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Growth of Brazilian Cotton Cultivars in Response to Soil Applied Boron

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ABSTRACT

The growth of cotton (*Gossypium hirsutum* L.) was evaluated in a 6 × 5 factorial experiment with 6 boron (B) levels (0.0, 0.5, 1.0, 1.5, 2.0, and 3.0 mg dm^{-3}), 5 cultivars ('CNPA 8H', 'BRS Aroeira', 'BRS Antares', 'BRS Sucupira', 'BRS Ipe'), and 3 replications. As B increased in the soil, leaf B concentrations increased linearly in 'BRS Aroeira' and 'CNPA 8H', and quadratically in 'BRS Ipe' and 'BRS Sucupira'. The concentrations of B in the leaves and in the soil increased with the B increasing in the soil. The agronomic characteristics evaluated showed 'BRS Aroeira' and 'BRS Sucupira' responding more and BRS responding less to the B doses applied. The variation in the effFiciency of B utilization was: 'BRS Aroeira' > 'CNPA 8H' = 'BRS Antares' > 'BRS Sucupira' > 'BRS Ipe'. Cultivar 'BRS Aroeira' had the greatest potential to respond positively to the addition of B to the soil.

Keywords: boron, cotton, plant growth, soil fertility

INTRODUCTION

The textile industry has a crescent demand for cotton which is considered the principal clothing fiber of the world. In Brazil, it is important to increase the cotton quality and yield since the cotton industry plays an important role in the social and economic relations of many regions in the country (Richetti and Melo Filho, 2001). Boron (B) deficiency has been detected in cotton crops and may cause drastic decreases in yield (Staut and Kurihara, 2001). Soil fertilizer

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applications without B may be a cause of lower cotton productivity in the Brazilian "cerrado" soils (Lopes, 1999).

Boron is present in the plant cell wall structures, being important for transport of sugars, cell wall synthesis, lignification process, carbohydrate metabolism, RNA, phenolic compounds, and indol-acetic acid metabolisms, and for cell membrane and cell wall integrity (Hu and Brown, 1994; Findeklee and Goldbach, 1996; Cakmak and Römheld, 1997; Matoh and Kobayashi, 1998). Accumulation of phenols in B deficient plant tissues is related to the appearing of detrimental effects in some cellular functions (Cakmak and Römheld, 1997). Boron is absorbed by plant roots mainly as undissociated boric acid (H_3BO_3) (Hu and Brown, 1997) and contents above 16 mg kg^{-1} in cotton recent matured leaves are considered sufficient for growth and yield (Rosolem et al., 1999). For plants in general, the critical level for B deficiency in soils is 0.60 mg kg^{-1} with hot water extraction (Raij et al., 1996; Alvarez V. et al., 1999), whereas for cotton, the critical range is between 0.4 and 0.55 mg kg^{-1} (Oosterhuis, 2001).

The selection of a cultivar efficient in B utilization may prevent drops in productivity and, consequently, in profit, mainly in situations where the application of B fertilizers is not possible for some reason (Rerkasem, 2002).

The cotton crop has been responsive to B application, mainly in sandy soils with low organic matter content, corrected pH, and adequately fertilized with nitrogen (N), phosphorus (P), and potassium (K) (Rosolem et al., 2001).

The aim of this work was to evaluate the response of Brazilian cotton cultivars to different doses of B applied to the soil.

MATERIAL AND METHODS

The experiment was carried out in a greenhouse at the Cotton National Research Center (07°13'50" of latitude south, 35°52'52" of longitude west, 551 m height), which is part of the Brazilian institution for agricultural and animal science research EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária) located in the city of Campina Grande, Paraiba State.

The plants were grown in a sandy soil (Table 1) collected in cotton field located in the Touro County, Rio Grande do Norte State.

The experiment was set in a completely random design with treatments arranged factorially 6 × 5 × 3 [6 B doses (0.0, 0.5, 1.0, 1.5, 2.0, and 3.0 mg dm^{-3}); 5 cotton cultivars ('CNPA 8H', 'BRS Aroeira', 'BRS Antares', 'BRS Ipe', and 'BRS Sucupira'); and 3 replications]. These cotton cultivars are among the most indicated ones for the northeast region of Brazil by EMBRAPA.

The plants were grown in plastic recipients containing 7 dm^3 of soil air dried and sieved to particles smaller than 2 mm diameter. The sowing was made with eight seeds in each recipient and the recipients were randomly distributed in the benches of the greenhouse. After 7 d, four plants were eliminated from each

Table 1
Chemical and physical characteristics of a soil used to grow cotton cultivars

pH(soil: water) (1:2.5)	P	K	Na^+	Ca^{2+}	Mg^{2+}	H+Al
	mg dm^{-3}			$cmol_c$ dm^{-3}		
5.3	2.39	19.41	0.01	0.48	0.42	1.54
Al^{3+}	Sum of bases	Effective CEC	CEC pH 7.0	Base saturation	Al saturation	Organic matter
	$cmol_c.dm^{-3}$				%	
0.13	0.96	1.09	2.50	38.40	11.93	0.68
Fe	Cu	Mn	Zn	B		
	mg.dm^{-3}					
5.60	0.33	15.40	0.70	0.33		
	Particle size					
	Sand		Silt		Clay	
	%					
	88.4		4.4		7.2	

recipient. Irrigation was made periodically to maintain the soil at field capacity. The B concentrations in the irrigation water were lower than 0.002 mg L^{-1}.

The cotton seeds were treated with benomyl to prevent the action of pathogens as *Colletotrichum gossypii, Fusarium spp*., and *Rhizoctonia solani*. The insect control was made with insecticides containing monocrotophos and buprofezin. All chemicals were used based on the recommendations regularly used for the cotton crop.

