BORON EXTRACTION AND VERTICAL MOBILITY IN PARANÁ STATE OXISOL, BRAZIL(1)

Waldemar de Oliveira Neto(2), Antonio Saraiva Muniz(3), Maria Anita Gonçalves da Silva(3), Cesar de Castro(4) & Clovis Manuel Borkert(4)

ABSTRACT

The deficiency or excess of micronutrients has been determined by analyses of soil and plant tissue. In Brazil, the lack of studies that would define and standardize extraction and determination methods, as well as lack of correlation and calibration studies, makes it difficult to establish limits of concentration classes for analysis interpretation and fertilizer recommendations for crops. A specific extractor for soil analysis is sometimes chosen due to the ease of use in the laboratory and not in view of its efficiency in determining a bioavailable nutrient. The objectives of this study were to: (a) evaluate B concentrations in the soil as related to the fertilizer rate, soil depth and extractor; (b) verify the nutrient movement in the soil profile; (c) evaluate efficiency of Hot Water, Mehlich-1 and Mehlich-3 as available B extractors, using sunflower as test plant. The experimental design consisted of complete randomized blocks with four replications and treatments of five B rates (0, 2, 4, 6, and 8 kg ha^{-1}) applied to the soil surface and evaluated at six depths (0–0.05, 0.05–0.10, 0.10–0.15, 0.15–0.20, 0.20–0.30, and 0.30–0.40 m). Boron concentrations in the soil extracted by Hot Water, Mehlich-1 and Mehlich-3 extractors increased linearly in relation to B rates at all depths evaluated, indicating B mobility in the profile. The extractors had different B extraction capacities, but were all efficient to evaluate bioavailability of the nutrient to sunflower. Mehlich-1 and Mehlich-3 can therefore be used to analyze B as well as Hot Water.

Index terms: available boron, hot water, Mehlich-1, Mehlich-3, soil analysis.

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(2) Químico e Pesquisador da Embrapa-Soja. Caixa Postal 231, CEP 86001-970 Londrina (PR). E-mail: waldemar@cnpso.embrapa.br

(3) Professor do Departamento de Agronomia, Universidade Estadual de Maringá – UEM. Av. Colombo, CEP 87020-900 Maringá (PR). E-mails: magsilva@uem.br; asmuniz@uem.br

(4) Pesquisador da Embrapa-Soja. E-mails: ccastro@cnpso.embrapa.br; cmborkert@cnpso.embrapa.br

RESUMO: *EXTRAÇÃO E MOBILIDADE VERTICAL DE BORO EM LATOSSOLO VERMELHO EUTROFÉRRICO NO ESTADO DO PARANÁ*

A deficiência ou o excesso de micronutrientes tem sido observada por meio de análises de solo e de tecido vegetal. No Brasil, a falta de estudos para definição e padronização de método de extração e determinação, assim como a falta de estudos sobre correlação e calibração, dificulta o estabelecimento de limites de classes de teores para a interpretação das análises e recomendações de adubação para as culturas. A opção por determinado extrator para a análise de solos, em algumas situações, ocorre em razão da facilidade de execução no laboratório e não devido à sua eficiência em determinar o nutriente biodisponível. Os objetivos deste trabalho foram: avaliar o teor de B no solo em função da dose do fertilizante, da profundidade do solo e do extrator; verificar a movimentação do nutriente no perfil do solo; e avaliar a eficiência da Água Quente, Mehlich-1 e Mehlich-3 como extratores de B disponível, tendo o girassol como planta-teste. O delineamento experimental foi em blocos completos ao acaso com quatro repetições, e os tratamentos, compostos por cinco doses de B (0, 2, 4, 6 e 8 kg ha^{-1}*), aplicadas na superfície do solo e avaliadas em seis profundidades (0 a 0,05, 0,05 a 0,10, 0,10 a 0,15, 0,15 a 0,20, 0,20 a 0,30 e 0,30 a 0,40 m). Os teores de B no solo, extraídos pelos extratores Água Quente, Mehlich-1 e Mehlich-3, aumentaram linearmente em função das doses de B, em todas as profundidades avaliadas, indicando que ele apresenta mobilidade no perfil. Os extratores foram diferentes na capacidade de extração do B, mas eficientes na avaliação da biodisponibilidade do nutriente para o girassol. Portanto, o Mehlich-1 e o Mehlich-3 podem ser utilizados na análise de B, assim como a Água Quente.*

Termos de indexação: boro disponível, água quente, Mehlich-1, Mehlich-3, análise de solos.

