Robert Valencia Agresoth¹, Ronal Villorina Padilla¹, Enrique Combatt Caballero¹, Jaime Mercado Lázaro¹, Sol Pajaro Fernandez¹

¹ Facultad de Ciencias Agrícolas, Universidad de Córdoba, Montería, Colombia.

*correspondence author: ecombatt@correo.unicordoba.edu.co

Graphical abstract

Effect of the application of different doses of boron in the growth of bean caupí (*Vigna unguiculata L. walp.*) in three soils of Córdoba – Colombia

Abstract

Boron is an essential micronutrient for the development and growth of plants, and its concentration in the soil solution is influenced by diverse physicochemical properties of the soil such as pH, texture, organic matter and humidity. Therefore, the objective of this work was to evaluate the effect of the application of different doses of boron on the growth of bean 'caupí' (*Vigna unguiculata L. walp.*), in three soils of Córdoba, in Colombia. For this, the research was conducted a greenhouse trial in the experimental area of the University of Córdoba. Eighteen (18) pots were used with soil samples for each acid, neutral and alkaline soil from the department of Córdoba, being the B applied in each treatment as boric acid solution (H_3BO_3). The treatments applied corresponded to the equivalent of 0.5, 1.2, 2.6, 4.0 and 6.0 kg ha⁻¹ and one control experiment without B. Subsequently and after 35 days, the culture was collected to determine the content of wet

Keywords

Boron
Soils
Acidity
Alkalinity
Beans
Corn

and dry mass. In addition, the B accumulated at leaf level. Likewise, samples of 1 kg of soil from each treatment were collected to determine the content of B. The data were analyzed by analysis of variance and regressions, with which the respective mathematical models that explain the trend of the treatments were obtained. The results showed that the highest gain in dry mass was obtained in the neutral and alkaline soils under the different doses of boron applied. In addition, for the acid soil the optimum level of B was 0.77 kg ha⁻¹, for the neutral soil the optimum, critical and toxic levels were 3.7, 3.33 and 4.07 kg ha⁻¹, respectively. In the alkaline soil, the optimal, critical and toxic levels were 3.2, 2.88 and 3.52 kg ha⁻¹.

Efecto de la aplicación de diferentes dosis de boro en el crecimiento del frijol Caupí (*Vigna unguiculata L. walp.*) en tres suelos de Córdoba – Colombia

Resumen

El boro es un micronutriente esencial para el desarrollo y crecimiento de las plantas, y su concentración en la solución del suelo influye en algunas propiedades fisicoquímicas del suelo, como el pH, la textura, la materia orgánica y la humedad. Por lo tanto, el objetivo del trabajo fue evaluar el efecto de la aplicación de diferentes dosis de boro en el crecimiento de frijol caupí (*Vigna unguiculata L. walp.*, en tres suelos de Córdoba - Colombia. Para ello, la investigación se realizó en un invernadero en el área experimental de la Universidad de Córdoba. Se utilizaron dieciocho (18) macetas con muestras de suelo para cada suelo ácido, neutro y alcalino del departamento de Córdoba, y el B se aplicó en cada tratamiento como solución de ácido bórico (H₃BO₃). Los tratamientos aplicados correspondieron al equivalente de 0.5, 1.2, 2.6, 4.0 y 6.0 kg ha⁻¹ y un control sin B. Posteriormente, y después de 35 días de establecimiento, se recogió el cultivo para determinar el contenido de masa húmeda y seca. Además, el B se acumuló a nivel de la hoja. De manera similar, se recolectaron muestras de 1 kg de suelo de cada tratamiento para determinar el contenido de B. Los datos se analizaron mediante análisis de varianza y regresiones, con el cual se obtuvieron los respectivos modelos matemáticos que explican la tendencia de los tratamientos. Los resultados mostraron que la mayor ganancia en masa seca se obtuvo en los suelos neutros y alcalinos bajo las diferentes dosis de boro aplicadas. Además, para el suelo ácido el nivel óptimo de B fue de 0.77 kg ha⁻¹, para el suelo neutro los niveles óptimos, críticos y tóxicos fueron de 3.7, 3.33 y 4.07 kg ha⁻¹, respectivamente. En el suelo alcalino, los niveles óptimos, críticos y tóxicos fueron 3.2, 2.88 y 3.52 kg ha⁻¹.

