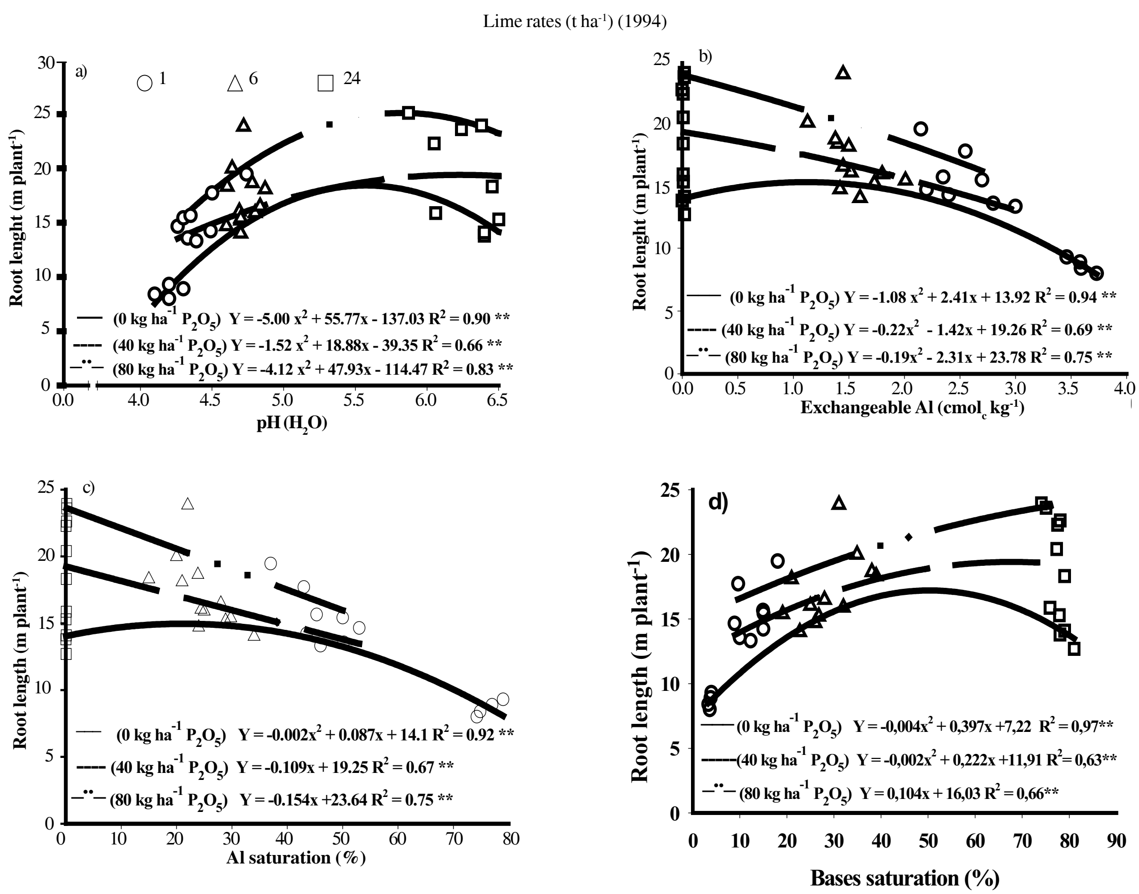

Figure 2. Length ratio of the root system of soybean plants and: a) pH in water, b) Al concentration, c) Al saturation, and d) base saturation affected by liming (1994) and by the phosphorus application, in a Rhodic Hapludox (Oxisol) cultivated under no-tillage for seven years after application of lime rates.

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