INTRODUCTION

Knowledge on the soil dynamics of a nutrient is essential to understand its availability in the soil-plant system. Boron availability is related to soil characteristics such as pH, mineralogical composition, texture and organic material. Valladares et al. (1999) found a negative correlation between available B and increase in soil pH in 103 soil samples from Rio de Janeiro. Similarly, B adsorption reached a maximum at pH 7.0 and the concentration available in solution diminished from surface to sub-surface soil samples with different textures. With the sub-surface movement of B, there was a positive correlation between nutrient absorption and gibbsite concentration (Soares et al., 2008).

Silva et al. (1995) evaluated B leaching in a dystropherric Red Latosol (typic Hapludox) under cotton, with an average clay content of 500 g kg^{-1} with successive annual applications over eight years; the authors verified that the nutrient was displaced as deep as 60 cm and the quantity extracted (Hot Water) was associated with the rate applied.

Levels of available B in soil can also be related to the extraction method. The results of extractors and methods used to evaluate the micronutrient availability vary greatly. This was mainly due to the chemical composition of the extractors as well as soil characteristics, which influence nutrient dynamics and extraction efficiency directly (Abreu et al., 1994).

There are various B extraction methods to evaluate plant availability. However, the results of some methods are better correlated with the plants. Among the extractors are Hot Water, proposed by Berger & Truog (1939), saline solutions ($CaCl_2$, $BaCl_2$) proposed by Abreu et al. (1994), Mehlich-1 acid solutions, proposed by Mehlich (1953), HCl, proposed by Tedesco et al. (1985) and complexing solutions (Mehlich-3), according to Mehlich (1984).

The recommendations of fertilizers for various States of Brazil are normally based on the correlation and calibration of soil concentrations with relative plant yields. The search for experimentally tested and proven methods becomes necessary when reliable results are desired, since the success of fertilizing practices depends largely on precise soil chemical analyses (Sfredo et al., 1984).

The objectives of this study were to evaluate: soil B concentrations as related to the fertilizer rate applied at each soil depth and by extractor type; B movement in the soil profile; and the efficiency of the Hot Water, Mehlich-1 and Mehlich-3 by the correlation of B content in sunflower and B concentrations obtained by the different methods.

MATERIALS AND METHODS

The study was carried out on an experimental farm of the Brazilian Agricultural Research Center (Embrapa) in Londrina, State of Paraná. In a homogeneous area of approximately 2.0 ha, ten samples of the soil classified as eutropherric Red Latosol (Rhodic Eutrudox) were collected at different depths between the sunflower rows. The physical and chemical properties were determined for each depth prior to the experiment (Table 1).

Phosphorus, K, Cu, Zn, Mn, and Fe were extracted by Mehlich-1; Ca^{2+}, Mg^{2+} and Al^{3+} were extracted by 1.0 mol L^{-1} KCl; both methods as specified by Embrapa (1999). For the S extraction, 0.01 mol L^{-1} monocalcium phosphate was used (Cantarella & Prochnow, 2001). Carbon was determined by means of sodium dichromate oxidation in sulfuric acid, following the method described by Silva (1999). Initial B extraction from soil was carried out using Hot Water, as described by Berger & Truog, (1939).

Granulometric analysis was determined by sedimentation, using the pipette method with 1.0 mol L^{-1} sodium hydroxide as dispersant, following the Embrapa method (Embrapa, 1979).

The experimental design consisted of randomized blocks with four replications in a 5 x 6 factorial scheme in which the effect of five B rates (0.0; 2.0; 4.0; 6.0; 8.0 kg ha^{-1}) were evaluated at six soil depths (0–0.05; 0.05–0.10; 0.10–0.15; 0.15–0.20; 0.20–0.30; 0.30–0.40 m). Boron concentrations were analyzed by Hot Water (Berger & Truog, 1939), Mehlich-1 (Mehlich, 1953) and Mehlich-3 (Mehlich, 1984) extractors and quantified by inductively coupled plasma-optical emission spectroscopy.

