Evaluation of Nutrient Status and Grain Yield of Two Corn Cultivars Under Different Soil Aluminum Levels After Liming

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ABSTRACT

This study was conducted to evaluate the effects of decreasing levels of Al saturation through the addition of lime under field conditions in the nutritional status and grain yield of two corn (Zea mays L.) cultivars: one tolerant and one non-tolerant to Al. The experiment was conducted on Red Yellow Latosol (Oxisol) at the Paraná, Brazil. Control plots received no lime (T0), the treatment T3 received lime to achieve 0% Al saturation and treatments T1 and T2 recieved 33.3% and 66.6%, respectively, of the lime applied to treatment T3. At full bloom stage, representative leaves ("nutritional leaves") were analysed for macro, micronutrients and Al contents, and in treatments T0 and T3 were also analyzed for Al distribution in shoot plants parts (stem, node, internode and leaves). Liming increased concentrations of N, P and Mg and decreased concentrations of Mn and Al in the "nutritional leaves"of both cultivars. The Al distribution in the shoot plant parts showed that its concentration was higher in the leaves than in any other plant part, independent of liming level. Grain yield of the tolerant cultivar was higher, although for both cultivars increase in yield was correlated with decrease in Al saturation.

Key words: Aluminum, acid soil, liming, tolerant, *Zea mays*, corn

INTRODUCTION

The presence of aluminum at toxic levels in the soil is one of the most important factors limiting agricultural production in tropical and subtropical climates, being a problem in over 50% of the Brazilian soils (Silva, 1976). Toxic Al symptoms are observed mainly in the roots (McLean & Gilbert, 1927), influencing the nutritional status of the plant as a whole. Al decreases levels of Ca, (Malavolta *et al.*, 1989), Mg (Fahl *et al.*., 1980), P (Ramires &Berengel, 1984), Zn, Mn (Clark, 1977) and Cu (Cambraia *et al.*,1983a) in the shoot parts of cultivated plants, thus affecting crop production (Clark, 1977; Cambraia *et al.*, 1983b; Quaggio *et al.*, 1987). The magnitude of the effects vary with species and cultivars, indicating the probable existence of individual mechanisms for Al tolerance as an adaptation to acidic soil conditions.
The objective of the study was to evaluate the effect of different levels of soil Al toxicity on the grain yield and nutritional status of two corn cultivars: one tolerant and one not tolerant to Al.

MATERIALS AND METHODS

The experiment was conducted at the Centro de Estações Experimentais - UFPR - Paraná, Southern Brazil (49 º 08' W; 25 º 25' S and 930 m of altitude).The average annual precipitation is 1500 mm with máximum temperature of 24ºC and minimum of 12ºC. The soil was classified as a Red-Yellow Latosol (Oxisol), whose chemical and physical characteristics are shown in Table 1.
The treatments arranged in a randomized complete block design, with four replications, consisted of four liming levels (dolomitic lime) applied to the soil prior to corn sowing. The cultivars used were HS7777 (non-tolerant to Al) and C525 (tolerant to Al) (Furlani & Hanna, 1984 and Furlani, 1993). 12, 90 and 30 kg ha^{-1} of N, P_2O_5 and K_2O, respectively, were applied at the furrow slice. Supplementary fertilizer (30 kg ha^{-1} of N and 15 kg ha^{-1} of K_2O) was added the soil 30 days after seed germination and at 60 days, 30 kg ha^{-1} of N. The liming levels were calculated through the construction of a calibration curve. The control treatment (T0) received no lime, and the highest

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level of liming (T3) was calculated so that the soil achieved 0% Al saturation (10.5 t $MgCaCO_3$ ha^{-1}). Treatments T1 and T2 received 33.3% and 66.6%, respectively, of the lime applied to T3. Table 2 presents the soil chemical analysis after treatment applications, at sowing and after harvest. The pH was determined by $CaCl_2$ 0,01M (1:2,5) method, H+Al by SMP, Ca,Mg and Al by KCl 1N (1:10) with EDTA 0,0125M titulation for Ca and Mg and NaOH 0,025N titulation for Al. K and P were determined by the Mehlich 1 (1:10) method, acording to EMBRAPA (1979).

At full bloom stage the first leaf bellow and opposite to the corn ear (chosen as representative of the plant nutritional status) of 20 random plants in each plot was harvested. A composit sample of the central part of these so called "nutritional leaves" was submitted to a 100 g/dm^3 HCl digestion and analyzed for N, P, K, Ca, Mg, Fe, Mn, Cu, Zn, B and Al content. The N was determined by the Kjeldahl digestion method, P and B by colorimetry and the remaining elements by atomic absorption spectrophotometry. Three whole plants in treatments T0 and T3 were also analysed for Al distribution in the stem, node, internode and leaves. At the physiological maturity stage, the plants were harvested and the grain yield was measured.

