Revista Brasileira de Ciência do Solo

Division - Soil Processes and Properties | Commission - Soil Chemistry

Boron Leaching Decreases with Increases on Soil pH

Alessandra Aparecida de Sá[(1)] and Paulo Roberto Ernani[(2)*]

[(1)] Universidade do Estado de Santa Catarina, Centro de Ciências Agroveterinárias, Departamento de Solos, Programa de Pós-Graduação em Ciência do Solo, Lages, Santa Catarina, Brasil.
[(2)] Universidade do Estado de Santa Catarina, Centro de Ciências Agroveterinárias, Departamento de Solos, Lages, Santa Catarina, Brasil.

ABSTRACT: Management of boron fertilization depends on the magnitude of B leaching in the soil profile, which varies proportionally with the concentration of B in the soil solution, which, in turn, decreases as the soil pH increases due to the higher sorption of B on soil solid surfaces. The objective of this study was to quantify the effect of liming and rates of B applied to the soil on B leaching. The experiment was carried out in the laboratory in 2012, and treatments consisted of a factorial combination of two rates of liming (without and with lime to raise the soil pH to 6.0) and five rates of B (0, 10, 20, 50 and 100 mg kg^{-1}, as boric acid). A Typic Rhodudalf was used, containing 790 g kg^{-1} clay and 23 g kg^{-1} organic matter; the pH(H_2O) was 4.6. Experimental units were composed of PVC leaching columns (0.10 m in diameter) containing 1.42 kg of soil (dry base). Boron was manually mixed with the top 0.15 m of the soil. After that, every seven days for 15 weeks, 300 mL of distilled water were added to the top of each column. In the percolated solution, both the volume and concentration of B were measured. Leaching of B decreased with increased soil pH and, averaged across the B rates applied, was 58 % higher from unlimed (pH 4.6) than from limed (pH 6.6) samples as a result of the increase in B sorption with higher soil pH. In spite of its high vertical mobility, the residual effect of B was high in this oxisol, mainly in the limed samples where 80 % of B applied at the two highest rates remained in the soil, even after 15 water percolations. Total recovery of applied B, including leached B plus B extracted from the soil after all percolations, was less than 50 %, showing that not all sorbed B was quantified by the hot water extraction method.

Keywords: acid soils, liming, boron fertilization, percolation, soil B.

*** Corresponding author:**
E-mail: paulo.ernani@udesc.br

Received: May 20, 2015
Approved: September 24, 2015

How to cite: Sá AA, Ernani PR. Boron Leaching Decreases with Increases on Soil pH. Rev Bras Cienc Solo. 2016;v40:e0150008.

INTRODUCTION

To assess the mobility of each nutrient in the soil, it is important to determine the frequency and forms of soil fertilizers to be applied in order to increase the efficiency of nutrient utilization by plants as well as to avoid leaching losses, which may contaminate the subsoil and underground waters.

Boron (B) is an essential micronutrient that most frequently limits crop growth and yield in tropical and subtropical soils. In addition, B has the highest vertical mobility in the profile (Oliveira Neto et al., 2009; Souza et al., 2012) because at the pH values normally found in soils this nutrient is predominantly found in the soil solution as $H_3BO_3^0$. This neutral form is chemisorbed with less intensity to soil solid components than its anionic form ($H_4BO_4^-$). Consequently, a significant fraction of soil applied B remains in the soil solution, available for plant uptake, but also susceptible to leaching (Pavan and Correa, 1988; Silva et al., 1995; Rosolem and Bíscaro, 2007; Oliveira Neto et al., 2009).