The sunflower hybrid M 732 (*Helianthus annuus* L.), planted in September 2002 and harvested in January 2003, was used as test plant for analysis of absorbed B. The crop was fertilized at planting with 300 kg ha^{-1} of 5-20-20 NPK fertilizer, applied in furrow and 45 kg ha^{-1} of N as sidedressing (ammonium sulfate), applied 25 days after emergence (DAE).

Sunflower leaves were collected at the beginning of flowering, stage R_4/R_5, according to the identification method of the sunflower development phases described by Scheneiter & Miller (1981). Leaves were randomly collected from the crop, with an average of 20 leaves per hectare, making up a composite sample. Then the leaves were washed with distilled water, oven-dried at 50 °C to constant weight and later ground in a Wiley mill. Leaf B concentrations were evaluated by dry digestion at 550 °C and quantified by inductively coupled plasma-optical emission spectrometry.

After harvesting the of sunflower, soil samples were collected and homogenized, dried at 30 °C and passed through a 2 mm sieve. The soil samples were collected with a core sampler, according to the treatments at different depths, between the sunflowers rows to determine B concentrations by the different extractors.

The variables were subjected to variance and regression analysis. For each depth, the regression equations were adjusted to the concentrations extracted and the applied rates. The identities of the extractors were verified according to Leite & Oliveira (2002), who established that two methods are statistically not different if and only if after linear regression adjustment, $\hat{y} = \beta_o + \varepsilon_1 x + \beta$, β_o is equal

Table 1. Chemical and physical characteristics of soil collected from different depths prior to boron application

Attribute	Depth (m)					
	0–0.05	0.05–0.10	0.10–0.15	0.15–0.20	0.20–0.30	0.30–0.40
pH $_{(CaCl_2)}$	5.93	5.90	5.83	5.58	5.61	5.36
Al^{3+} (c mol$_c$ dm^{-3})(1)	0.00	0.00	0.00	0.00	0.00	0.00
H+Al^{3+} (cmol$_c$ dm^{-3})(5)	3.18	2.86	3.40	4.2	3.6	3.85
K^+ (cmol$_c$ dm^{-3})(2)	0.41	0.45	0.36	0.14	0.15	0.15
Ca^{2+} (cmol$_c$ dm^{-3})(1)	5.35	5.35	4.77	4.72	4.75	3.65
Mg^{2+} (cmol$_c$ dm^{-3})(1)	2.96	3.19	2.52	2.28	2.37	1.89
C (g dm^{-3})(4)	17.30	17.40	16.10	16.00	13.30	10.70
P (mg dm^{-3})(2)	8.80	10.60	7.90	7.90	6.00	3.50
B (mg dm^{-3})(1)	0.23	0.22	0.22	0.22	0.23	0.24
Zn (mg dm^{-3})(2)	4.50	4.70	4.00	3.87	3.40	1.70
Cu (mg dm^{-3})(2)	22.30	21.90	21.00	20.80	20.00	21.00
Mn (mg dm^{-3})(2)	196.00	195.00	196.00	194.00	190.00	195.00
Fe (mg dm^{-3})(2)	100.00	106.00	100.00	106.00	101.00	102.00
Sand (g kg^{-1})(6)	99.00	100.40	105.50	114.00	92.00	90.00
Silt (g kg^{-1})(6)	153.00	153.00	161.50	152.50	124.50	119.50
Clay (g kg^{-1})(6)	748.50	742.50	733.00	733.50	783.50	790.50

(1) KCl Extractor. (2) Mehlich Extractor 1. (3) Hot Water. (4) $K_2Cr_2O_7$. (5) SMP Solution. (6) NaOH.

to zero, β_1 is equal to 1, and the value of r is close to 1. The identity was evaluated by Hot Water vs. Mehlich-1, Hot Water vs. Mehlich-3 and Mehlich-1 vs. Mehlich-3. In order to evaluate the efficiency of the extractors, regression equations were adjusted between the estimated concentrations for Hot Water, Mehlich and Mehlich-3 and the B concentrations in sunflower leaves.

RESULTS AND DISCUSSION

Boron concentration in relation to soil depth

At each soil sampling depth, B concentrations were different, according to the fertilizer rates and extractor, with interaction between them ($p < 0.01$, Table 2).