Before sowing, the B doses (0.0, 0.5, 1.0, 1.5, 2.0, and 3.0 mg dm^{-3}) were prepared with H_3BO_3. Additionally, for all treatments an added solution (100 mL per 3 kg of soil) containing 100 mg kg^{-1} N as ammonium phosphate ($NH_4H_2PO_4$); 300 mg kg^{-1} P as $NH_4H_2PO_4$; 150 mg kg^{-1} K mg/kg as potassium phosphate (KH_2PO_4); 40 mg kg^{-1} S as potassium sulfate (K_2SO_4); 1.33 mg kg^{-1} copper (Cu) as copper sulfate ($CuSO_4.5H_2O$); 1.55 mg kg^{-1} iron (Fe) as iron chloride ($FeCl_3.6H_2O$); 3.66 mg kg^{-1} manganese (Mn) as manganese chloride ($MnCl_2.4H_2O$); 0.15 mg kg^{-1} molybdenum (Mo) as sodium molybdate ($NaMoO_4.2H_2O$); 4.00 mg kg^{-1} zinc (Zn) as zinc sulfate

($ZnSO_4.7H_2O$) (Novais et al., 1991). The dose of N was divided, 1/3 applied at the sowing and the remaining 2/3 applied 30 d after that.

The soil pH, P, K, sodium (Na), calcium (Ca), magnesium (Mg), aluminum (Al), H + Al, organic matter, Fe, Cu, Mn, Zn, and the physical characteristics (Table 1) were determined according to EMBRAPA (Embrapa, 1997). Boron (Table 1) was extracted from the soil with hot water and determined by colorimetry with curcumin (Tedesco, 1995). This B analysis was used for the soil samples collected after harvesting the plants.

The 5ª leaf of each cotton plant, having as reference the stem apex, was collected 80 d after the sowing. The material was dried at 65–70°C for 48 h, ground in a Willey Mill, passed through a 20 mesh sieve, and after calcination, the leaf B concentration was determined by colorimetry with azomethine-H (Tedesco, 1995).

At the 30th, 60th, and 90th d after sowing, one plant per recipient was cut near to the soil surface. The aerial parts of the plants were dried at 65–70°C for 48 h and the dry weight recorded. At the 90th day, it was recorded the plant height, the height of insertion of the first fruiting branch, the diameter of the stem at 1 cm from soil surface. The leaf area Y (in cm^2) was determined as recommended by Wendt (1967), by measuring the longitudinal length of the leaf (X in cm) and using the equation: $\log Y = 0.045 + 1.910 \log X$; ($R^2 = 0.98$). Additionally, the number of flower buds, number of flowers, number of fruits, number of vegetative branches, and number of fruiting branches per plant were recorded. The number of abscised reproductive structures (flower buds, flowers, and fruits) per plant was counted and the number of days between sowing and the opening of the first flowers in the cultivars were recorded.

Analysis of variance was performed to test the interactions between cultivars and doses of B applied, independently if there was a significant effect, in order to evaluate the effect of B applied to soil within each cultivar. The models tested for the equations were linear, quadratic, cubic, and quadratic. For number of flower buds, flowers, and fruits per plant and days for opening of the first flower as well as for number of vegetative branches, fruiting branches, and abscised reproductive structures per plant, the equations were generated with the data transformed to square root values. Among the models with significant determination coefficient, it was chosen the model with higher determination coefficient (R^2). The coefficients were tested based on the residue mean square, up to the 10% probability level.

RESULTS AND DISCUSSION

The concentrations of B in the soil varied from 0.47 to 1.04 mg dm^{-3} in the recipients where the 'CNPA 8H' was grown, 0.66 to 1.24 mg dm^{-3} for the 'BRS Aroeira', 0.79 to 1.28 mg dm^{-3} for the 'BRS Antares', 0.48 to 1.21 mg dm^{-3} for the 'BRS Ipe', and 0.46 to 0.97 mg dm^{-3} for the 'BRS Sucupira' (Table 2).

Table 2
Soil B concentration, plant height, height of 1st fruiting branch insertion and stem diameter of cotton cultivars as a function of B applied to the soil