Palabras claves

Boro
Suelos
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Frijoles
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Corresponding author:

ecombatt@correo.unicordoba.edu.co

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¹ Facultad de Ciencias Agrícolas. Universidad de Córdoba, Montería, Colombia

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Abstract

Boron is an essential micronutrient for the development and growth of plants, and its concentration in the soil solution is influenced by diverse physicochemical properties of the soil such as pH, texture, organic matter and humidity. Therefore, the objective of this work was to evaluate the effect of the application of different doses of boron on the growth of bean 'caupí' (*Vigna unguiculata L. walp.*), in three soils of Córdoba, in Colombia. For this, the research was conducted a greenhouse trial in the experimental area of the University of Córdoba. Eighteen (18) pots were used with soil samples for each acid, neutral and alkaline soil from the department of Córdoba, being the B applied in each treatment as boric acid solution (H_3BO_3). The treatments applied corresponded to the equivalent of 0.5, 1.2, 2.6, 4.0 and 6.0 kg ha⁻¹ and one control experiment without B. Subsequently and after 35 days, the culture was collected to determine the content of wet and dry mass. In addition, the B accumulated at leaf level. Likewise, samples of 1 kg of soil from each treatment were collected to determine the content of B. The data were analyzed by analysis of variance and regressions, with which the respective mathematical models that explain the trend of the treatments were obtained. The results showed that the highest gain in dry mass was obtained in the neutral and alkaline soils under the different doses of boron applied. In addition, for the acid soil the optimum level of B was 0.77 kg ha⁻¹, for the neutral soil the optimum, critical and toxic levels were 3.7, 3.33 and 4.07 kg ha⁻¹, respectively. In the alkaline soil, the optimal, critical and toxic levels were 3.2, 2.88 and 3.52 kg ha⁻¹

Palabras Claves

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1. Introduction

Boron, B, is one of the micronutrients essential for the normal development of vegetables (Cara et al. 2002). Its concentration in the soil solution is influenced by the dynamics of the physicochemical properties of the soil. Hu et al. (1996) affirm that there is a duality between need and phytotoxicity, in such a way that a minimum concentration is required for the survival of the plant, but an excessive concentration produces negative effects

and decreases the yield of production. Belvins and Lukaszewski (1998) indicate that an optimal boron level for a species could be toxic or inadequate for other plant species.

According to the IGAC (2009), in the department of Córdoba, the arable land has an approximate area of 589,469 ha, which corresponds to 23.6 % of the total area. In which the soil formation factors such as climate, parent material, topography, organisms and time, affect the development of physical, chemical and biological processes that characterize the

evolutionary process of soils. Factors that directly influence the fertility and availability of macro and micronutrients essential for plant nutrition. The Geographical Institute Agustín Codazzi reports in the region, different types of soils grouped in eight orders, emphasizing the orders of soils Entisols, Inceptisols, Vertisols, Andisols, Molisols, Alfisols, Ultisols and Oxisols, which have very variable dynamics with respect to the boron availability. According to Imtiaz et al. (2010) the shortcomings of B are a very common agricultural problem in the world, which have repercussions on low yields, quality and loss of many crop species.

Koshiha et al. (2009) state that the deficiencies of B in soils cause many anatomical, biochemical and physiological changes in plants, affecting their vegetative and reproductive growth. Causing the inhibition and death of meristematic cells and affecting the assimilation of other nutrients by plants. Dell and Huang (1997) claim that the amount of yield losses directly depends on the duration of the deficiency and the growth stage of the plant in which it occurs.