All data were subjected to analysis of variance to determine treatments and interaction effects. Relationships between liming levels and nutrient content of the "nutritional leaves" , and grain yield were analyzed by means of linear regression. Correlation tests were performed between foliar nutrient content and soil pH and Al saturation.

RESULTS AND DISCUSSION

Different liming levels did not affect significantly the concentrations of K, Ca, Zn, Cu and B in the "nutritional leaves" of both cultivars. The tolerant cultivar had significantly higher levels of all nutrients, except for Ca (Table 3). Only concentration in the tolerant "nutritional leaves" showed a significant correlation with soil pH (r = 0.64) and soil Al saturation (r = -0.64). This indicates a possible relationship between Ca absorption and Al tolerance, as suggested by Foy & Brown (1963) and Foy & Fleming (1978).

Table 1 - Chemical and physical characteristics of the soil prior to the instalation of the experiment.

Depth	pH	Al	H+Al	Ca	Mg	K	P	O.M.	Sand	Silt	Clay
cm	$CaCl_2$ 0,01M	mmol$_c$ dm^{-3}					mg kg^{-1}	mg dm^{-3}	%		
00-20	4.4	44	128	13	13	1.3	1	94	16.8	27.2	56.0
20-40	4.4	47	139	07	05	0.6	1	49	18.4	21.6	60.0

Table 2 - Average chemical characteristics of the soil (0-15 cm) at sowing (So-11/93) and after harvest (Ha-6/94).

Treatment		pH	Ca	Mg	Al	K	P	O.M.	Al
		$CaCl_2$	mmol$_c$ dm^{-3}				mg dm^{-3}	g dm^{-3}	%
T0	So	4.2	19	15	36	2.5	3.3	95	50.4
	Ha	3.9	13	11	51	1.9	3.9	78	66.4
T1	So	4.5	40	27	15	2.3	3.3	95	17.9
	Ha	4.4	46	27	23	1.9	3.4	86	24.8
T2	So	4.4	53	42	05	2.9	3.0	98	4.7
	Ha	4.7	58	46	08	2.0	3.4	87	7.6
T3	So	4.8	52	41	04	2.2	2.8	89	4.6
	Ha	5.2	83	58	01	1.6	3.1	81	1.0

Table 3 - Average of K, Ca, Zn, Cu and B nutritional leaves of the tolerant (C 525) and non-tolerant (HS 7777) corn cultivars to Al.

Cultivars*	K	Ca	Mg	Zn	Cu	B
	..................g dm^{-3}	....		.................mg dm^{-3}	....	
HS7777**	12.0 b	3.3 a	2.44 b	23.30 b	11.28 b	11.75 b
C525**	20.6 a	3.4 a	2.82 a	42.85 a	14.55 a	13.56 a

* - means in each column followed by the same letter are not significantly different (*P*=0,05).
** - average to 16 replications

Mg levels in the "nutritional leaves" of both cultivars increased with liming (Fig.1). The average Mg content of the tolerant cultivar was higher (Table 3), mainly in treatments with lower Al in the soil (T2 and T3). This is an important result, once this difference among tolerant and non-tolerant cultivars has not been observed in nutrient solution experiments (Ramirez & Barengel, 1984; Cambraia *et al.*, 1983a).

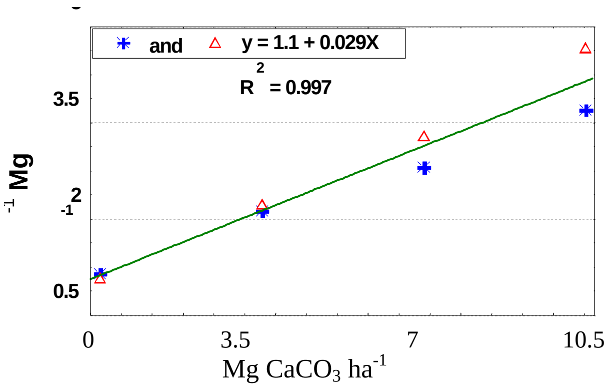

Figure 1 - Average concentration of Mg in the "nutritional leaves" of the tolerant (Δ) and non tolerant (*) corn cultivars as affected by increasing liming quantity.