Boron concentrations in soil estimated by Hot Water, Mehlich-1 and Mehlich-3 increased linearly with B rate applied to the soil surface at each depth evaluated, indicating that the nutrient was mobile in the soil (Figure 1). Boron movement in soil was closely related with the B soil concentration and rate applied, as observed by Rosolem & Biscaro (2007). These authors added 5 kg ha^{-1} B as boric acid to the surface and verified that B concentrations present in water percolated through the soil column were 10 times as high as in treatments without B application.

In acidic soil, B in solution occurs predominantly as H_3BO_3, a weak acid that has a very low dissociation rate that makes it highly leached in the soil (Tanaka et al., 1993; Silva et al., 1995; Quaggio et al., 2003). Thus, of the total B applied, a part was moved in the form of H_3BO_3. Silva et al. (1995) studied B leaching in an Ultisol under cotton and reported that the nutrient reached a depth of 60 cm after nine years of annual borax application in the sowing furrow. While B mobility is favored by acidic conditions, the movement of the element in deeper layers is related to the application time and rate, initial concentration of the element (Rosolem & Biscaro, 2007), quantity of percolated water (Patil et al., 1997; Communar & Keren, 2006, 2007) and magnitude of soil absorption. Azevedo et al. (2001) affirm that B absorption directly correlates with organic material content, specific clay surface, presence of kaolinite, and exchangeable Al.

In the 0–0.05 m layer (Figure 1a), the lowest concentrations occurred with Hot Water extraction (0.20–0.86 mg dm^{-3}), compared with Mehlich-1 (0.24–1.04 mg dm^{-3}), which extracted more than Mehlich-3 (0.25–0.96 mg dm^{-3}). Hot water also extracted less nutrient from the layer 0.05–0.10 m (Figure 1b). At the highest B fertilizer rate, the concentration extracted was 0.89 mg dm^{-3}, with Hot Water, while Mehlich-1 and 3 extracted, at the same B rate a mean of 1.08 mg dm^{-3}. Similarly, less B was extracted when Hot Water was used than by Mehlich and Mehlich-3 in the 0.10–0.15 m (Figure 1c) and 0.15–0.20 m layers (Figure 1d).

Boron occurs at low concentrations in the layers 0.20–0.30 m (Figure 1e) and 0.30–0.40 m (Figure 1f), but at the same time increased linearly with the rates applied. However, Hot Water was the method that extracted most B from the soil, compared to the other extractors at these depths. Differences in extractor capacity are reflected in the extractor composition and soil-extractor interaction (Bataglia & Raij, 1990; Abreu et al., 1994, 1997; Rosolem et al., 2008, Mylavarapu et al., 2002), as influenced by the B-soil interaction (Rosolem & Biscaro, 2007; Soares et al., 2008).

Boron concentrations decrease with greater depth at all rates applied (Figure 1). Higher B concentrations, from the soil surface to a depth of 0.20 m, are associated with H_3BO_3 fertilization, a form that moves easily. On the other hand, there are higher concentrations of organic material, which plays an important role in B adsorption and at the same time represents an important natural source of the nutrient (Elrashisdi & Connor, 1982; Oliveira Neto et al., 2003). Boron adsorption directly correlates with soil organic material, which is greater at the soil surface (Azevedo et al., 2001). Depressive effects are registered for organic material, in B extraction with Hot Water (Ferreira et al., 2001) as well as by acidic extraction (Lima et al., 2007). However, it is known that in conditions with more organic material, these effects will have a higher magnitude in the Hot Water extractor.

Table 2. Results of variance analysis of B in soil according to fertilizer rate (borax) and extractors (Hot Water, Mehlich-1 and Mehlich-3), at each sampling depth

	Depth of soil sample (m)					
	0–0.05	0.05–0.10	0.10–0.15	0.15–0.20	0.20–0.30	0.30–0.40
F Value (**) (rate)	117.8276	258.7389	213.9694	241.4417	20.6667	22.0099
F Value (**) (extractor)	14.0532	12.7686	23.6249	9.2004	36.8425	72.4254
F Value (**) (rate x extractor)	10.3887	5.5652	6.6620	8.9174	4.7750	18.9359
Average B content (mg dm^{-3})	0.5063	0.5447	0.5360	0.4668	0.2240	0.2125
CV (%)	10.267	10.710	12.608	12.694	16.020	17.301

(**) significant at 1.0 % using SAS statistical program (SAS, 2000).