Besides occurring in the soil as an anion, the chemisorption of B increases with decreased soil acidity (Soares et al., 2005; Rosolem and Bíscaro, 2007) up to pH values near 9.0 (Communar and Keren, 2006). This behavior is similar to the chemical adsorption of cations in the soil. In addition to acidity, some other soil attributes also affect the sorption of B, including mineralogical composition (Alleoni and Camargo, 2000; Azevedo et al., 2001; Soares et al., 2008), texture (Alleoni and Camargo, 2000; Saltali et al., 2005) and the organic matter content (Azevedo et al., 2001; Soares et al., 2008), with consequences on the concentration of B in the soil solution (Steiner and Lana, 2013; Szulk and Rutkowska, 2013). Thus, leaching of B is higher from sandy soils than from clayey soils, especially in regions with high average annual rainfall (Silva et al., 1995; Communar and Keren, 2006), where B may reach the subsoil within a short period of time (Silva et al., 1995).

Recently limed soils, both after calcium carbonate application (Alleoni and Camargo, 2000) and aluminum hydroxide precipitation (Alleoni and Camargo, 2000), have a high capacity to sorb B, via adsorption or precipitation, a phenomenon that seems to decrease over time (Rosolem and Bíscaro, 2007). Most soils from the Brazilian states of Rio Grande do Sul and Santa Catarina are highly buffered, requiring large amounts of limestone to increase the pH (Ernani and Almeida, 1986). Even in this situation, increases on crop yield due to the application of micronutrients to the soil, including B, is rare (CQFSRS/SC, 2004). For this reason, few trials have been conducted in these soils to study the dynamics of micronutrients, including mobility and leaching. The objective of this experiment was to evaluate the influence of both liming and the rate of B applied on the leaching of B in an acidic clayey soil from southern Brazil.

MATERIALS AND METHODS

The experiment was conducted in the laboratory at Santa Catarina State University in Lages, southern Brazil, in 2012. Samples of a *Nitossolo Vermelho Distroférrico* (Santos et al., 2013), a Typic Rhodudalf (Soil Survey Staff, 2014), were taken from a 0.30-m deep layer in a native grass field that had never been cropped or fertilized. The soil contained 790 g kg^{-1} clay and 23 g kg^{-1} organic matter, and the pH(H_2O) was 4.6.

Treatments were arranged in a completely randomized experimental design, with three replications. The design was factorial, involving two rates of lime application (with and without) and five rates of B, corresponding to 0, 10, 20, 50 and 100 mg kg^{-1}, applied as boric acid. Finely ground dolomitic limestone was used to increase the soil pH(H_2O) to 6.5. After liming, all samples were incubated for four months before the beginning of percolations.

Experimental units were PVC leaching columns, made from tubes 0.30 m long and 0.10 m in diameter, containing 1.42 kg of soil (dry base). A PVC cap containing a 3-mm central hole was adjusted at the bottom of each tube in order to drain the percolated solution directly into collecting bottles. The lower 0.25 m of each column was filled with soil, without compaction, and the superficial 0.05 m was free of soil to facilitate water addition during the percolation procedure. Boron was homogeneously incorporated into the top 0.15 m of soil, using a boric acid solution.

Columns were placed in longitudinal wooden supports to allow the placement of the collecting bottles below them. Percolations began a week later and were performed weekly for 15 weeks. For each percolation, 300 mL of distilled water was added to the soil surface. Considering the surface area of 0.0078 m^2 (0.10 m diameter), the amount of water added was equivalent to irrigation of 38 mm per event, totaling 570 mm in the entire experimental period. The percolated solution was collected the next day, to determine the volume and concentration of B using the method described by Tedesco et al. (1995).

Boron in the soil was determined in the samples after the end of all percolations. It was extracted by the hot water procedure in a digestion block adjusted to 140 °C, for 9 min, using 5 g of soil and 12.5 mL of distilled water. After cooling down to room temperature, samples were centrifuged for 15 min at 2,000 rpm, and 5 mL aliquots were used to quantify B by colorimetry, using curcumin, according to Tedesco et al. (1995).

The percentage of B recovered in each treatment was calculated by summing leached B and B in the soil determined after all percolations, relative to the amount of B applied.