B dose	Soil B concentration	Plant height	Height of 1st fruiting branch insertion	Stem diameter
	mg dm^{-3}		cm	
		'CNPA 8H'		
0.0	0.47 (0.14)	69.33 (7.33)	30.33 (3.81)	0.83 (0.02)
0.5	0.72 (0.10)	83.00 (3.51)	34.00 (1.76)	0.89 (0.03)
1.0	0.81 (0.24)	76.33 (5.70)	34.33 (1.69)	0.83 (0.04)
1.5	1.04 (0.18)	81.00 (7.57)	32.83 (5.07)	0.81 (0.06)
2.0	0.94 (0.34)	72.17 (8.30)	31.83 (3.56)	0.90 (0.04)
3.0	0.77 (0.10)	78.00 (4.73)	32.33 (2.33)	0.82 (0.03)
Mean	0.79 a	76.6 ab	32.6 ab	0.85 a
		'BRS Aroeira'		
0.0	0.66 (0.12)	70.33 (5.04)	34.33 (2.74)	0.82 (0.05)
0.5	0.83 (0.09)	67.50 (1.32)	34.17 (2.46)	0.87 (0.07)
1.0	1.12 (0.22)	73.33 (6.74)	32.50 (3.51)	0.80 (0.03)
1.5	0.98 (0.23)	72.00 (3.00)	30.33 (0.88)	0.82 (0.03)
2.0	1.02 (0.06)	74.33 (2.33)	33.00 (1.00)	0.82 (0.02)
3.0	1.24 (0.19)	82.33 (4.84)	35.33 (4.10)	0.88 (0.04)
Mean	0.97 a	73.3 ab	33.3 ab	0.83 a
		'BRS Antares'		
0.0	0.91 (0.08)	70.83 (4.95)	27.67 (2.91)	0.89 (0.01)
0.5	0.79 (0.16)	73.33 (5.93)	30.17 (1.69)	0.83 (0.02)
1.0	0.84 (0.07)	84.33 (7.36)	33.17 (1.17)	0.90 (0.03)
1.5	0.84 (0.04)	81.33 (7.75)	34.67 (3.18)	0.87 (0.03)
2.0	1.27 (0.22)	85.33 (1.76)	31.00 (3.55)	0.83 (0.03)
3.0	1.28 (0.28)	85.00 (7.23)	36.33 (4.91)	0.93 (0.11)
Mean	0.99 a	80.0 a	32.2 ab	0.87 a
		'BRS Ipe'		
0.0	1.21 (0.24)	69.67 (1.76)	32.00 (0.00)	0.80 (0.02)
0.5	0.48 (0.01)	77.50 (3.55)	27.00 (0.87)	0.88 (0.01)
1.0	0.99 (0.10)	70.83 (0.44)	32.50 (1.50)	0.84 (0.08)
1.5	0.79 (0.08)	66.00 (4.62)	30.83 (1.36)	0.83 (0.01)
2.0	0.96 (0.09)	66.67 (6.23)	33.67 (2.03)	0.84 (0.01)
3.0	1.15 (0.15)	69.00 (7.01)	33.50 (3.25)	0.87 (0.09)
Mean	0.93 a	69.9 b	31.6 b	0.84 a
		'BRS Sucupira'		
0.0	0.46 (0.10)	66.33 (6.33)	32.33 (1.33)	0.81 (0.06)
0.5	0.73 (0.10)	80.00 (3.61)	36.00 (2.18)	0.84 (0.07)
1.0	0.84 (0.03)	72.33 (1.86)	34.67 (3.09)	0.77 (0.01)
1.5	0.97 (0.20)	74.83 (4.09)	33.00 (2.18)	0.89 (0.01)
2.0	0.83 (0.10)	81.50 (2.02)	40.33 (4.64)	0.88 (0.05)
3.0	0.88 (0.10)	81.67 (4.26)	41.33 (2.85)	0.81 (0.04)
Mean	0.78 a	76.1 ab	36.3 a	0.83 a

*Values in parentheses represent the mean standard error.

Means followed by the same letter in the column are not different at the 5% probability by the Tukey Test.

Table 3
Regression equations for the variation of soil B concentration, plant height, height of 1st fruiting branch insertion and stem diameter of cotton cultivars as a function of B applied to the soil

Cultivar	Equation	R^2
	Soil B concentration (mg dm^{-3})	
'CNPA 8H'	$\hat{y} = 0.47 + 0.553848\ B - 0.1509524^{*}\ B^2$	0.993
'BRS Aroeira'	$\hat{y} = 0.75 + 0.1668572^{*}\ B$	0.744
'BRS Antares'	$\hat{y} = 0.77 + 0.1671428^{*}\ B$	0.644
'BRS Ipe'	$\hat{y} = 1.16 - 1.0308\ B + 0.608902^{\circ}\ B^{0,5}$	0.616
'BRS Sucupira'	$\hat{y} = 0.63 + 0.1171428^{\circ}\ B$	0.510
	Plant height (cm)	
'CNPA 8H'	$\hat{y} = \bar{y} = 76.6$	
'BRS Aroeira'	$\hat{y} = 67.8 + 4.167^{\circ}\ B$	0.799
'BRS Antares'	$\hat{y} = 73.5 + 4.8762^{*}\ B$	0.685
'BRS Ipe'	$\hat{y} = \bar{y} = 69.9$	
'BRS Sucupira'	$\hat{y} = 70.7 + 4.0619^{\circ}\ B$	0.516
	Height of 1st fruiting branch insertion (cm)	
'CNPA 8H'	$\hat{y} = \bar{y} = 32.6$	
'BRS Aroeira'	$\hat{y} = \bar{y} = 33.3$	
'BRS Antares'	$\hat{y} = 29.0 + 2.38572^{*}\ B$	0.661
'BRS Ipe'	$\hat{y} = \bar{y} = 31.6$	
'BRS Sucupira'	$\hat{y} = 32.5 + 2.8472^{*}\ B$	0.666
	Stem diameter (cm)	
'CNPA 8H'	$\hat{y} = \bar{y} = 0.85$	
'BRS Aroeira'	$\hat{y} = \bar{y} = 0.83$	
'BRS Antares'	$\hat{y} = \bar{y} = 0.88$	
'BRS Ipe'	$\hat{y} = \bar{y} = 0.84$	
'BRS Sucupira'	$\hat{y} = \bar{y} = 0.83$	

^{o}Significant at the 10% probability level; * Significant at the 5% probability level.

There was a positive and linear relationship between the B concentrations in the soil and the doses applied in the treatments for the cultivars 'BRS Aroeira', 'BRS Antares', and 'BRS Sucupira' whereas for the 'CNPA 8H' and 'BRS Ipe' cultivars the relationship were, respectively, quadratic and quadratic with square root base (Table 3).