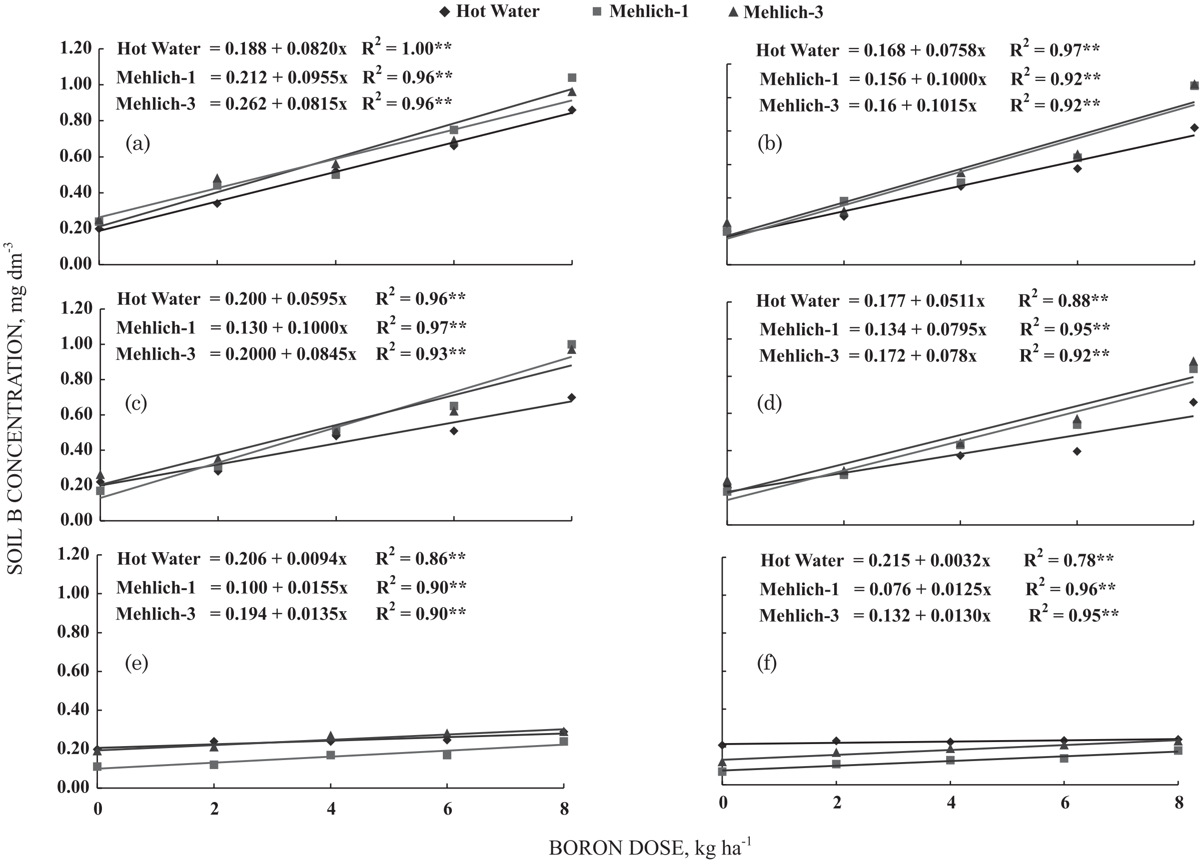

Figure1. Boron concentration in soil according to B rate and Hot Water, Mehlich-1 and Mehlich-3 extractors in the depths: (a) 0–0.05 m; (b) 0.05–0.10 m; (c) 0.10–0.15 m; (d) 0.15–0.20 m; (e) 0.20–0.30 m; (f) 0.30–0.40 m in eutropherric Red Latosol (Rhodic Eutrudox)

In the layer 0.20–0.40 m, B concentrations were low. At this depth, Bataglia & Raij (1990) and Silva & Ferreira (1998) also reported that Mehlich-1 extracted less B than the Hot Water extractor in soil with low concentrations of the nutrient in a more sandy texture. With increasing depth, the contribution of organic material diminished, with increasing importance of the inorganic fraction, which increases forms of inorganic B. Under these conditions, the acidity of the extractors encouraged positively charged oxide formation, increasing adsorption of B (Azevedo et al., 2001).