Carvalho et al. (1996) highlight that different agronomic responses of some crops in Brazil, have been reported to the application of B. Bono et al. (1999) found variable responses to fertilization with B in the subhumid Pampean region. Fujiwara and Matoh (2009), indicate that there is a favorable effect of boron on the growth of plants, and it is a common practice to fertilize with boron to increase crop production (Goldbach and Wimmer, 2007).

On the other hand, for the agricultural systems of Colombia and especially the department of Córdoba, fertilization has become an indispensable practice to achieve sustainable production. Taking into account that national and international efforts have been devoted to investigate only the fundamental macronutrients N, P and K, increasing the problem due to the lack of information on the response to micronutrient applications such as B. In addition, the adequate, critical and toxic levels of the element in the cultivars established in the different soil types of the region are unknown. There is also little experience on the ways and times of application of the boric fertilizers and their effect on the productivity and quality of the crops established in the area.

Concerning, it is fundamental to have a knowledge of the micronutrient B under the environmental conditions in which the cultivars are sown, in order

to guide the fertilization plans, to be efficient and efficient in the use of the nutrient. For this reason, the objective of this study was to evaluate the effect of the application of different doses of boron on the growth of cowpea beans (*Vigna unguiculata* (L.) *walp.*) In three soils of Córdoba - Colombia.

2. Experimental section

2.1. Field phase

400 kg of acid, neutral and alkaline soils characteristic of the department of Córdoba were collected. Which belong to the taxonomic classification of order Oxisols, Inceptisols and Vertisols (IGAC 2009). The soils were collected at a depth of 0 - 20 cm, in three locations that were georeferenced as Montelíbano (07°56'53.1"N - 75°26'57.40"W) in which the soil was collected the acid soil. In the municipality of Montería (08°47'26.2"N - 75°51'39.6"W) the neutral ground and Moñitos (09°08'38.58"N - 76°09'48.06"W) the alkaline soil. Once the soils were selected, they were transported in polypropylene bags to the Soils and Waters Laboratory of the Faculty of Agricultural Sciences of the University of Córdoba. Where they were dried at room temperature, disintegrated by grinding and passed through a mesh screen 4.0 mm. Subsample was taken from each soil, which were screened by 2 mm mesh, for its physico-chemical character-ization according to the methodologies of the IGAC (2006), followed by the soils laboratory of the University of Córdoba.

2.2 Greenhouse phase

3.5 kg of soil were weighed, which were previously sieved by 4.0 mm mesh. This soil was placed in plastic pots, to form an experimental unit. The pots were placed in a complete experimental design at random, according to a factorial scheme 6 x 3 x 1 (dose x soils x culture) with three repetitions, for 54 experimental units. The treatments were constructed with the following doses: 0.0 - 0.5 - 1.2 - 2.6 - 4.0 - 6.0 kg ha⁻¹ of B, equivalent to 0.0 - 0.25 - 0.6 - 1.3 - 2.0 - 3.0 mg kg⁻¹ of B per pot. The boron source used was boric acid applied as a solution to the soil. The experimental units were incubated for 15 days with the respective doses of B, after which time the sowing was carried out. For this in each pot eight seeds of cowpea beans were sown; and the

experimental units were maintained near field capacity and five days after the emergence, five plants were eliminated, to compose each experimental unit with three plants.

For the fertilization of the crop, 1250, 900 and 990 mg per pot of N, P and K were applied fractionally at 5, 15 and 25 days after sowing, and 175 and 105 mg/Ca and Mg per pot were applied, from CaCl_2 and $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$. For micronutrients, applied in mg kg^{-1} 3.66, 400, 1.33, 0.15 and 1.56 of Mn, Zn, Cu, Mo and Fe respectively. Using as sources $\text{MnSO}_4 \cdot 3\text{H}_2\text{O}$, $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, $\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$ and $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$. All the nutritional elements were applied to the soil in solution.

