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Economic viability of *Phaseolus vulgaris* (BRS Estilo) production in irrigated system in a function of application of leaf boron

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ABSTRACT

Foliar fertilization may be a viable strategy to boron supply in irrigated cropping systems with common beans (*Phaseolus vulgaris*), since it prevent B leaching. The aim of this work was to evaluate the economic viability and physiological parameters of the common beans production in irrigated cropping systems using sources and increasing foliar boron doses. A field experiment was carried out using an experimental block design in a factorial scheme $2 \times 5 \times 3$, with two sources of B (boric acid and borax) and five doses: 0 (control), 2, 4, 6 e 8 kg ha^{-1}, with three repetitions. Foliar B applications were performed at 40 days after seeds germination, in pre-flowering stage. Physiological process (transpiration, stomatal conductance, CO_2 internal concentration, net photosynthesis, and relative chlorophyll index), B level in leaves and grain yield were measured. These data were used to determine the economic viability of B fertilization in common beans. Both boric acid and borax increased B levels in common beans leaves. Borax affected some physiological process reducing stomatal conductance and increasing net photosynthesis. Using borax, the highest net photosynthesis was observed at a rate of 4 kg ha^{-1}, while the boric acid increased net photosynthesis linearly after increasing B doses application. An enhance of 311 kg ha^{-1} in the grain yield was observed using borax related to the control (without B application); however, grain yield decreased linearly after application of increasing B doses, as boric acid. Comparing the economic viability of sources and doses of B, the highest profitability is obtained using borax at a rate of 4 kg ha^{-1}, which promoting a differential profit of US$534.44 per hectare compared to common beans cropping without B.

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Boron fertilization; micronutrients; mineral plant nutrition; photosynthesis; physiological quality

Introduction

Common beans (*Phaseolus vulgaris*, L.) is one of the most cultivated crops in tropical countries of South America. It is frequently used in food security programs as a protein source, to guarantee suitable human nutrition in developing countries (Souza et al. 2011). In Brazil, this crop has an important social role, since it is usually cultivated by small farmers, promoting social and economic sustainability (Embrapa 2012).

Fertilization is one of the most important factors driving crops productivity. In tropical ecosystems, which usually have soils with low fertility, this practice is even more important. Nowadays, since macronutrients doses are quite well know, micronutrients doses to guarantee a balanced plant nutrition need to be better understood. Boron (B) deficiency is common in tropical soils (Mattiello et al. 2009; Souza et al. 2011; Tomaz et al. 2011; Euba Neto et al. 2014) since they are low in it. However, boron application in excess can reduce crop production.

In tropical soil from Brazilian Savanna ecosystem, even when B is applied, boron availability is influenced by soil pH (Sá & Ernani 2016), organic matter (Lima et al. 2007) and granulometry. Other important factor affecting soil availability of B is the water percolation into the soil; heavy rain or irrigation in tropical ecosystems usually induces B leaching, reducing B availability (Prado 2008).

Boron leaching caused by rain or irrigation can drastically reduce B level in soil, mainly in soils with sandy texture, and this factor should be considered in fertilization programs to B supply (Trautmann et al. 2014; Goldbach & Wimmer 2007; Silva et al. 2016; Barbosa et al. 2016). In these areas, foliar application of B may reduce B losses and increase B fertilization efficiency, which improve farmers gain and prevent environmental contamination. However, since B doses causing deficiencies or toxicity are near, the adequate dose and sources of B need to be determined to promote high productivity (Trautmann et al. 2014; Lemiska et al. 2014).

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Boron is an essential nutrient to plant´s growth and development. It has an important role in physiological process, such as transport and metabolism of carbohydrates, cell membranes integrity, syntheses and elongation of wall cells (Wimmer & Eichert 2013; Liu et al. 2014), nitrogen metabolism, hormones activity, and others related to flowering, growing, pollen tube and fructification (Malavolta 2006; Dechen and Nachtigall 2007; Prado 2008; Marschner 2012). Moreover, B may affect Ca^{2+} level in the cytosol and the protein stabilization process (González-Fontes et al. 2014).