While acidic conditions encourage B mobility, B movement in depth will be a function of applied rate, application date, initial concentration of the element in the soil (Rosolem & Biscaro, 2007), and quantity of water percolated (Patil et al., 1997; Communar & Keren, 2006, 2007).

Boron moves in soil due to diffusion processes and by descending flow, moving along with water in percolation. The movement is therefore controlled by physical processes characterized by the gradient of water concentration and B concentration (in function of the rate applied). Still, B movement in soil is mainly controlled by physical-chemical processes, which are determined by the adsorption/desorption phenomenon. The desorption rate is positively related to the rate of water percolation (Patil et al., 1997; Communar & Keren et al., 2006, 2007) and inversely with the concentration of clay and organic material content in the soil (Zerrari et al., 2001). The lower B concentrations below 0.20 m reflect the interaction of factors that influence its movement.

When correlated, the coefficients between Hot Water, Mehlich-1 and Mehlich-3 extractors were high (Figure 2). They differed in extraction capacity according to B rates and depths, according to the extractor identity test proposed by Leite & Oliveira (2002); except when relating Mehlich-1 vs. Mehlich-3 and Hot Water vs. Mehlich-3, in the layer 0.10–0.15 m and 0.15–0.20 m, respectively (Table 3, Figure 1). The results did not agree with those reported by Abreu et al. (1997), which refer to the similarity of extraction of the three extractors. However, it is worth remembering the difference in criteria used by the authors, since the criteria proposed by Leite & Oliveira (2002) to establish identities of the extractors are more rigorous.

Boron concentrations found in soil were within the critical limits for the nutrient (0.40 to 2.30 mg dm^{-3}),

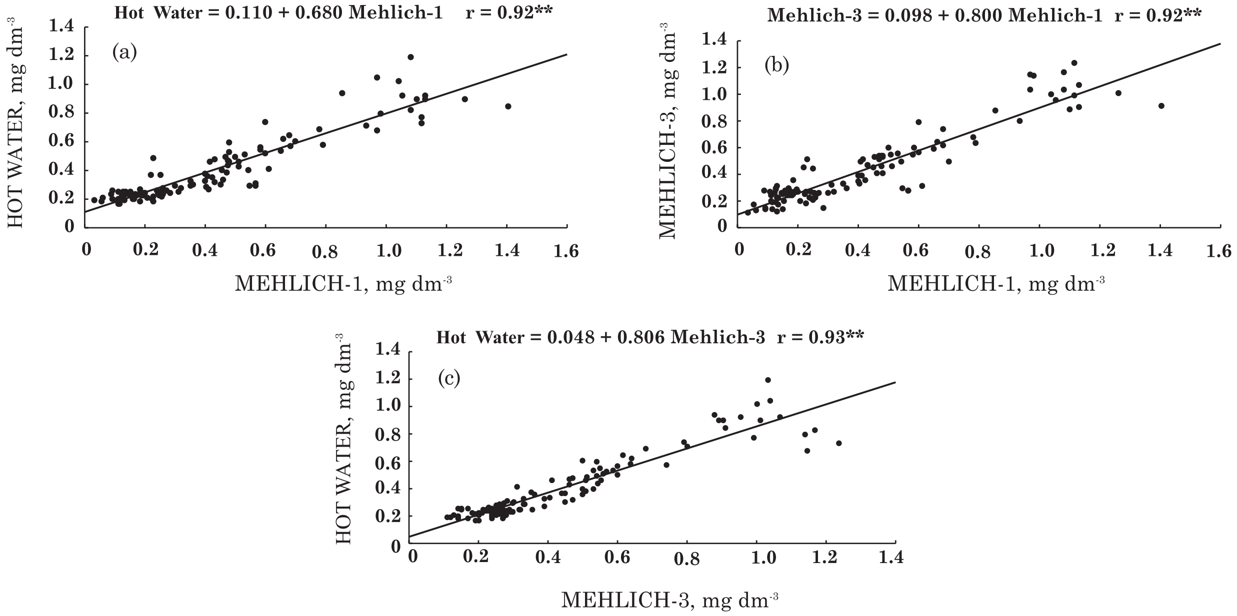

Figure 2. Correlation between results of different B extractors: (a) Hot Water and Mehlich-1; (b) Mehlich-3 and Mehlich-1; (c) Hot Water and Mehlich-3.