Once the culture was established, the plants were irrigated with distilled water with a frequency of one application per day, maintaining the soils approximately at field capacity taking into account the evapotranspiration and the development of the cultivar. After 35 days after sowing, a cut of the aerial part was made 1.0 cm from the surface, to classify the different tissues in roots, stems and leaves, to determine the wet mass, in addition these tissues were dried in an oven at 70 °C for 72 h for the determination of the dry mass.

To extract the content of B absorbed by the crop, the sample of leaves and stems were milled and digested with an acid mixture (HNO_3 : HClO_4 : H_2SO_4 3:1:1 v/v) (Empraba, 1997). The B was quantified by the colorimetric method with azomethine-H reagent at a wavelength of 420 nm (Wolf 1974).

For the determination of B available in the soils, the extraction solution HCl 0.05 mol L^{-1} was used (Silva and Ferreyra, 1998). The response variables to be considered in this experiment corresponded to the gain of wet and dry mass for cowpea beans, in the different soils, the contents of B extracted by the extracting solution in the experimental units of each soil and the boron accumulated in the area of plant. The results were subjected to analysis of variance (ANOVA), regression to 5 % of significance using the SAS program version 9.2. The optimal, critical and toxic levels of B in the soils and plants were determined through regression equations that were estimated with 100 %, 90 % of the maximum production and 10 % in the reduction of the maximum yield of the dry matter of the aerial part of the plants. Taking into account the content of B in the soil (Fageria, 2000).

3. Results and Discussion

3.1 Physicochemical characterization of the soil

According to the results of the physicochemical analysis of the soil for the different localities (Table 1), a pH of 5.5 classified as moderately acidic was found for the soil of Montelíbano, with a high interchangeable acidity of 5.4 $\text{cmol}^+ \text{kg}^{-1}$, low contents of organic matter, low effective cation exchange capacity (CEC) and low contents of P and S.

As for the minor elements, it was found that the soil presented low contents of Cu, Fe, Zn, Mn and B. Gupta (1993) and Rocha (1995), indicate that the availability of B depends on the source material and the mineralogy, because the Fe and Al reactions control its solubility. Rosolem et al. (2008) confirm that the contents of B in acid soils are affected by factors such as pH, texture, organic matter and mineralogy, and that as these factors vary between soils, and greater divergence will be noted in the content of B.

For the soil of Montería, its pH is neutral and has a low content of organic matter, due to the high degrees of oxidation as a consequence of agricultural management. The base content and the effective cation exchange capacity was medium and a marked deficiency of S and P. The content of the micronutrients in general terms was in an optimum range. These chemical conditions of fertility are due to the textural class of silty clayey clay, topography and to the parental material that originated this soil. In addition, for the soil of Moñitos, its pH was slightly alkaline, with high interchangeable calcium and magnesium contents, with high capacity of effective cation exchange product of the content of bases and low content of organic matter.

The minor elements were found indeficient contents, due to the low solubility of these elements, which form insoluble compounds at this pH. In relation to B, its content was low, because it increases the adsorption of this element by the calcium and magnesium compounds, forming mainly calcium borate compounds, which have low solubility (Gupta, 1979). However, the good fertility from the chemical point of view is due to the parent material and the clayey textural class, which allows the absorption of elements such as calcium, magnesium and potassium.

Table 1. Physical-chemical characterization of three soils collected in the department of Córdoba.