In this context, the aim of this work was to evaluate the physiological aspects and the economic viability of common beans production in irrigated system using sources and increasing foliar boron doses.

Material and methods

Experimental area

An experiment was carried out at Federal University of Goias, Goiania, Brazil (16°35″ latitude south and 49° 21′ longitude west, at approximately 730 m of altitude and 1600 mm average annual rainfall), in an area with central pivot irrigation system. The climate is Aw (mega thermal) or tropical savannah, with dry winters and rainy summers, according to Köppen classification. Soil was classified as Rhodic Hapludox (Soil Survey Staff 2014). The soil analysis showed the following properties: pH = 5.1; Organic matter = 29 g dm^{-3}; P = 6.7 mg dm^{-3}; K = 0.52 $cmol_c$ dm^{-3}; Ca = 1.7 $mmol_c$ dm^{-3}; Mg = 0.6 $mmol_c$ dm^{-3}; S= 1.2 mg dm^{-3}; B = 0.19 mg dm^{-3}; Cu = 2.8 mg dm^{-3}; Fe = 82 mg dm^{-3}; Mn = 44 mg dm^{-3}; Zn = 4.6 mg dm^{-3}; H + Al = 2.4 $mmol_c$ dm^{-3}; CEC = 52.2 $mmol_c$ dm^{-3}; Base saturation (%) = 54%, with 470 g kg^{-1} of clay.

Experimental design

The experimental design was a randomized block, in a factorial scheme 2 × 5 × 3, with two sources of B (boric acid – 17% of B and borax – 11% of B) and five doses: 0 (control), 2, 4, 6 e 8 kg ha^{-1}, with three repetitions. Each plot had a total area of 5.06 m^2 (2.25 m × 2.25 m).

Experiment development

Prior to sowing, lime application was performed at 310 kg ha^{-1} (92% of total power neutralization), and the application amount was determined by the base saturation method (Troeh & Thompson 1993), with the aim of increase bases saturation to 65%. Using a conventional tillage system, common beans, cultivar BRS Estilo (is a new common bean cultivar with Carioca grain, suitable for cultivation in 12 states in the five macro-regions of Brazil), was sown in rows, with each plot having 5 lines spaced 0.45 m apart with a plant density of 17 plants per linear meter. On the same day, 20 kg ha^{-1} of N, 110 kg of P_2O_5 and 70 kg ha^{-1} of K_2O were applied using the following fertilizer: urea, single superphosphate and potassium chlorate, respectively. Topdressing nitrogen fertilization was performed at 20 and 40 days after seeds germination (DAG), using urea at 80 and 40 kg ha^{-1} of N, respectively. Foliar B treatments were applied 40 DAG.

Physiological parameters

The physiological parameters measured were: transpiration rate (T) (mmol m^2 s^{-1}), stomatal conductance (gs) (mmol m^2 s^{-1}), CO_2 internal concentration (Ci) (ppm) and net photosynthesis (µmol m^2 s^{-1}). These measurements were taken at R5 stage (between pre-flowering and pods formation), using an Infrared Gas Analyzer (IRGA, Li-COR, Lincoln, USA). Inside the plot, plants were chosen in a randomized pattern, and the first completely expanded leaf from the apex of the main stem was used. The measurements were performed between 9:00 h and 14:00 h.

The relative chlorophyll index (RCI) was determined at 46 DAG, using a chlorophyll meter, model FALKER®, ClorofiLOG. The equipment uses photodiodes emitting at three wavelengths: two emit within the red band, close to the peaks of each type of chlorophyll (λ = 635 and 660 nm) and one in the near infrared (λ = 880 nm). In this way, an inferior sensor receives the radiation transmitted through the leaf structure, and using this data the equipment provides the relative indexes of chlorophyll (Falker 2008).

In each plot, plants were taken in a randomized pattern, and the first completely expanded leaf from the apex of the main stem was used.