Data were statistically analyzed through ANOVA, using the SAS package. Cumulative B leaching among B rates were compared through Tukey test. Comparisons of B leaching as well as B in the soil as affected by B rates in the presence or absence of liming were evaluated through regression curves by the F-test ($p<0.05$).

RESULTS AND DISCUSSION

The amount of leached B decreased with liming. Treatments with no lime had higher leaching than limed soils, and the absolute difference between them decreased with increased rates of B applied. Averaged across the B rates, B leaching was 58 % higher at pH 4.6 than at pH 6.0 (Figure 1), mainly due to the highest B sorption in treatments with higher acidity (Alleoni and Camargo, 2000), which results in less B in the soil solution (Elrashidi and O'Connor, 1982; Cruz et al., 1987; Goldberg et al., 1993; Soares et al., 2008). In our study, at a rate of 20 mg kg^{-1} B, the difference in leaching caused by liming was 122 %, while at a rate of 100 mg kg^{-1} B, it was 44 % (Figure 1). This decrease was probably due to an increase in B saturation at exchange sites with increased B applied. Hidrogen ions compete with borates for sorption sites in soil; thus, as the concentration of H^+ in the soil solution decreases, more anions of B migrate from the soil solution to specific adsorption sites in the solid components, both organic and inorganic, constituted by functional hydroxylated groups (Goldberg, 1997). Additionally, the relative proportions of $H_3BO_4^-$ and H_3BO_3 in the soil solution increases as the soil pH rises (Evans, 1987), and $H_3BO_4^-$ is sorbed with much higher intensity than H_3BO_3. In soils with a pH below 7.0, however, H_3BO_3 is the predominant form of B in the soil solution, which is highly susceptible to leaching (Silva et al., 1995; Quaggio et al., 2003). Increases in B sorption up to 33 % following the liming of some soils in São Paulo state, Brazil, were observed by Alleoni and Camargo (2000).

The total amount of B leached increased with increased amounts of B applied to the soil, regardless of soil pH (Figures 1 and 2). Averaged across unlimed treatments, 26 % of the applied B was leached after 15 percolations with distilled water; in the limed treatments,

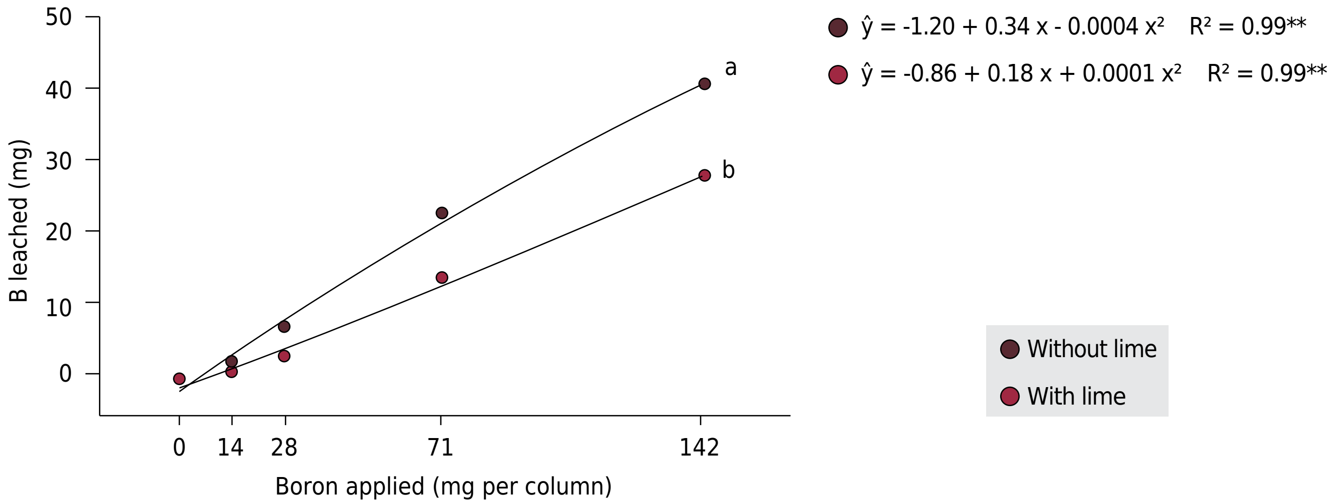

Figure 1. Total amount of boron leached after 15 percolations with distilled water as affected by liming and rates of boron applied. Average of three replications. Regression curves followed by different letters differ by the F-test at the 5 % significance level. **: significant at 1 %.