LOCATION				
Properties	MONTELÍBANO	MONTERIA	MOÑITOS	Units
	Values			
Clay	55.3	28.7	40.3	%
Sand	20.0	18.3	28.3	%
Silt	24.7	53.0	31.3	%
Texture	Clayey	Candid silty clay	Clayey	---
pH	4.6	6.4	7.2	1:1
MO	0.34	1.19	1.02	%
S	19.3	4.6	7.7	mg kg ⁻¹
P	2.7	18.5	35.6	mg kg ⁻¹
Ca	0.70	9.60	33.0	cmol ⁺ kg ⁻¹
Mg	0.02	7.30	14.2	cmol ⁺ kg ⁻¹
K	0.04	0.34	0.10	cmol ⁺ kg ⁻¹
Na	0.02	0.12	0.51	cmol ⁺ kg ⁻¹
Al+H	5.42	-----	-----	cmol ⁺ kg ⁻¹
CEC	6.2	17.4	47.8	
Fe	9.8	33.6	5.6	mg kg ⁻¹
Mn	1.6	58.8	21.0	mg kg ⁻¹
Cu	0.9	3.8	0.8	mg kg ⁻¹
Zn	0.4	3.5	0.9	mg kg ⁻¹
B	0.26	0.40	0.25	mg kg ⁻¹
Ca/B	2.69	24.0	132	-----

pH Soil-water ratio 1: 1. MO: Walkley - Black. S: Monobasic calcium phosphate 0.008 mol L⁻¹. P: Bray-II modified. Ca, Mg, K, Na. Ammonium acetate 1.0 mol L⁻¹ pH 7.0. Al + H: KCl 1.0 mol L⁻¹. CEC: Sum of bases. Cu-Fe- Zn Mn: double acid. B: HCl 0.05 mol L⁻¹. Texture: Bouyoucos.

Table 2. Mean square and level of significance for the contents of soil and accumulated in the aerial part of the plant, wet and dry mass of the bean canopy in three typical soils of the department of Córdoba.

SOILS		BEAN					
		FV	GL	B Soil	B Plant	Wet canopy mass	Dry canopy mass
ACID	dose	5	0.033**	348.81**	107.97*	0.16 ^{ns}	0.087 ^{ns}
	mistake	12	0.00031	16.12	31.87	0.33	0.093
	overall	17	0.01	113.97	54.25	0.28	0.091
	cv		4.20	1.70	9.51	89.26	20.44
	half		0.42	2.35	59.34	6.44	1.49
NEUTRAL	dose	5	0.052**	351.06**	9.55 ^{ns}	1.029 ^{ns}	0.08*
	mistake	12	0.0001	7.225	68.71	1.79	0.02
	overall	17	0.015	108.37	51.31	1.57	0.039
	cv		5.78	9.47	7.93	10.21	8.43
	half		0.23	28.45	104.42	13.13	1.75
ALKALINE	dose	5	0.08**	68.64**	107.28 ^{ns}	5.944**	0.068*
	mistake	12	0.0006	2.24	62.68	0.73	0.02
	overall	17	0.025	21.77	75.8	2.26	0.036
	cv		7.91	7.11	5.48	4.91	9.21
	half		0.33	21.06	144.23	17.42	1.64

ns: not significant; *. Significant at 5%; ** Highly significant at 1%.

3.2 Wet and dry biomass

There was a significant effect ($p < 0.01$) for production of wet canopy mass. In relation to the doses of B applied in acid soil. For the neutral soil, statistically significant differences were found for the dry root mass production and in the alkaline soil, the dry matter production of the canopy and the root was significantly affected. Similarly, a highly significant effect was found for B in the soil and B accumulated in the area of the crops (Table 2).

3.3 Dry mass in the part of the canopy and the roots

The coefficients of the regressions between the dry mass gain in the aerial part of the plants and the doses of B applied in the bean crop in the three soils were variable with respect to their significance (Table 3). Observing by means of the regression equations that the available B present in the acid soil is sufficient to meet the requirements of the crop, until the stage at which the experiment was carried out. However, in the neutral and alkaline soils there was a response in dry mass gain of the aerial part of the plants, when increasing the dose of B.

Bono et al. (1999) found variable responses to fertilization with B in the subhumid Pampean region, also indicate that trials where fertilization is used and especially in those that study micronutrients, cannot reach accurate conclusions without considering the other edaphoclimatic variables that condition the answers.