Only N content of the tolerant cultivar which was consistently higher than that of the non-tolerant cultivar (Fig 2), was considered satisfactory for corn growth (Malavolta *et al.*, 1989). A significant negative correlation was found between Al saturation in the soil and N content in the leaves of the tolerant cultivar (r = -0.78), which seemed to be more efficient in absorbing this element.

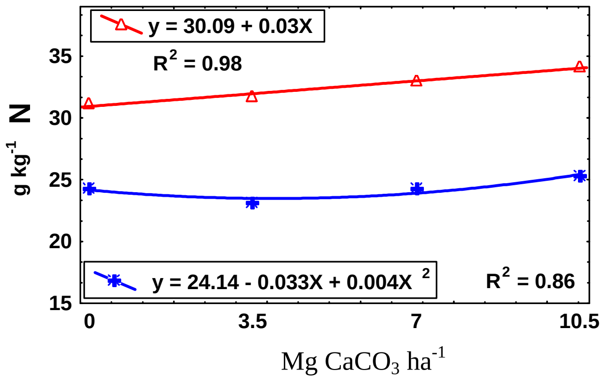

Figure 2 - Average concentration of N in the "nutritional leaves" of the tolerant (Δ) and non tolerant (*) corn cultivars as affected by increasing liming quantity.

The tolerant cultivar also showed higher absorption of P (Fig. 3). Foliar levels of P were significantly correlated with pH (r = 0.86), soil Al saturation (r = -0.80) and corn production (r = 0.80), which suggest a possible relationship between Al tolerance and P absorption and translocation ability of the cultivar (Ramirez & Berengel,1984).

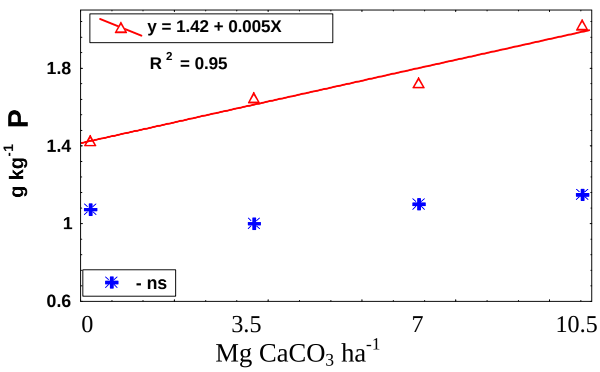

Figure 3 - Average concentration of P in the "nutritional leaves" of the tolerant (Δ) and non tolerant (*) corn cultivars as affected by increasing liming quantity. ns - not significant – 5 %.

Addition of lime resulted in higher Fe content only in the tolerant cultivar (Fig. 4). Such a difference between cultivars was not observed by Clark (1977) or Cambraia *et al.* (1983a), working with nutrient solution.

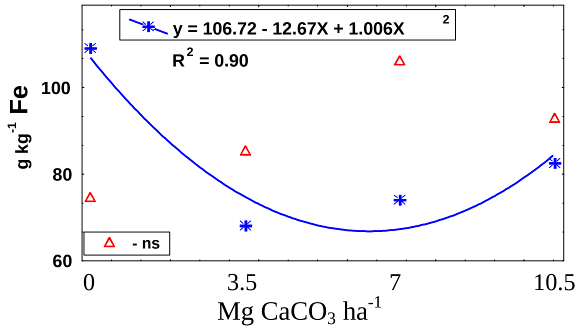

Figure 4 - Average concentration of Fe in the “nutritional leaves” of the tolerant (Δ) and non tolerant (*) corn cultivars as affected by increasing liming quantity. ns - not significant – 5 %.

Levels of Mn decreased with liming for both cultivars (Fig. 5). Foliar Mn was negatively correlated with levels of lime (r=-0,60 in tolerant and r=-076 in non-tolerant) demonstrating the lime effect in decreasing Mn availability for plant uptake (Fassbender,1982; Ritchey *et al.*, 1982, Quaggio, 1989). Clark (1977) and Cambraia *et al.* (1983 a) observed an inverse behavior in corn cultivars growing in nutrient solution, possibly because of competition between Al and Mn for absorption sites (Alan & Adams, 1979). Significant negative correlations were found between Mn x Ca (r = -0.77) and Mn x Mg (r = -0.73) for the tolerant cultivar, and only between Mn x Mg (r = -0.66) for the non-tolerant cultivar, showing the same compensation effect in cation absorption (Marschner,1986).