The foliar B level was evaluated in the pre-flowering stage. Samples were taken from 20 plants in each plot, using the diagnostic leaves (first leaf completely expanded), as recommended by Souza et al. (2011). The boron analyses were performed using the dry digestion method with the use of a muffle furnace and B determination was performed using a spectrophotometry with azomethine-H (Silva 2009).

In each plot, 2 m of the three central lines were harvested in 5th of October 2015. The plant´s material was weighed and sub-sampled to determine grain yield (kg ha^{-1}).

Economic analysis

The economic analysis was done using the partial budget technique (Noronha 1987). The differential profit was calculated using the budget costs and the differential income, using the control treatment as a reference. Grain productivity was used to calculate the productivity gain in B treatments related to the control (PG). The production value (PV) was obtained by the following equation:

$$PV = PG*P$$

Were: P = product price in Brazil. The average price deflated of the US$ kg^{-1} 0.81 (Agrolink 2017) was used, this value was calculated using data of price from the last 15 years (2001 up to 2016).

The differential profit was obtained by the following equation:

$$Pd = Id - Cd$$

Were: Pd = differential profit; Id = differential Income = $Iti - It_{0;}$ Cd = differential cost = $Cti - Ct_{0;}$ ti = Treatment i; t_0 = Control.

Statistical analyses

The statistical analyses were performed in a factorial scheme with two factors: B sources and B doses. When was observed significant interaction between the factors, the interactions were partitioned and the separated effect of each factor was not considered. Using the Sisvar program, Brazil (Ferreira 2014) the B source effect was evaluated using the Tukeýs test ($p \leq 0.05$) and the B doses effect was described using a regression analysis. The parameters used to choose the regression model were the F test significance, predict and adjusted R^2 and the residual plots independence (including Durbin-Watson test to verify correlation between adjacent residuals).

Results and discussion

Relative chlorophyll index _RCI

Boron application did not affect the relative chlorophyll index (RCI), with average index of 40.03 and 40.56 μg cm^{-2} for boric acid and borax, (Table 1). High chlorophyll index is associated with high N level in plants, because each chlorophyll molecule has 4 atoms of N (Godoy et al. 2008). Since B is related to N metabolism, boron deficiency may affect N levels, and, as a consequence, chlorophyll index.

In B deficient plants, there are some amino acid accumulation, and reduction of N in protein form, due to the B role in protein and nucleic acids synthesis (Cristóbal & Fontes 2007; Prado 2008). Moreover, boron is related to N assimilation, photosynthetic activity and carbohydrates metabolism (Malavolta 2006), which all these process affecting N levels in plants.

Table 1. Relative chlorophyll index (RCI), B amounts in leaves, and grain yield of *Phaseolus vulgaris* in function of sources and increasing boron doses.

Treatments	RCI	B-leaf	Grain yield
Sources (S)	μg cm^{-2}	mg kg^{-1}	kg ha^{-1}
Boric acid	40.03 a	82.54a	3471a
Borax	40.56 a	75.34b	3782b
F	0.38^{ns}	21.04**	84.98**
Rates (R) (kg ha^{-1} of B)			
0	41.81	66.66	3617
2	41.32	65.65	3530
4	40.10	78.45	3811
6	38.90	86.48	3509
8	39.34	100.46	3667
F	1.69^{ns}	75.54**	10.33**
S×R	0.68^{ns}		
	3.45*	46.62**	
C.V.	5.85	5.44	2.55

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5% probability. C.V. – Coefficient of variation.
**, * and ^{ns}significant at 1 and 5% and not significant at 5% of probability by the F test, respectively.

Silveira and Gonzaga (2017) evaluated the correlation between the RCI and the N sufficiency index (NSI) and concluded that for each 0.1 percentage point increase in the NSI to reach the adequate level (95%), it is necessary to apply 1.1–1.5 kg ha^{-1} of top-dressing N.