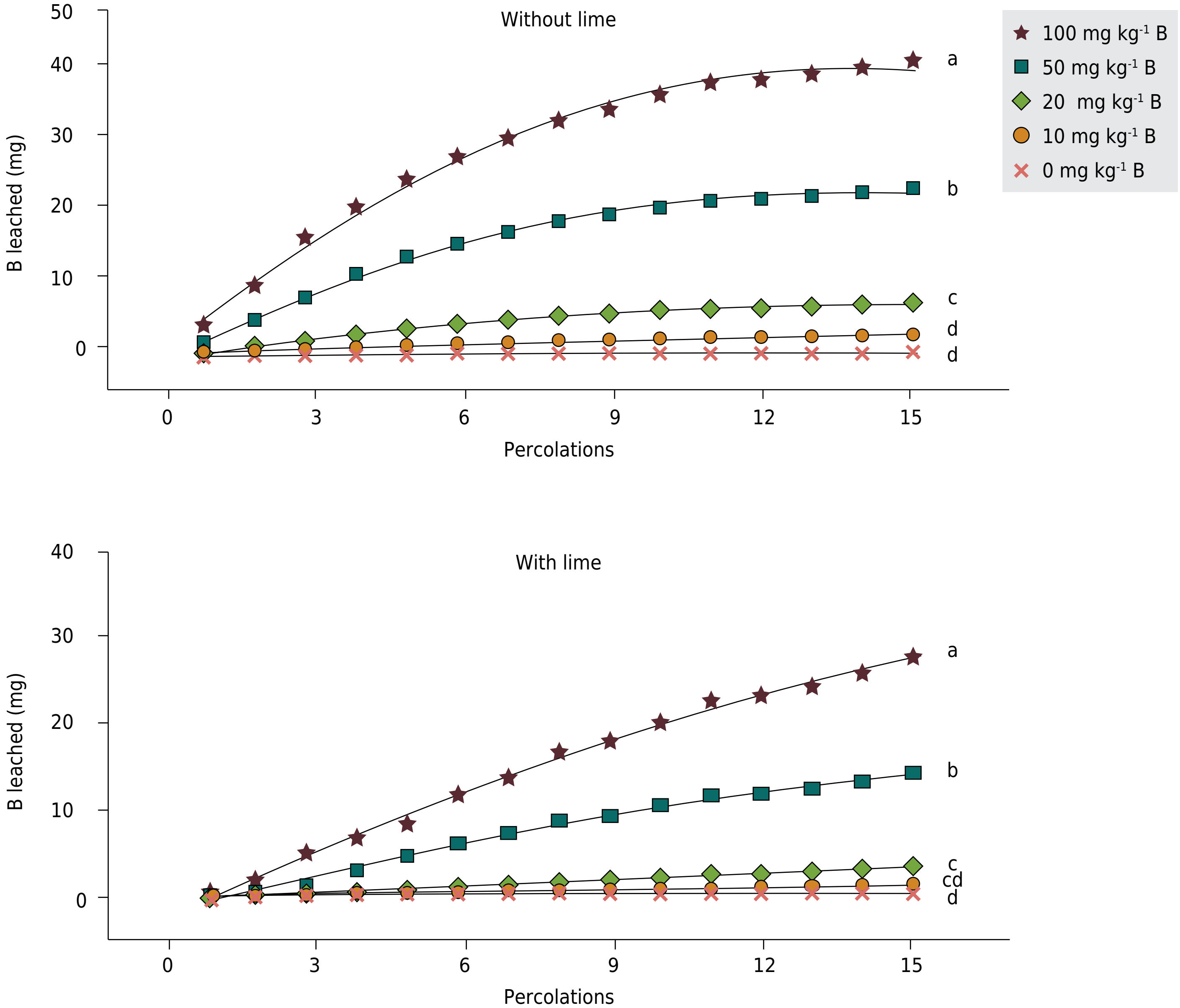

Figure 2. Cumulative boron leached during 15 percolations with distilled water as affected by liming and rates of boron applied. Average of three replications. Total cumulative values followed by the same letter are not different by the Tukey test at the 5 % significance level.

however, only 15 % were leached (Figure 1). Thus, besides the reasonable mobility of B in soils (Oliveira Neto et al., 2009), its residual effect in this Oxisol was high because more than 70 % of the applied B still remained in the soil after all percolations, which corresponded to 570 mm of irrigation distributed in 15 weekly events.

The rate of B leaching decreased slightly as the percolation events proceeded, regardless of the soil pH (Figure 2), especially in the absence of lime. In the limed treatments, the amount of leached B increased almost linearly up to the last percolation, regardless of the rate of B applied (Figure 2).

The percentage of leached B increased up to a rate of 50 mg kg^{-1} B applied, regardless of the soil pH (Table 1), due to a progressive increase in saturation sites occupied by B. In the unlimed treatments, leached B increased from 18 % at a rate of 10 mg kg^{-1} B up to 28 % at a rate of 50 mg kg^{-1}; in the treatments that received lime, leached B increased from 8 to 20 %, respectively. In the present study, adsorption isotherms were not performed, which could show the maximum capacity of B adsorption (MCBA) by the soil. In some soils from Paraná state, Brazil, which are very similar to the soil used in the present study, MCBA is up to 50 mg kg^{-1} (Steiner and Lana, 2013), but in some soils from São Paulo state, however, MCBA is only 11 mg kg^{-1} (Alleoni and Camargo, 2000). At the highest rate applied in this study (100 mg kg^{-1} B), even considering that B was mixed with only 60 % of the soil volume of each column, the amount added would be larger than the MCBA, and even so, less than 30 % of the applied B was leached (Table 1). A positive relationship between leached B and B in the soil, and leached B and the rate applied, but not between leached B and the addition of lime were also found by Rosolem and Bíscaro (2007).

Table 1. Concentration of boron in the soil after all 15 percolations, total boron leached and total boron recovered, as affected by liming and the rate of boron addition to the soil

B added	B leached		B leached		B recovered	
	Without lime	With lime	Without lime	With lime	Without lime	With lime
mg kg^{-1}	mg kg^{-1}		% of applied		% of total applied	
0	0.1	0.1	-	-	-	-
10	1.8	0.8	17.7	7.9	43	34
20	5.1	2.3	25.3	11.4	46	28
50	15.8	9.7	31.7	19.5	43	37
100	28.1	19.4	28.1	19.4	38	35