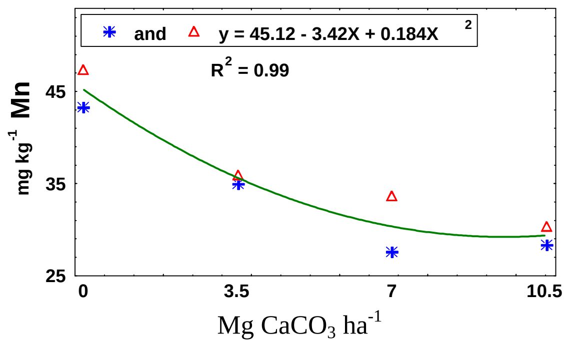

Figure 5 - Average concentration of Mn in the “nutritional leaves” of the tolerant (Δ) and non tolerant (*) corn cultivars as affected by increasing liming quantity.

Increase in liming decreased Al concentration in the “nutritional leaves” of both cultivars due to the decrease in exchangeable Al in the soil (Fig. 6). The Al distribution in the shoot plant parts (Fig. 7), however, showed that the concentration of the element was higher in the leaves than in any other plant part, independent of the liming and/or Al neutralization in the soil. The concentration in all plant parts, except the nodes of the tolerant cultivar, decreased with the lime.

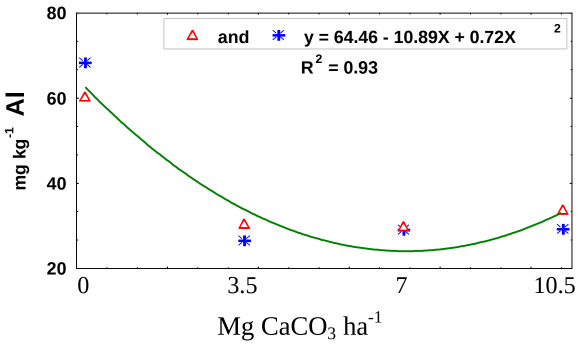

Figure 6 - Average concentration of Al in the “nutritional leaves” of the tolerant (Δ) and non tolerant (*) corn cultivars as affected by increasing liming quantity.

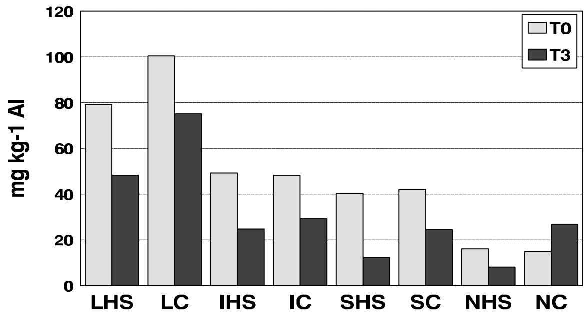

Figure 7 - Average Al content in the leaves (L), internodes (I), nodes (N) and stem (S) of the tolerant - C525 (C) and non-tolerant - HS7777 (HS) corn cultivars, according to aluminun saturation of the soil. T0 = no liming; T3 = 10.5 Mg ha^{-1} $CaCO_3$.

Grain yield increased in a linear way with the quantity of lime added, with the tolerant cultivar being more responsive to liming and significantly more productive (Fig.8).

Corn yield was negatively correlated with Al saturation in the tolerant (r=-0.65) as well as non-tolerant (r=-0.69) cultivars, indicating reduction of Al saturation in the soil as one of the possible effects of liming in grain yield.

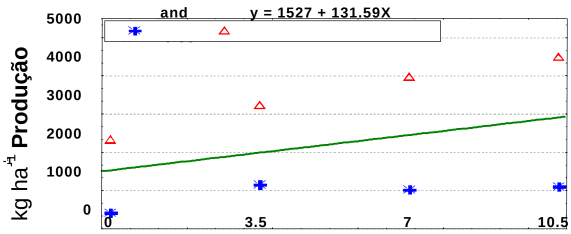

Figure 8 - Average grain yield of both cultivars as a function of liming. ΔTolerant cultivar-C525; * Non tolerant cultivar-HS7777.

RESUMO

Este estudo teve o objetivo de avaliar o efeito de níveis decrescentes de saturação por Al em função da calagem, em condições de campo, na nutrição e produtividade de grãos de dois cultivares de milho: um tolerante e outro sensível ao Al. O experimento foi conduzido em um Latossolo Vermelho-Amarelo (Oxisol), no estado do Paraná - Brasil. O tratamento T0 não recebeu calagem, o tratamento T3 recebeu calagem para obter 0% de saturação por Al e os tratamentos T1 e T2 receberam 33,3% e 66,6% da quantidade aplicada no T3, respectivamente. No pleno florescimento foram coletadas folhas representativas do estado nutricional ("folhas nutricionais") para análise dos macro e micronutrientes e Al. Nos tratamentos T0 e T3 foi avaliado a distribuição do Al na parte aérea (caule, nó, entre-nó e folhas). A calagem aumentou a concentração de N, P e Mg e diminuiu a de Mn e Al nas "folhas nutricionais" nos dois cultivares. A distribuição do Al na parte aérea mostrou maior concentração nas folhas que nas outras partes da planta, independente da calagem. A produtividade de grãos do cultivar tolerante foi maior, entretanto, para ambos os cultivares, o aumento da produtividade correlacionou-se com o decréscimo da saturação por Al.