Relative chlorophyll index was obtained using a portable chlorophyll meter, which is an easy and cheap alternative to N determination in *Phaseolus vulgaris*.

Foliar B levels

An increase of B levels in common beans leaves was observed following foliar B application (Table 1). Applying 8 kg ha^{-1} of B, boron levels had a 55.6 and 66.5% increase after borax or boric acid application, respectively (Figure 1). In Brazilian Savanna agroecosystems, where this experiment was carried out, the indicated B level range from 30 up to 60 mg kg^{-1} (Sousa & Lobato 2004). Since the lowest B level was found in the Control (58.9 mg kg^{-1}) in all B doses, the B levels in leaves were higher than the recommended. In the highest B dose application were found B level in leaves ranging from 91.7 to 107.2 mg kg^{-1} of B in leaves after borax and boric acid application, respectively. Boric acid application increased B accumulation more than borax application (Table 1), which may be related to the higher solubility of this source compared with borax. However, in the highest dose (8 kg ha^{-1}) both sources promoted visual symptoms of B toxicity, i.e. chlorotic followed by necrosis in new leaves tip and margins (Lemiska et al. 2014). However, since B mobility is limited, boron toxicity in older leaves may

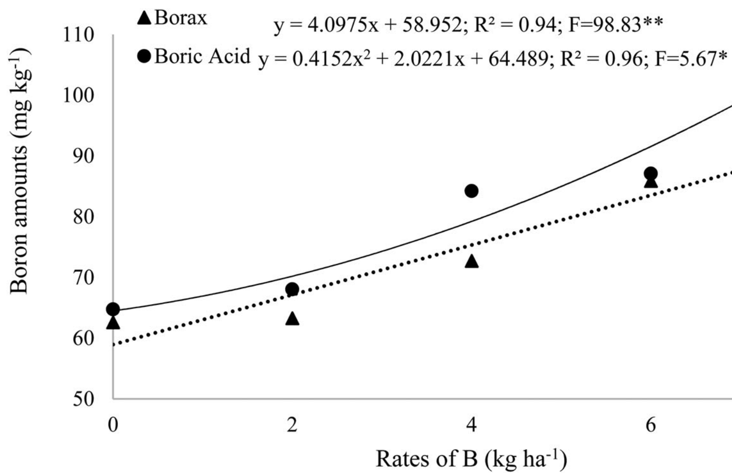

Figure 1. Boron amounts in leaves of *Phaseolus vulgaris* in function of sources and increasing boron doses in soil.
Note: ** and * – significant at 1 and 5% of probability by the F test, respectively.

not means B excess in the entire plant (Dechen & Nachtigall 2007).

Applying B on leaves, there are an increase in B absorption related to soil application (Maeda et al. 2011), with this nutrient being deposited in form of complex in the cellular wall (Prado 2008). Moreover, since B has a limited mobility in phloem (Marschner 2012), there are an accumulation of B in the diagnostic leaves, which are used to B quantification.

Grain yield

Borax application increased by 8% grain yield compared with boric acid (Table 1), representing a 311 kg ha^{-1} increment (Figure 2). Boric acid reduced grain production, suggesting a phytotoxic effect of this source. In fact, higher levels of B were observed after acid boric application compared to borax, high B doses can reduce photosynthesis, since it can cause reduction in leaf area due to leaves chlorosis followed by necrosis (Malavolta 2006; Prado 2008). Moreover, high micronutrients level in plants can reduce plant´s growth (Mattiello et al. 2009).

On the other hand, boron has a key role in many plant´s process, including cell wall formation and stability, maintenance of structural and functional integrity of biological membranes, movement of sugar or energy into growing parts of plants, and pollination and seed set. Moreover, boron is related to nitrogen fixation and nodulation in legume crops, as common beans (Dechen & Nachtigall 2007; Prado 2008; Marschner 2012; Fageria et al. 2015). Because that, boron application can increase grain yield, as observed after application of increasing doses of borax.