Table 3. Result of the identity test among extractors Hot Water, Mehlich-1 and Mehlich-3, in the different soil depths

Method	n	$ß_o$	$ß_1$	r	Medium error	F (H0)	te	r ≥ (1- t ē)	Conclusion
				0.00 a 0.05 m					
AQ x M1	20	-0.0018^{ns}	1.1467**	0.94**	0.1437	6.46**	3.66**	yes	different
AQ x M3	20	0.0817^{ns}	0.9947**	0.94**	0.1782	8.05**	4.64**	yes	different
M1 x M3	20	0.1208*	0.8053**	0.93**	0.0440	3.44ns	1.18ns	no	different
				0.05 a 0.10 m					
AQ x M1	20	-0.0204^{ns}	1.1615**	0.93**	0.1010	3.61*	1.19ns	yes	different
AQ x M3	20	0.0386^{ns}	1.0406**	0.94**	0.1515	4.14*	3.96*	yes	different
M1 x M3	20	0.0815^{ns}	0.8508**	0.96**	0.0863	3.67*	1.43ns	yes	different
				0.10 a 0.15 m					
AQ x M1	20	-0.0360^{ns}	1.1501**	0.91**	0.0396	1.42ns	0.70ns	no	different
AQ x M3	20	0.0187^{ns}	1.0964**	0.87**	0.1263	1.84ns	2.52*	yes	different
M1 x M3	20	0.0572^{ns}	0.9453**	0.95**	0.1388	1.11ns	1.81ns	yes	equal
				0.15 a 0.20 m					
AQ x M1	20	-0.0877^{ns}	1.3163**	0.91**	0.0513	3.92*	0.86ns	no	different
AQ x M3	20	0.0150^{ns}	1.0043**	0.97**	0.0499	0.75ns	1.36ns	yes	equal
M1 x M3	20	0.1330**	0.6531**	0.90**	0.0736	11.97**	0.86ns	no	different
				0.20 a 0.30 m					
AQ x M1	20	-0.5278^{ns}	3.1223**	0.75**	-0.1076	5.75*	0.98ns	no	different
AQ x M3	20	0.0502^{ns}	0.8185*	0.54*	0.0311	0.33ns	0.66ns	no	different
M1 x M3	20	0.2192**	0.1278ns	0.34ns	0.4530	59.01**	2.82ns	no	different
				0.30 a 0.40 m					
AQ x M1	20	-0.2143^{ns}	1.5955**	0.57**	-0.3715	22.26**	6.39**	no	different
AQ x M3	20	-0.0375^{ns}	1.1012ns	0.40ns	-0.0687	0.65ns	1.16ns	no	different
M1 x M3	20	0.1487**	0.4228ns	0.42ns	0.7074	16.05**	4.39**	yes	different

n: number of observation; β_o: regression intercept; β_1: declivity; r: correlation coefficients; F (H0): F test; t: t test for medium error; r ≥ (1- t $_{\bar{e}}$); ns: not significant; *: significant at 5 %; **: significant at 1 %.

according to Souza Lima et al. (2007) who evaluated B extractors in ten soils in Pernambuco. Castro et al. (2006) reported that sunflower had better dry mass production, grain production, and oil content when soil B concentration was 0.50 mg dm^{-3}, compared to 0.25 or 2.00 mg dm^{-3}.

The extractor correlation coefficients observed down to the depth of 0.20 m (Table 3) were high (> 0.90) and significant, at 1.0 %. From this depth downwards, coefficients diminished, with no registered significance between the Mehlich-1 and Mehlich-3 extractors at the two depths evaluated (0.20–0.30 m and 0.30–0.40 m) nor between Hot Water and Mehlich-3 at 0.30–0.40 m. However, considering the identity criteria proposed by Leite & Oliveira (2002), the extractors Mehlich-1 and Mehlich-3 were shown to be different from Hot Water extraction. Therefore, extractor use viability criteria should complete the correlation between concentrations extracted and plant growth measurements.