For the treatment without B, the means of soil B concentrations were 0.46 mg dm^{-3} in recipients where the 'BRS Sucupira' was grown, 0.47 mg dm^{-3} for 'CNPA 8H', 0.66 mg dm^{-3} for 'BRS Aroeira', 0.91 mg dm^{-3} for 'BRS Antares', and 1.21 mg dm^{-3} for 'BRS Ipe' (Table 2). The critical level of B in the soil is in the range 0.4–0.6 mg dm^{-3} (Silva and Carvalho, 1994; Alvarez V. et al., 1999). In the recipients with 'BRS Sucupira' and 'CNPA 8H'

the B availability in the soil was in the range 0.4–0.6 mg dm^{-3}, whereas for 'BRS Aroeira', 'BRS Antares', and 'BRS Ipe' it was above that. This shows that even in the treatment without B application, the B concentration in the soil was above or near the sufficiency level for plant growth.

The plant heights were in the range 69.3 to 83.0 cm for the 'CNPA 8H' cultivar, 67.5 to 82.3 cm for 'BRS Aroeira', 70.8 to 85.3 cm for 'BRS Antares', 66.0 to 77.5 cm for 'BRS Ipe', and 66.3 to 81.7 cm for 'BRS Sucupira' (Table 2). The regression analysis shows a positive and linear adjustment between plant height and B applied to soil in the 'BRS Aroeira', 'BRS Antares', and 'BRS Sucupira', whereas for 'CNPA 8H' and 'BRS Ipe' there was no response (Table 3). For the height of the first fruiting branch insertion, in response to the B applied to soil, the same adjustments for the equations were observed, except for 'BRS Aroeira' that was linear and positive. In cotton, this is a characteristic of each cultivar (Souza and Beltrão, 1999); however, it may be changed by the environmental conditions. The proper insertion of the first fruiting branch is important since it allows efficacy in the cotton mechanical harvest and assures a higher quality of the product. It was verified (Rosolem and Costa, 1999), under the lack of B, even temporarily, a diminishing of the cotton plant height as well as of the first fruiting branch insertion height in the cotton plant.

The stem diameter was not influenced by the B doses (Tables 2 and 3) similarly to the observation for the cotton cultivar 'IAC 22' in greenhouse (Rosolem and Bastos, 1997).

The leaf area varied from 2394 to 3509 cm^2 for cultivar 'CNPA 8H', 1224 to 2912 cm^2 for 'BRS Aroeira', 2443 to 3380 cm^2 for 'BRS Antares', 2452 to 3060 cm^2 for 'BRS Ipe', and 1682 to 2562 cm^2 for 'BRS Sucupira' (Table 4). Only 'BRS Aroeira' and 'BRS Sucupira' showed leaf area increase as a function of the B applied to the soil (Table 5).

The dry matter at the 90th day after sowing varied from 23.3 to 33.9 g $plant^{-1}$ for the 'CNPA 8H' cultivar, 20.1 to 29.1 g $plant^{-1}$ for 'BRS Aroeira', 27.3 to 31.6 g $plant^{-1}$ for 'BRS Antares', 25.1 to 38.4 g $plant^{-1}$ for 'BRS Ipe', and 19.9 to 27.6 g $plant^{-1}$ for 'BRS Sucupira' (Table 4). At the 30th day after sowing, the quadratic equation and the quadratic equation based in square root data showed the best adjustment for dry matter adjusted as a function of B doses, for 'BRS Aroeira' and 'BRS Ipe', respectively (Table 5). At the 60th and the 90th day after sowing, there was no equation adjustment, except for the aerial part of 'CNPA 8H' at the 90th day, which was a quadratic equation based in square root data. It seems that the lack of response in the dry matter increase to the B doses applied, for most cultivars, was due to the B originally present in the soil.

The number of flower buds per plant was in the range 14.7 to 19.3 for the 'CNPA 8H' cultivar, 11.0 to 18.0 for 'BRS Aroeira', 12.3 to 21.0 for 'BRS Antares', 13.0 to 18.3 for 'BRS Ipe', and 11.0 to 16.3 for 'BRS Sucupira' (Table 6) and was not affected by the doses of B (Table 7). Flowers per plant were in the range 0.0 to 1.3 for the 'CNPA 8H' cultivar, 0.3 to 1.0 for 'BRS Aroeira',

Table 4
Leaf area and shoot dry matter at the 30, 60 e 90 days after sowing of cotton cultivars as a function of B applied to the soil