REFERENCES

Alan, S. M. & Adams, W. A.(1979), Effects of aluminum on nutrient composition and yield of oats. *J Plant Nutr.*, **1**, 365-375.

Cambraia, J.; Lemos Filho, J. P.; Estevão, M. M. & Oliva, M. A. (1983a), Efeito do alumínio sobre os teores de Mg, Fe, Mn e Cu em sorgo. *Rev. Ceres*, **30**, n. 167, 45-54.

Cambraia, J.; Lemos Filho, J. P.; Oliva, M. A. & Estevão, M. M. (1983b), Efeito do alumínio sobre a fotossíntese em dois cultivares de sorgo. *Rev. Ceres*, **30**, n.167, 55-62.

Clark, R. B. (1977), Effect of aluminum on growth and mineral elements of Al-tolerant and Al-intolerant corn. *Plant and Soil*, **47**: 653-662.

EMBRAPA (1979), *Manual de métodos de análise de solos*. SNLCS, Rio de Janeiro.

Fahl, J. I.; Hiroce, R.; Carelli, M. L. C. & Castro, J. L. de. (1980), Efeitos do alumínio na nutrição, desenvolvimento e produção de cultivares de batatinha (*Solanum tuberosum*, L.). *R. Bras. Ci. Solo*, **4**, 22-26.

Fassbender, H. W. (1982), *Química de suelos, con énfasis en suelos de América Latina*. San José: IICA.

Foy, C. D. & Brown, J. C. (1963), Toxic factors in acid soils: I: Characterization of aluminum toxicity in cotton. *Soil Sci. Soc. Am. Proc.*, **28**: 27-32.

Foy, C.D. & Fleming, A.L.(1978), The physiology of plant tolerance to excess available aluminum an manganese in acid soils. In: JUN, G. A. (ed.). Crop tolerance to subotinal land conditions. Madison: ASA/CSSA/SSSA. p.301-343. (Special Publication; n.32)

Furlani, P.R. (1993) Tolerância de cultivares de milho ao alumínio. In: *Seminário de milho safrinha* (1993: Assis). Resumos. Campinas: Editor. 27-31.

Furlani, P.R. & Hanna, L.G. (1984), Avaliação da tolerância de plantas de arroz e milho ao alumínio em solução nutritiva. *R. bras. Ci. Solo*, **8**, 205-208.

Malavolta, E.; Vitti, G. C. & Oliveira, S. A. (1989), *Avaliação do estado nutricional das plantas*. Piracicaba: Associação Brasileira para Pesquisa da Potassa e do Fosfato.

Marschner, H. (1986), *Mineral nutrition of higher plants*. London: Academic Press.

McLean, F. T. & Gilbert, B. E. (1927), The relative aluminum tolerance of crop plants. *Soil Sci.*, **24,** 163-175.

Quaggio, J. A.; Ishimura, I.; Saes, L. A. & Yanai, K. (1987), Resposta da abobrinha-italiana a doses de calcários com diferentes teores de magnésio em solo orgânico do Vale da Ribeira, *R. Bras. Ci. Solo*, **11**, 167-173.

Quaggio, J.A. (1989) Respostas das culturas à calagem em outros estados. In: Seminário sobre correção da acidez do solo, (2.: 1989: Santa Maria). Anais. Santa Maria: UFSM. 177-199.

Ramirez, R. & Berengel, T. (1984), Influencia del aluminio sobre la acumulacion y distribucion del P, Ca, Mg y Al en lineas de maiz. *Agron. Trop.*, **34**, n.4-6, 143-152.

Ritchey, K. D.; Silva, J. E. & Costa, V. F. (1982), Calcium deficiency in clayey B horizons of savanna oxisols. *Soil Sci.*, **133**, 378-382.

Silva, A. R. (1976), Melhoramento genético para resistência à toxidez de alumínio e manganês no Brasil. Antecedentes, necessidade e possibilidades. *Tópicos para discussão e pesquisa. Cienc. e Cultura*, **28**, 147-149.

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