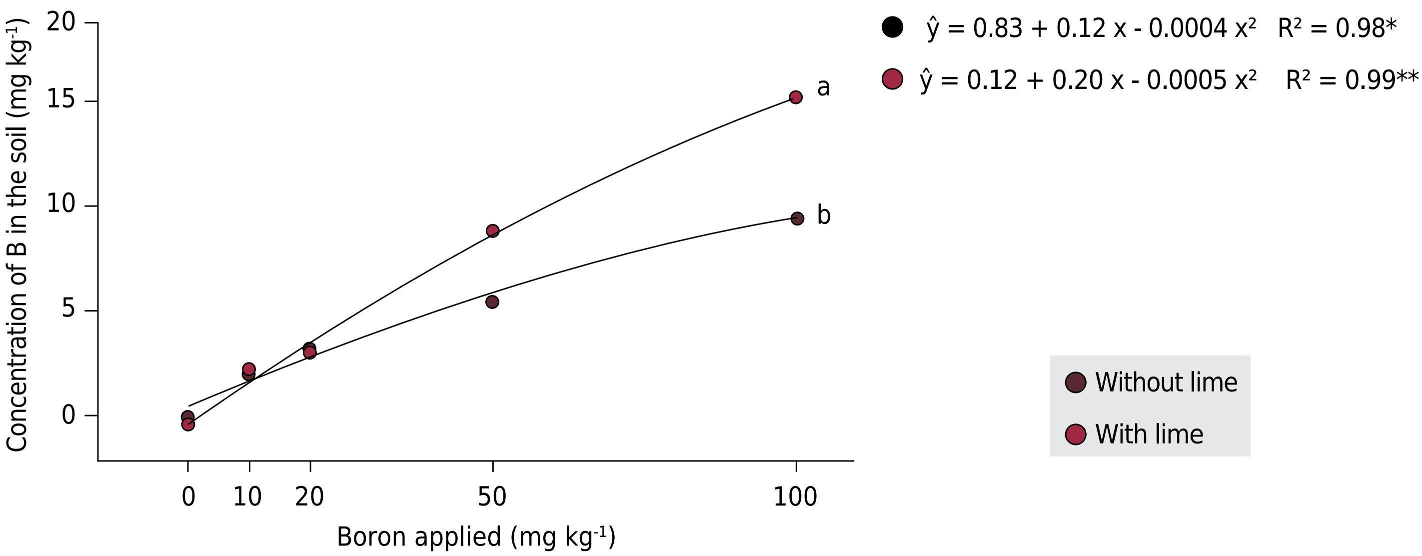

Figure 3. Concentration of boron in the soil after 15 percolations with distilled water as affected by liming and rates of boron applied. Average of three replications. Regression curves followed by different letters differ by the F-test at the 5 % significance level. **: significant at 1 %.

The concentration of B in the soil, determined after all percolations, increased quadratically with increases in the amount applied. The values were higher in limed than in unlimed treatments (Figure 3) due to the lower leaching of B from soils treated with lime relative to those to which lime had not been applied (Figure 1).

The amount of total B recovered was lower than 50 %, and it was not influenced by the rate applied (Table 1). At a rate of 50 mg kg^{-1} B, the amount of leached B plus B in the soil, determined after all percolations using the hot water method, varied from 37 % with lime to 43 % in the absence of lime (Table 1).

CONCLUSIONS

Leaching of B increased with increases in the rate of B applied, and was lower in limed than in unlimed treatments. However, despite the reasonable mobility, the residual effect of B applied to soil was high regardless of the soil pH.

The mean recovery of boron, including leached B and B in the soil after all percolations, was less than 50 % of the amount of B applied, showing that the hot water methodology does not quantify all B sorbed by soil.

REFERENCES

Alleoni LRF, Camargo OA. Boron adsorption in soils from the State of São Paulo, Brazil. Pesq Agropec Bras. 2000;35:413-21. doi:10.1590/S0100-204X2000000200020

Azevedo RA, Faquin V, Fernandes LR. Adsorção de boro em solos de várzea do Sul de Minas Gerais. Pesq Agropec Bras. 2001;36:957-64. doi:10.1590/S0100-204X2001000700005

Comissão de Química e Fertilidade do Solo - CQFSRS/SC. Manual de adubação e calagem para os estados do Rio Grande do Sul e Santa Catarina. Porto Alegre: Sociedade Brasileira de Ciência do Solo/Núcleo Regional Sul; 2004.

Communar G, Keren R. Rate-limited boron transport in soils: the effect of soil texture and solution pH. Soil Sci Soc Am J. 2006;70:882-92. doi:10.2136/sssaj2005.0259

Cruz MCP, Nakamura AM, Ferreira ME. Adsorção de boro pelo solo: efeito da concentração e do pH. Pesq Agropec Bras. 1987;22:621-6.