Relationship between B in soil B absorbed by sunflower

When evaluating the effect of B rate applied to the soil on B concentration in sunflower leaves, a significant and positive interaction was verified. There was a quadratic effect ($p < 0.001$) with a peak at the B rate of 7.73 kg ha^{-1} resulting in to 68 mg kg^{-1} of B in leaves (Figure 3). However, the foliar B concentration in the control was 47 mg kg^{-1}, a value considered appropriate for sunflower cultivation (Sfredo et al., 1984; Blamey et al., 1997).

Pearson's correlation coefficients for soil B concentration at all depths and sunflower leaf B concentrations were highly significant, indicating strong dependence between the variables (Table 4). Alvarez V. (1995) registered that an extractor is considered adequate when variations in concentrations extracted correspond to variations in quantities absorbed. In this context, the extractors proved to be sensitive in evaluating B concentrations available to sunflower at the different depths according to the rate applied.

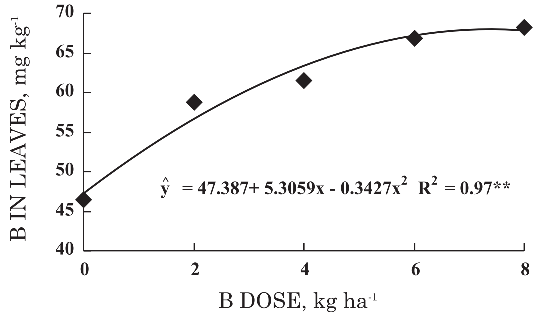

Figure 3. Boron concentration in sunflower leaf tissue as related to the B rate applied to soil.

Table 4. Correlation coefficient between boron concentrations in soil and sunflower, according to depth and extractor

Extractors	Depths (cm)					
	0–5	5–10	10–15	15–20	20–30	30–40
Hot Water	0.92**	0.87**	0.87**	0.80**	0.89**	0.95**
Mehlich-1	0.88**	0.87**	0.87**	0.85**	0.81**	0.94**
Mehlich-3	0.92**	0.95**	0.83**	0.81**	0.99**	0.99**

** in the columns, significant correlation at 1.0 % probability.

Other studies register differences between acidic and Hot Water extractors in evaluating available B. Renan & Gupta (1991) verified greater correlation between B concentrations obtained with acidic extractors and B concentration in leaves of four plant species, compared to B extracted with hot water. The correlation between B extracted by acidic solution and B foliar concentration was better than that for B extracted by Hot Water, according to Ponnamperuma et al. (1981) in rice, and Souza Lima et al. (2007) in maize. Bataglia & Raij (1990) verified lower correlation coefficients for B extracted by Mehlich-1 and B absorbed by sunflower when compared to results for Hot Water; similarly, Ribeiro & Tucunango Saraiba (1984) obtained a correlation between B in the soil and B in sorghum of 0.65 for Hot Water and 0.58 for Mehlich-1.

According to the identity criteria proposed by Leite & Oliveira (2002), the extractors are different, although they proved to be effective to analyze B available to sunflower. However, Walworth et al. (1992) concluded that there were advantages in using the Mehlich-3 extractor, for allowing the simultaneous extraction of Ca, Mg, K, P, B, Fe, Cu, Mn, and Zn.

No significant correlation was observed between Mehlich-1 and Mehlich-3 extractors, at 0.20–0.30 m and 0.30–0.40 m depths and between Hot Water and Mehlich-3 extractors at 0.30–0.40 m depth (Table 3). Despite this fact, significant correlations were registered at 1.0 % between B extracted and B absorbed at all depths, for all extractors (Table 2), demonstrating that Hot Water, Mehlich-1 and Mehlich-3 extractors are appropriate for evaluating plant-available B. Thus the fundamental aspect in the decision about which extractor to use is the correlation between concentrations extracted and concentrations in plant. This shows that the extraction methods studied here can be used to quantify B in sunflowers for the soil tested.

CONCLUSIONS

1. Soil B concentrations extracted by Hot Water, Mehlich-1 and Mehlich-3 increased linearly according to B rate applied to the soil surface at each depth, indicating that B was mobile in the soil.

2. The extractors differed in extraction capacity, according to B rate and depth, with greater extraction at the surface.

3. Hot Water, Mehlich-1 and Mehlich-3 were efficient in evaluating B available to sunflower grown on eutropherric Red Latosol (Rhodic Eutrudox).

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