B dose	Leaf area*	Shoot dry matter		
		30 days	60 days	90 days
mg dm^{-3}	cm^2	g $plant^{-1}$		
		'CNPA 8H'		
0.0	2394 (199)	2.80 (0.08)	13.83 (1.82)	23.3 (1.31)
0.5	3068 (243)	2.57 (0.26)	20.32 (6.41)	33.9 (2.90)
1.0	2675 (279)	2.54 (0.15)	15.22 (3.08)	27.9 (3.48)
1.5	2430 (47)	2.75 (0.58)	13.54 (1.61)	31.9 (4.60)
2.0	3509 (326)	3.21 (0.10)	14.63 (0.57)	32.2 (2.35)
3.0	2588 (107)	3.00 (0.24)	14.24 (3.31)	26.4 (1.96)
Mean	2777 a	2.81 a	15.30 a	29.27 a
		'BRS Aroeira'		
0.0	1836 (342)	2.24 (0.04)	14.15 (0.98)	22.0 (4.96)
0.5	2021 (121)	2.44 (0.52)	18.80 (1.47)	24.7 (2.03)
1.0	1976 (352)	2.59 (0.65)	19.36 (1.84)	23.2 (3.31)
1.5	1224 (60)	2.90 (0.28)	11.99 (1.33)	20.1 (4.81)
2.0	1990 (259)	2.48 (0.33)	15.62 (1.05)	22.8 (2.41)
3.0	2912 (168)	1.83 (0.25)	13.49 (1.66)	29.1 (4.99)
Mean	1993 a	2.41 a	15.57 a	23.60 a
		'BRS Antares'		
0.0	2443 (66)	2.65 (0.35)	14.21 (3.30)	27.3 (3.16)
0.5	2484 (207)	2.47 (0.12)	15.46 (0.34)	29.6 (3.55)
1.0	2788 (228)	1.92 (0.18)	14.18 (2.40)	30.7 (4.07)
1.5	3380 (375)	2.04 (0.06)	15.55 (1.55)	31.6 (3.14)
2.0	2769 (597)	2.66 (0.49)	11.73 (3.0)	29.6 (3.27)
3.0	2949 (526)	2.49 (0.48)	14.38 (2.55)	29.6 (8.15)
Mean	2802 a	2.37 a	14.25 a	29.73 a
		'BRS Ipe'		
0.0	2483 (335)	2.86 (0.10)	13.67 (1.07)	25.8 (2.93)
0.5	3060 (219)	2.12 (0.03)	9.00 (1.45)	38.4 (1.01)
1.0	2214 (255)	2.00 (0.36)	11.59 (1.43)	25.1 (1.30)
1.5	2452 (182)	2.44 (0.37)	13.31 (0.51)	26.0 (1.76)
2.0	2539 (402)	2.51 (0.52)	13.67 (3.31)	27.0 (4.74)
3.0	2096 (145)	2.93 (0.40)	14.51 (4.05)	25.4 (5.98)
Mean	2474 a	2.48 a	12.62 a	27.95 a
		'BRS Sucupira'		
0.0	2294 (145)	2.52 (0.11)	17.46 (3.59)	24.7 (6.27)
0.5	2144 (72)	2.22 (0.07)	12.01 (1.87)	23.3 (1.74)
1.0	1711 (194)	2.49 (0.19)	13.73 (2.05)	22.6 (2.58)
1.5	2562 (423)	2.67 (0.35)	12.91 (2.48)	27.6 (3.03)
2.0	2524 (335)	2.95 (0.21)	14.58 (0.53)	27.1 (3.85)
3.0	1682 (582)	2.70 (0.39)	11.99 (3.63)	19.9 (5.08)
Mean	2152 a	2.59 a	13.78 a	24.20 a

*Values in parentheses represent the mean standard error.

Means followed by the same letter in the column are not different at the 5% probability by the Tukey Test.

Table 5
Regression equations for leaf area and shoot dry matter at the 30, 60 e 90 days after sowing of cotton cultivars as a function of B applied to the soil

Cultivar	Equation	R^2
	Leaf area (cm^2)	
'CNPA 8H'	$\hat{y} = \bar{y} = 2777$	
'BRS Aroeira'	$\hat{y} = 2042 - 718.878^{*}\ B + 330.630^{*}\ B^2$	0.690
'BRS Antares'	$\hat{y} = \bar{y} = 2802$	
'BRS Ipe'	$\hat{y} = \bar{y} = 2474$	
'BRS Sucupira'	$\hat{y} = 2346 - 1522.906\ B + 1593.82\ B^2 - 386.6744^{*}\ B^3$	0.731
	Shoot dry matter at 30 days (g $plant^{-1}$)	
'CNPA 8H'	$\hat{y} = \bar{y} = 2.81$	
'BRS Aroeira'	$\hat{y} = 2{,}19 + 0.80305\ B - 0.30746^{*}\ B^2$	0.901
'BRS Antares'	$\hat{y} = \bar{y} = 2.37$	
'BRS Ipe'	$\hat{y} = 2.84 - 1.76302\ B + 1.06570^{\circ}\ B^{0.5}$	0.929
'BRS Sucupira'	$\hat{y} = \bar{y} = 2.59$	
	Shoot dry matter at 60 days (g $plant^{-1}$)	
'CNPA 8H'	$\hat{y} = \bar{y} = 15.30$	
'BRS Aroeira'	$\hat{y} = \bar{y} = 15.57$	
'BRS Antares'	$\hat{y} = \bar{y} = 14.25$	
'BRS Ipe'	$\hat{y} = \bar{y} = 12.63$	
'BRS Sucupira'	$\hat{y} = \bar{y} = 13.78$	
	Shoot dry matter at 90 days (g $plant^{-1}$)	
'CNPA 8H'	$\hat{y} = 23.57 + 17.1198\ B - 8.74491^{\circ}\ B^{0.5}$	0.666
'BRS Aroeira'	$\hat{y} = \bar{y} = 23.65$	
'BRS Antares'	$\hat{y} = \bar{y} = 29.73$	
'BRS Ipe'	$\hat{y} = \bar{y} = 27.96$	
'BRS Sucupira'	$\hat{y} = \bar{y} = 24.19$	

^{0}Significant at the 10% probability level.
*Significant at the 5% probability level.

0.3 to 1.3 for 'BRS Antares', 0.3 to 0.7 for 'BRS Ipe', and 0.0 to 1.0 for 'BRS Sucupira'. Only for the 'CNPA 8H', the number flowers per plant was adjusted as a function of B doses and the equation was linear and negative (Table 7). The number of fruits per plant varied from 3.7 to 5.7 for the 'CNPA 8H' cultivar, 3.7 to 6.0 for 'BRS Aroeira', 4.0 to 8.3 for 'BRS Antares', 5.7 to 10.7 for 'BRS Ipe', and 2.0 to 5.7 for 'BRS Sucupira' (Table 6). Cubic ('BRS Ipe') and quadratic ('BRS Sucupira') equations were adjusted for number of fruits per plant and B doses (Table 7).