In the acid soil (Figure 1a), for the bean crop it was found that as the doses of B were increased, the production of the dry mass in the area part of the plants was reduced. Thus, the maximum biomass gain was 6.59 g, with 0.624 kg ha⁻¹ of B available that is found in this soil. This response of low assimilation by the plants, is explains why this content is high and under these conditions the nutritional reserve is limited. In addition, in this phenological stage, beans require low amounts of the element, on the other hand the physical and chemical conditions of these soils, hinder the assimilation of nutrients such as phosphorus and potassium, essential for the growth of plants.

For the dry mass gains at different doses of boron in the neutral soil (Figure 1b), it is observed that the crop presented a biomass gain of 13.72 g, when applying 3.7 kg ha⁻¹ of B. Likewise. When

increasing the doses of B, a decrease in biomass was found, which indicates that at doses higher than 3.7 kg ha⁻¹ for this soil, they can be considered as phytotoxic. According to Barker and Pilbeam (2007) the extractions of this element by the monocotyledons are smaller than in the dicotyledons in a range of 2 to 5 mg kg⁻¹. On the other hand, the high nutritional potential of these soils is due to their source materials, which allows plants to have at their disposal a greater availability of nutrients that are necessary to develop satisfactorily. For alkaline soil (Figure 1c), a gradual increase in dry matter gain (18.72 g) was observed until reaching 2.6 kg ha⁻¹, although no symptoms of toxicity were observed at higher doses of applied B. These results can be explained taking into account that this crop has low requirements for this element. Therefore, at this stage of development this crop does not require higher amounts of B for its vital functions. However, Gupta (1979) states that deficiencies of B are present in soils with high calcium content, due to the increase in the adsorption of B by calcium.

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Table 3. Simple regression equations and coefficients of determination between the gain in dry mass in the aerial part of the bean and the different doses of B applied to the soil.

Soils	Equation	R ²
Acid	$Y = 6.6308 - 0.0528x$	62 %
Neutral	$Y = 12.47 + 0.67x - 0.09x^2$	80 %
Alkaline	$Y = 16.075 + 1.6698x - 0.2614x^2$	56 %

Figure 1. Relationship between the dry mass of the aerial part of bean and the boron applied in the acid (a), neutral (b) and alkaline (c) soil.

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3.4 Optimal, critical and toxic levels of boron in three soils planted with beans in Córdoba, Colombia

The different critical and toxic levels of B for the bean crop are framed in the differences that exist between the physical and chemical characteristics of the soils, the species and the age of the plants, in addition to the criteria adopted by the researchers to establish such values. Criteria that are necessary to take into account to perform regionalized tests for the determination of levels in soils and plants for each condition.

In the determination of the different levels in the bean crop in the acidic soil, a decreasing linear tendency was found in the response of the bean to the application of different doses of available boron. However, in these acidic conditions, the amount of B available from the soil, which is part of the inorganic and organic properties, was sufficient to obtain the maximum yield of dry mass with 6.59 g (Figure 2a). Likewise, it was determined that the optimum level of B available was 0.77 kg ha⁻¹ and in leaf tissue the optimum level of B was 37.9 mg kg⁻¹ for this amount of B in the soil. In addition, the results found did not allow to evaluate the levels of deficiencies and toxicity, due to the linear model that expresses the possession of the treatments applied.

The optimal levels of available B found in this soil and in these species shows that the availability and assimilation of this nutrient is related to the attributes present in this soil, the climate and the ability of the plants to assimilate a certain amount of the solution of the ground. However, according to Johnson (2006), fertilization in soil deficient in B increases crop yields. Similarly, the decreasing trend is explained by possible phytotoxic effects and according to Herrera et al. (2010) high amounts of B decrease vegetative organ growth, chlorophyll content and photosynthetic rate, due to osmotic imbalances and inability to resist damage caused by high amounts of B and Fageria (2000), found that the content of B suitable in an acid soil of Brazil for bean, millet, soybean and wheat crops were 0.9, 1.3, 2.6 and 0.4 mg kg⁻¹ of B respectively and the toxic level for these cultures were 2.8, 5.7, 5.2 mg kg⁻¹ of B and 4.3 mg kg⁻¹ of B correspondingly.