Elrashidi MA, O'Connor GA. Boron sorption and desorption in soils. Soil Sci Soc Am J. 1982;46:27-31. doi:10.2136/sssaj1982.03615995004600010005x

Ernani PR, Almeida JA. Comparação de métodos analíticos para avaliar a necessidade de calcário dos solos do Estado de Santa Catarina. Rev Bras Cienc Solo. 1986;10:143-50.

Evans LJ. Retention of boron by agricultural soils from Ontario. Can J Soil Sci. 1987;67:33-42. doi:10.4141/cjss87-003

Goldberg S, Forster HS, Heick EL. Boron adsorption mechanisms on oxides, clay minerals and soils inferred from ionic strength effects. Soil Sci Soc Am J. 1993;57:704-8.

Goldberg S. Reactions of boron with soils. Plant Soil. 1997;193:35-48. doi:10.1023/A:1004203723343

Oliveira Neto W, Muniz AS, Silva MAG, Castro C, Borkert CM. Boron extraction and vertical mobility in Paraná State Oxisol, Brazil. Rev Bras Cienc Solo. 2009;33:1259-67. doi:10.1590/S0100-06832009000500019

Pavan MA, Correa AE. Reações de equilíbrio solo-boro. Pesq Agropec Bras. 1988;23:261-9.

Quaggio JA, Mattos Junior D, Cantarella H, Tank JA. Fertilização com boro e zinco no solo em complementação à aplicação via foliar em laranjeira Pêra. Pesq Agropec Bras. 2003;38:627-34. doi:10.1590/S0100-204X2003000500011

Rosolem CA, Bíscaro T. Adsorção e lixiviação de boro em Latossolo Vermelho-Amarelo. Pesq Agropec Bras. 2007;42:1473-8. doi:10.1590/S0100-204X2007001000015

Saltali K, Bilgili AV, Tarakcioglu C, Durak A. Boron adsorption in soils with different characteristics. Asian J Chem. 2005;17:2487-94.

Santos HG, Jacomine PKT, Anjos LHC, Oliveira VA, Lumbreras JF, Coelho MR, Almeida JA, Cunha TJF, Oliveira JB. Sistema brasileiro de classificação de solos. 3ª. ed. Brasília, DF: Embrapa; 2013.

Silva NM, Carvalho LH, Kondo JI, Bataglia OC, Abreu CA. Dez anos de sucessivas adubações com boro no algodoeiro. Bragantia. 1995;54:177-85. doi:10.1590/S0006-87051995000100020

Soares MR, Alleoni LRF, Casagrande JC. Parâmetros termodinâmicos da reação de adsorção de boro em solos tropicais altamente intemperizados. Quim Nova. 2005;28:1014-22. doi:10.1590/S0100-40422005000600016

Soares MR, Alleoni LRF. Casagrande JC. Adsorção de boro em solos ácricos em função da variação do pH. Rev Bras Cienc Solo. 2008;32:111-20. doi:10.1590/S0100-06832008000100011

Soil Survey Staff. Keys to soil taxonomy. 12th.ed. Washington, DC: United States Department of Agriculture, Natural Resources Conservation Service; 2014.

Souza TR, Villas Bôas RL, Quaggio JA, Salomão LC, Foratto LC. Dinâmica de nutrientes na solução do solo em pomar fertirrigado de citros. Pesq Agropec Bras. 2012;47:846-54. doi:10.1590/S0100-204X2012000600016

Steiner F, Lana MC. Effect of pH on boron adsorption in some soils of Paraná, Brazil. Chilean J Agric Res. 2013;73:181-6. doi:10.4067/S0718-58392013000200015

Szulk W, Rutkowska B. Diagnostics of boron deficiency for plants in reference to boron concentration in the soil solution. Plant Soil Environ. 2013;59:372-7.

Tedesco MJ, Gianello C, Bissani CA, Bohnen H, Volkweiss SJ. Análise de solo, plantas e outros materiais. Porto Alegre: Universidade Federal do Rio Grande do Sul; 1995.