The number of days for the opening of the first flower varied from 54 to 58 for the 'CNPA 8H' cultivar, 52 to 58 BRS for Aroeira, 51 to 56 for 'BRS Antares', 52 to 55 for 'BRS Ipe', and 55 to 57 for 'BRS Sucupira' (Table 6). There was a positive and linear relationship between number of days for the

Table 6
Number of squares, flowers and fruits per plant, and days for the opening of the 1st flower in cotton cultivars as a function of B applied to the soil

B Dose	# of squares per plant	# of flowers per plant	# of fruits per plant	Days for opening of the 1st flower
mg dm^{-3}		'CNPA 8H'		
0.0	17.3 (1.86)	1.33 (0.33)	3.67 (0.67)	55 (0.33)
0.5	19.3 (3.71)	1.33 (0.33)	3.67 (1.76)	56 (0.00)
1.0	14.6 (1.45)	1.00 (0.58)	4.33 (1.45)	55 (0.00)
1.5	16.3 (1.76)	0.00 (0.00)	5.67 (0.33)	54 (0.88)
2.0	18.3 (2.85)	0.33 (0,33)	3.67 (0,33)	58 (0.33)
3.0	15.6 (2.60)	0.33 (0.33)	5.00 (0.58)	57 (1.00)
Mean	16.9 a	0.72 a	4.33 bc	56 a
		'BRS Aroeira'		
0.0	15.3 (5.24)	0.67 (0.33)	3.67 (1.45)	55 (0.88)
0.5	13.6 (2.19)	0.33 (0.33)	6.00 (1.53)	52 (0.58)
1.0	13.0 (4.51)	0.33 (0.33)	4.67 (1.20)	56 (1.45)
1.5	13.3 (1.20)	1.00 (0.58)	4.00 (1.53)	58 (1.45)
2.0	11.0 (2.08)	1.00 (0.58)	4.00 (0.58)	56 (0.88)
3.0	18.0 (2.65)	0.67 (0.67)	4.00 (1.00)	58 (2.03)
Mean	14.0 a	0.67 a	4.39 bc	56 a
		'BRS Antares'		
0.0	21.0 (1.15)	1.33 (0.67)	5.67 (1.20)	53 (1.53)
0.5	12.3 (0.67)	0.67 (0.33)	7.67 (0.33)	51 (0.33)
1.0	18.0 (0.58)	0.33 (0.33)	4.00 (2.08)	55 (0.33)
1.5	17.0 (3.79)	1.00 (0.00)	6.33 (1.20)	53 (0.58)
2.0	15.3 (3.38)	1.00 (0.58)	6.67 (1.45)	54 (2.33)
3.0	18.6 (3.48)	0.33 (0.33)	8.33 (2.19)	56 (0.67)
Mean	17.0 a	0.78 a	6.44 ab	54 a
		'BRS Ipe'		
0.0	18.3 (0.33)	0.67 (0.33)	6.00 (0.58)	55 (0.58)
0.5	16.6 (3.84)	0.67 (0.33)	10.67 (0.88)	53 (1.45)
1.0	18.3 (5.24)	0.67 (0.67)	6.67 (1.20)	55 (0.33)
1.5	16.0 (1.53)	0.33 (0.33)	5.67 (1.45)	54 (1.00)
2.0	17.6 (2.73)	0.33 (0.33)	6.33 (2.40)	5. (0.58)
3.0	13.0 (3.00)	0.33 (0.33)	6.67 (1.67)	55 (2.31)
Mean	16.7 a	0.50 a	7.00 a	54 a
		'BRS Sucupira'		
0.0	14.3 (2.33)	0.67 (0.33)	2.00 (0.58)	55 (1.15)
0.5	15.6 (2.40)	0.67 (0.33)	3.67 (0.67)	57 (0.88)
1.0	13.6 (4.18)	0.00 (0.00)	4.00 (1.00)	56 (1.33)
1.5	16.3 (1.86)	0.00 (0.00)	5.67 (0.33)	57 (0.33)
2.0	11.0 (0.58)	1.00 (0.58)	5.00 (0.58)	56 (0.33)
3.0	11.6 (5.24)	0.33(0.33)	3.33(0.67)	57 (0.67)
Mean	13.8a	0.44a	3.94c	56a

*Values in parentheses represent the mean standard error.

Means followed by the same letter in the column are not different at the 5% probability by the Tukey Test.

Table 7
Regression equations for number of flower buds, flowers and fruits per plant, and number of days before opening of the 1st flower in cotton cultivars as a function of B applied to the soil

Cultivar	Equation[1]	R^2
	Number of flower buds per plant	
'CNPA 8H'	$\hat{y} = \bar{y} = 16.9$	
'BRS Aroeira'	$\hat{y} = \bar{y} = 14.1$	
'BRS Antares'	$\hat{y} = \bar{y} = 17.1$	
'BRS Ipe'	$\hat{y} = \bar{y} = 16.7$	
'BRS Sucupira'	$\hat{y} = \bar{y} = 13.8$	
	Number of flowers per plant	
'CNPA 8H'	(1) $\hat{y} = 1.07 - 0.167682^{*}\ B$	0.586
'BRS Aroeira'	$\hat{y} = \bar{y} = 0.67$	
'BRS Antares'	$\hat{y} = \bar{y} = 0.78$	
'BRS Ipe'	$\hat{y} = \bar{y} = 0.50$	
'BRS Sucupira'	$\hat{y} = \bar{y} = 0.44$	
	Number of fruits per plant	
'CNPA 8H'	$\hat{y} = \bar{y} = 4.3$	
'BRS Aroeira'	$\hat{y} = \bar{y} = 4.4$	
'BRS Antares'	$\hat{y} = \bar{y} = 6.4$	
'BRS Ipe'	(1) $\hat{y} = 2.57 + 0.618963\ B - 0.323484\ B^2 + 0.0367707^{*}\ B^3$	0.508
'BRS Sucupira'	(1) $\hat{y} = 1.39 + 0.510464\ B - 0.0735525^{*}\ B^2$	0.932
	Days for opening of the first flower	
'CNPA 8H'	$\hat{y} = \bar{y} = 56$	
'BRS Aroeira'	(1) $\hat{y} = 7.35 + 0.0504412^{**}\ B$	0.479
'BRS Antares'	(1) $\hat{y} = 7.24 + 0.0347002^{*}\ B$	0.447
'BRS Ipe'	$\hat{y} = \bar{y} = 54$	
'BRS Sucupira'	$\hat{y} = \bar{y} = 56$	