For the neutral soil, the culture presented the maximum dry mass response with 13.72 g at a dose of 3.7 kg ha⁻¹ (Figure 2b). Likewise, at higher doses

there is a depressive effect in the accumulation of dry matter. This result contrasts with that reported in canola (*Brassica napus*) and sunflower (*Helianthus annuus*) in which the greater amount of B supplied, the plants accumulate more dry matter, but at high doses of this element there is toxicity (Asad et al. 2002).

With the equation that describes the tendency of the doses of B, it was determined that the optimal, critical and toxic levels for the neutral soil established with beans, were 3.7, 3.33 and 4.07 kg ha⁻¹ and in the plant the optimum level was 44.2 mg kg⁻¹ respectively. Paula (1995) notes that boron levels of 2 mg dm⁻³ cause growth reduction without showing symptoms of toxicity in rice plants grown in alluvial soil. Nable et al. (1997) states that the contents of B in soil above 5 mg dm⁻³ are considered toxic to plants.

This behavior indicates that the bean plants responded to the application of element B, it is also important to indicate that for this experiment no negative responses were found to the applications of B in the leaf tissue. Mariano et al. (2000) found critical levels of B for beans in lowland soils in the range of 0.57 to 1.89 mg dm⁻³.

In the alkaline soil it was found that the optimal dose was 3.2 kg ha⁻¹ to obtain 18.72 g dry bean mass (Figure 2c). At higher doses, similar responses to neutral soils are presented, with a decrease in dry mass gain. This crop response is directly related to the chemistry of alkaline soils, in which low applications of B are insolubilized in calcium borate forms. Therefore, making applications of the element for the cultivation of beans are able to increase the production of biomass.

Golberg (1997) states that as the pH of the soil solution increases, usually in a range of 3 to 9, the availability of B for plants decreases, because the two aqueous species involved, boric acid [B(OH)₃] and borate [B(OH)₄⁻], not only have different affinities to be adsorbed by the soil, but also that their proportions in the equilibrium of the solution vary with the pH.

For this alkaline soil (Figure 2c) the optimal, critical and toxic levels of B were 3.2, 2.9 and 3.5 kg ha⁻¹, in addition, the optimum level in the aerial part of the plant was 28.6 mg kg⁻¹. On the other hand, a gradual increase in the concentration of B accumulated in leaf tissue was found as the applied dose of B in the soil was increased. However, in this soil, the amount of B accumulated in the plant was

lower when the highest dose of B was applied, compared to acid soil and neutral soil, without observing symptoms of toxicity. De Souza et al. (2007) found lower critical and toxic levels for the more clayey soil, as the highest values were obtained for the sandy soil.

Figure 2. Relationship between the dry mass of the aerial part of bean and the boron available extracted with HCl 0.5 mol L⁻¹ in the acid (a), neutral (b) and alkaline (c) soil.

4. Conclusions

The application of B dose in the three soils presented different response in bean dry mass gain, being the acid soils (6.59 g) the one with the lowest dry biomass gain and the alkaline (18.72 g) with the best response. For acid soil the optimum level of B was 0.77 kg ha^{-1} . In the neutral soil the optimal, critical and toxic levels were: 3.7, 3.33 and 4.07 kg ha^{-1} . In the alkaline soil the optimum, critical and toxic levels were 3.2, 2.88 and 3.52 kg ha^{-1} . The optimal levels of B for the aerial part of the plant in the acid soil was 37.9 mg kg^{-1} , in the neutral soil 44.2 mg kg^{-1} and in the alkaline soil 28.6 mg kg^{-1} .

Conflict of interest

The authors state no conflict of interest

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