Ganie et al. (2014) observed an increase in flowering and grain production in *Phaseolus vulgaris* following

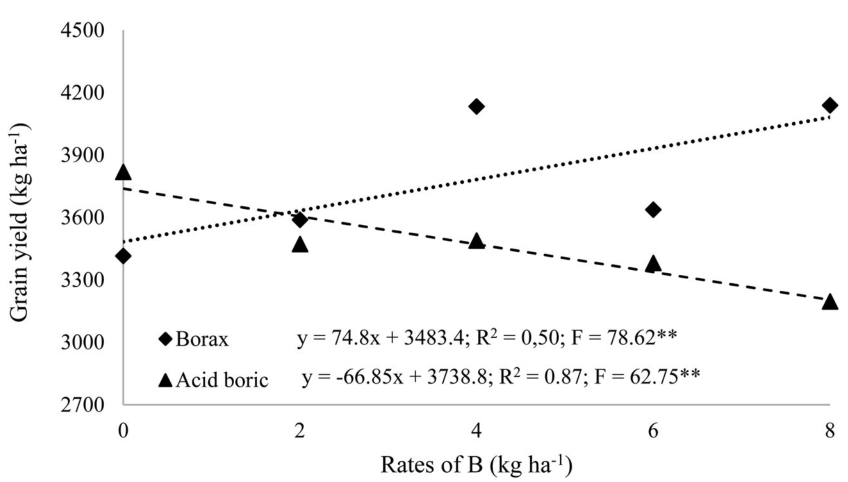

Figure 2. Grain yield of *Phaseolus vulgaris* in function of sources and increasing boron doses in soil.
Note: ** – significant at 1% of probability by the F test.

Table 2. Physiological variables of *Phaseolus vulgaris* in function of sources and increasing boron doses.

Treatments	Stomatal conductance	Liquid photosynthesis	Transpiration	Internal concentration of CO_2
Sources (S)	mmol m^2 s^{-1}	μmol m^2 s^{-1}	mmol m^2 s^{-1}	ppm
Boric acid	276.01a	11.97a	4.30a	338.52b
Borax	224.41b	11.91a	4.54a	358.54a
F	50.69**	0.02^{ns}	0.89^{ns}	27.73**
Rates (R) (kg ha^{-1} of B)				
0	256.63	10.74	4.34	347.24
2	251.66	11.44	4.36	357.06
4	266.31	13.09	4.73	348.79
6	242.86	12.54	4.34	345.07
8	233.62	11.88	4.36	344.48
F	2.41^{ns}	4.55**	0.35^{ns}	1.42^{ns}
S×R	2.93*	5.98**	0.79^{ns}	6.82**
C.V.	7.93	8.83	15.71	2.99

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5% probability. C.V. – Coefficient of variation.
**, *and ^{ns}significant at 1 and 5% and not significant at 5% of probability by the F test, respectively.

application on soil of doses up to 1.5 kg ha^{-1} of B. In this study they used an Indian soil with 0.56 mg kg^{-1} of B. Since 1.5 kg ha^{-1} of B was the highest dose applied, increasing B doses they may found a higher grain production. In another study, Harmankaya et al. (2008) applying foliar B doses up to 3 kg ha^{-1}, observed an increase of 20% in grain production of *Phaseolus vulgaris* cultivated in a soil with 0.19 mg kg^{-1} of available B. These results are similar to those obtained in the present study.

Physiological parameters

Boron sources and doses affected stomatal conductance and CO_2 internal concentration. (Table 2), moreover an interaction effect was observed between these factors. Stomatal conductance was higher (23%) after boric acid application compared with borax. An inverse behavior was observed for CO_2 internal concentration, which was higher with borax (6%). Increasing borax doses cause a decrease in stomatal conductance (Figure 3), which was 17% lower after application of 8 kg ha^{-1} of B, compared with control; and a linear increase in CO_2 internal concentration (figure 4). Since gas exchange is reduce with reduced stomatal conductance, higher CO_2 internal concentration is expected after a reduction of stomatal conductance, as observed in borax treated plants.