[1]Equations adjusted with data transformed for $\sqrt{x}$.
*Significant at the 5% probability level
**Significant at the 1% probability level.

opening of the first flower and the B doses applied to soil for 'BRS Aroeira' and 'BRS Antares' cultivars (Table 7). It seems that the increase of B added delayed the opening of the first flower for these cultivars; however, the coefficients of determination R^2 were low (below 0.5). For 'CNPA 8H', 'BRS Ipe', and 'BRS Sucupira' there was no response to B. The standard range for the opening of the first flower is from 45 to 55 d (Souza and Beltrão, 1999) depending on the cultivar and the weather conditions.

The number of vegetative branches per plant varied from 0.67 to 1.67 for cultivar 'CNPA 8H', 0.67 to 2.0 for 'BRS Aroeira', 0.67 to 3.33 for 'BRS Antares', 0.33 to 2.33 for 'BRS Ipe', and 1.67 to 2.67 for 'BRS Sucupira'. For

reproductive branches per plant the variations were 11.67 to 12.67 for cultivar 'CNPA 8H', 11.0 to 13.33 for 'BRS Aroeira', 13.0 to 14.0 for 'BRS Antares', 12.33 to 13.67 for 'BRS Ipe', and 10.67 to 14.33 for 'BRS Sucupira'. The abscised reproductive structures per plant were in the range 8.33 to 13.67 for cultivar 'CNPA 8H', 5.33 to 8.67 for 'BRS Aroeira', 8.33 to 11.67 for 'BRS Antares', 2.0 to 9.0 for 'BRS Ipe', and 6.0 to 11.0 for 'BRS Sucupira' (Table 8). Only the number of reproductive branches per plant in the 'BRS Sucupira' responded to the B application in a cubic relationship (Table 9).

Without B, the leaf concentrations were 16.6 for 'BRS Aroeira', 19.9 mg kg^{-1} for 'CNPA 8H', 20.0 mg kg^{-1} for 'BRS Antares', 29.1 mg kg^{-1} for 'BRS Sucupira', and 34.4 mg kg^{-1} for 'BRS Ipe'. As B was applied to the soil, the highest leaf B concentrations were 39.9 mg kg^{-1} for 'CNPA 8H', 45.9 mg kg^{-1} for 'BRS Aroeira', 45.1 mg kg^{-1} for 'BRS Antares', 51.5 mg kg^{-1} for 'BRS Ipe', and 47.8 mg kg^{-1} for 'BRS Sucupira' (Table 8). The concentration range considered adequate for plant growth is 30–50 mg kg^{-1} (Silva et al., 1995). The low B concentrations in the leaves of plants grown in the treatment without B, for most cultivars, were reflected in the deficiency symptoms observed in the plants. Silva and Carvalho (1982) observed deficiency in treatments without B when the cotton leaf concentration was in the range 15–40 mg kg^{-1}.

For the treatments with B (doses 0.5 to 3.0 mg dm^{-3} B), the leaf concentrations were in the range considered adequate for cotton by Silva et al. (1995), except for the 'CNPA 8H' cultivar. The leaf B concentrations in the treatments without B (0.0 mg dm^{-3}) were 16.6 mg kg^{-3} for 'BRS Aroeira', 19.9 mg kg^{-3} for 'CNPA 8H', 20.0 mg kg^{-3} for 'BRS Antares', 29.1 mg kg^{-3} for 'BRS Sucupira', and 34.4 mg kg^{-3} for 'BRS Ipe' (Table 8). The mean of the shoot dry matter from the sum of the values at 30, 60, and 90 d, at the zero B dose were 12.8 g for 'BRS Aroeira', 13.1 g for 'CNPA 8H', 14.7 g for 'BRS Antares', 14.8 g for 'BRS Sucupira', and 14.1 g for 'BRS Ipe'. The similarity of the shoot dry matter and the differences in B leaf concentrations in the cotton plants suggest a differential efficiency of B utilization by the cultivars, as it follows: 'BRS Aroeira' > 'CNPA 8H' = 'BRS Antares' > 'BRS Sucupira' > 'BRS Ipe'. As the B applied to the soil was increased, only 'BRS Aroeira' plants showed response in plant height, leaf area, shoot dry matter production at 30 and 60 d, number of days for opening of the first flower, and B leaf concentration. Additionally, the soil in the recipients with the 'BRS Aroeira' plants showed increased B concentrations as a function of the increase of the B applied to the soil. It seems that the 'BRS Aroeira' is the cultivar with the greatest possibility to respond to applications of B to the soil.