Regarding net photosynthesis (NP), an interaction effect between B doses and sources was observed. After increasing doses of boric acid, net photosynthesis increased linearly, with the highest NP rate (13.50 μmol m^2 s^{-1}) observed after application of 8 kg, it represents an enhance of 29% compared with control. This increase in NP after B application can be attributed to some alterations in organic compounds in leaves (Silva 2007), which improve the chloroplast membrane regulation and the electron transportation in thylakoids, reducing photoinhibition potential (Goldbach et al. 2007).

Using borax as source, the highest net photosynthesis (13.35 μmol m^2 s^{-1}) was observed after application of 3.87 kg ha^{-1} of B, and represented an 25% increase compared with control (Figure 5). However, when higher

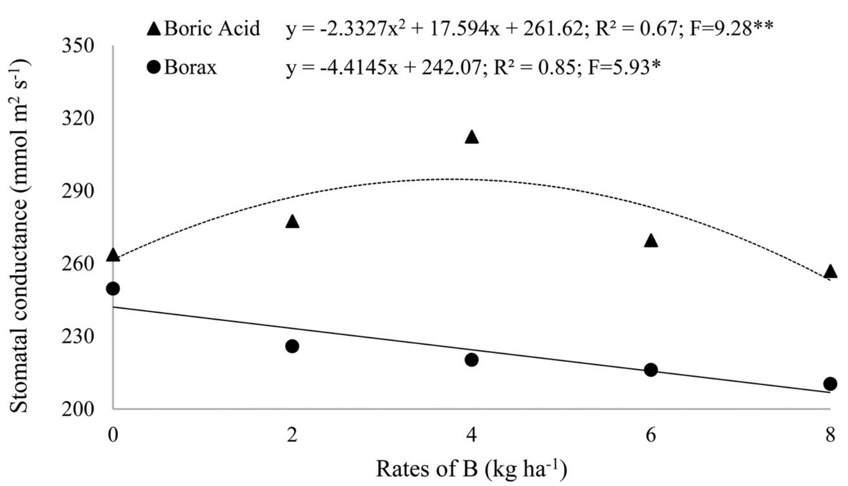

Figure 3. Stomatal conductance of *Phaseolus vulgaris* in function of sources and increasing boron doses in soil.
Note: ** and * – significant at 1 and 5% of probability by the F test, respectively.

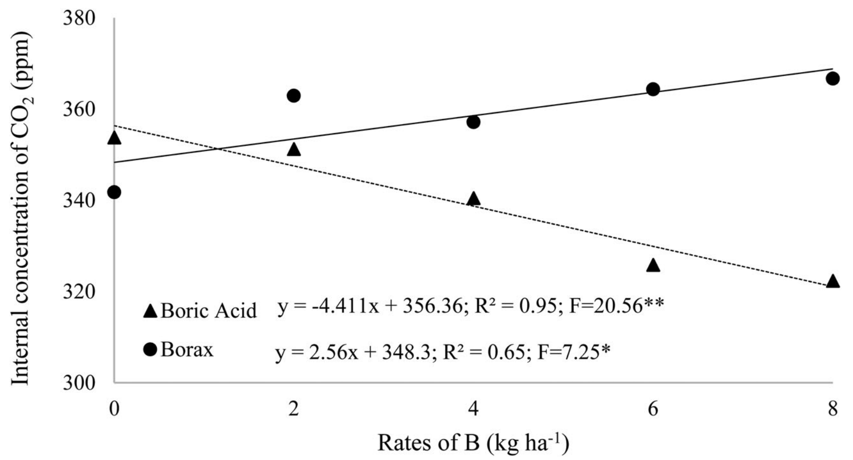

Figure 4. Internal concentration of CO_2 of *Phaseolus vulgaris* in function of sources and increasing boron doses in soil.
Note: ** – significant at 1% of probability by the F test.

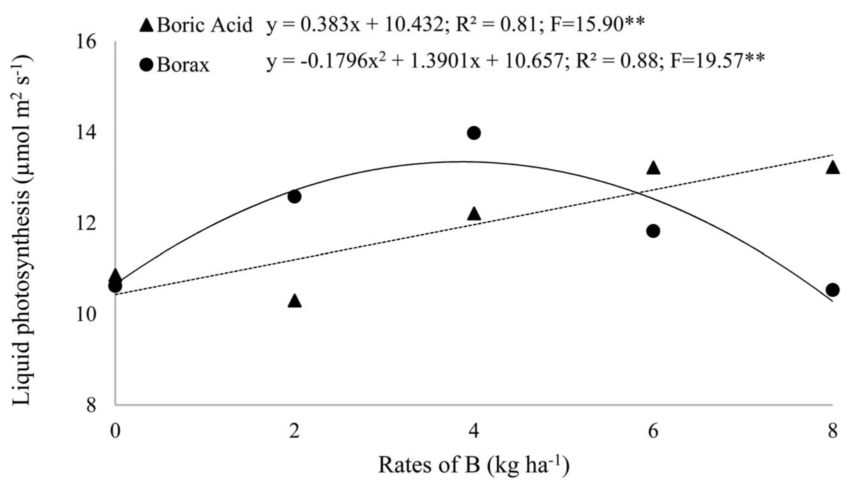

Figure 5. Liquid photosynthesis of *Phaseolus vulgaris* in function of sources and increasing boron doses in soil.
Note: ** and * – significant at 1 and 5% of probability by the F test, respectively.

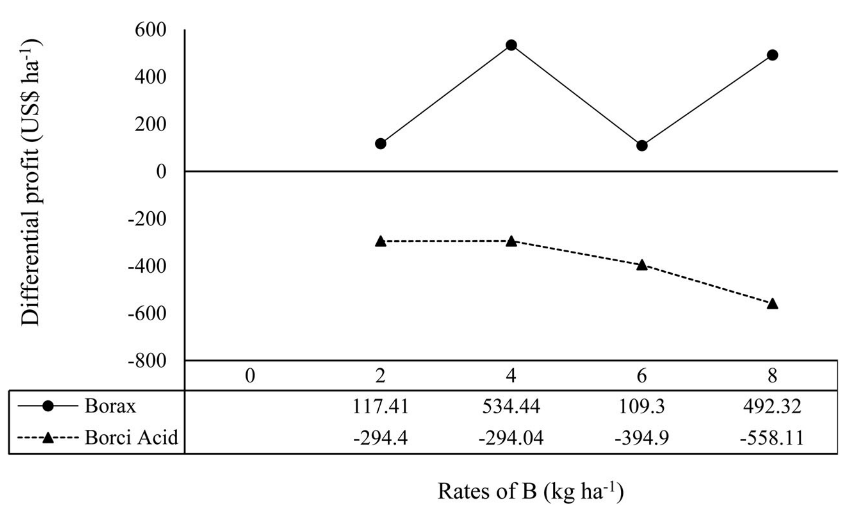

Figure 6. Differential profit of *Phaseolus vulgaris* in function of sources and increasing boron doses in soil.

doses were applied, a reduction in net photosynthesis was observed. According to Silva (2007), when B is applied in excess high B levels in cytoplasm may cause NAD^+ complex formation, which reduces photosynthesis.

Economical analyses

The boric acid application was not profitable (Figure 6) compared with control, showing negative differential profit in all evaluated doses. However, all borax doses promoted a positive differential profit (Figure 6), with the dose of 4 kg ha^{-1} being more efficient than the others. Since micronutrients contributed with only 0.5% of total production costs (Richetti & Melo 2013), boron application, using borax as source, at a rate of 4 kg ha^{-1} of B, is highly recommendable and it can increase grain production providing a differential profit of US$ 534.44 per hectare compared to systems without B application.

Disclosure statement

No potential conflict of interest was reported by the authors.

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