The regression equations (Table 9) showed a linear and positive relationship between the leaf B concentrations and the B doses applied to the soil for the 'CNPA 8H' and 'BRS Aroeira' cultivars. For the cultivars 'BRS Ipe' and 'BRS Sucupira' there was a quadratic relationship indicating the decrease in the increment of the leaf B as a function of the increased dose of B. The 'BRS Antares' had a quadratic adjustment based on the square root. In general, there

Table 8
Number of vegetative and fruiting branches per plant, abscised fruiting structures per plant, and B concentrations in the leaf of cotton cultivars as a function of B applied to the soil

	N° vegetative branches	N° fruiting branches	N° abscised fruiting structures	B concentration in the 5th leaf from the stem apex
mg dm^{-3}				mg kg^{-1}
			'CNPA 8H'	
0.0	1.00 (0.00)	12.67 (0.33)	8.33 (1.86)	19.9 (0.88)
0.5	1.00 (0.58)	12.67 (0.33)	10.67 (0.33)	26.2 (4.19)
1.0	1.67 (0.33)	11.67 (0.33)	8.33 (1.20)	25.7 (1.14)
1.5	0.67 (0.33)	12.33 (1.33)	10.67 (3.76)	32.3 (2.49)
2.0	0.67 (0.33)	12.67 (1.20)	13.67 (1.45)	39.9 (2.19)
3.0	1.00 (0.00)	11.67 (0.67)	8.33 (0.33)	39.3 (2.84)
Mean	1.00 a	12.3 ab	10.0 a	30.5 b
			'BRS Aroeira"	
0.0	2.00 (1.15)	12.00 (0.58)	5.67 (1,20)	16.6 (0.54)
0.5	1.00 (0.58)	11.67 (0.88)	6.33 (3.53)	30.8 (0.16)
1.0	0.67 (0.33)	12.00 (0.58)	6.67 (2.91)	31.5 (1.49)
1.5	2.00 (1.00)	11.67 (0.33)	7.67 (2.03)	35.3 (3.53)
2.0	2.00 (0.58)	11.00 (0.58)	5.33 (0.88)	40.9 (3.13)
3.0	1.00 (0.58)	13.33 (0.88)	8.67 (1.45)	45.9 (6.35)
Mean	1.40 a	11.9 b	6.7 ab	33.5 ab
			'BRS Antares'	
0.0	2.00 (1.00)	13.00 (1.15)	8.67 (3.84)	20.0 (2.38)
0.5	2.33 (1.20)	13.33 (0.33)	9.00 (1.00)	34.0 (3.28)
1.0	1.33 (0.33)	13.33 (0.67)	9.33 (1.20)	39.6 (1.20)
1.5	2.33 (0.88)	13.33 (1.20)	9.67 (3.71)	42.8 (4.74)
2.0	3.33 (0.33)	14.00 (1.00)	11.67 (5.17)	43.7 (3.49)
3.0	0.67 (0.33)	14.00 (1.00)	8.33 (2.85)	45.1 (1.54)
Mean	2.00 a	13.5 a	9.4 ab	37.5 ab
			'BRS Ipe'	
0.0	1.33 (0.67)	13.67 (0.33)	9.00 (2.52)	34.4 (2.74)
0.5	0.33 (0.33)	13.67 (0.88)	2.00 (0.58)	38.8 (3.44)
1.0	2.33 (0.88)	13.00 (1.00)	8.67 (0.67)	42.9 (4.07)
1.5	2.33 (0.33)	13.33 (0.67)	5.67 (1.45)	42.5 (1.66)
2.0	0.67 (0.33)	12.33 (1.45)	3.67 (0.67)	51.5 (1.93)
3.0	0.67 (0.67)	13.33 (0.33)	7.33 (1.76)	46.3 (0.45)
Mean	1.3 a	13.2 ab	6.1 b	42.7 a
			'BRS Sucupira'	
0.0	2.00 (0.58)	10.67 (0.88)	7.33 (2.19)	29.1 (2.10)
0.5	2.33 (0.88)	14.33 (0.67)	9.00 (2.31)	36.6 (1.52)
1.0	2.67 (1.45)	13.00 (1.53)	6.00 (2.31)	44.4 (1.63)
1.5	1.67 (0.33)	12.00 (0.58)	9.00 (2.00)	42.5 (4.83)
2.0	2.00 (1.15)	12.33 (0.88)	11.00 (1.53)	47.8 (1.21)
3.0	1.67 (0.33)	11.33 (2.19)	7.67 (0.67)	29.1 (7.24)
Mean	2.1 a	12.3 ab	8.3 ab	38.2 ab

*Values in parentheses represent the mean standard error.

Means followed by the same letter in the column are not different at the 5% probability by the Tukey Test.

Table 9
Regression equations for number of vegetative and fruiting branches per plant, abscised fruiting structures per plant, and B concentrations in the leaf of cotton cultivars as a function of B applied to the soil

Cultivar	Equation	R^2
	Number of vegetative branches per plant	
'CNPA 8H'	$\hat{y} = \bar{y} = 1.00$	
'BRS Aroeira'	$\hat{y} = \bar{y} = 1.44$	
'BRS Antares'	$\hat{y} = \bar{y} = 2.00$	
'BRS Ipe'	$\hat{y} = \bar{y} = 1.28$	
'BRS Sucupira'	$\hat{y} = \bar{y} = 2.10$	
	Number of fruiting branches per plant	
'CNPA 8H'	$\hat{y} = \bar{y} = 12.3$	
'BRS Aroeira'	$\hat{y} = \bar{y} = 11.9$	
'BRS Antares'	$\hat{y} = \bar{y} = 13.5$	
'BRS Ipe'	$\hat{y} = \bar{y} = 13.2$	
'BRS Sucupira'	$_{(1)}\hat{y} = 3.32 + 0.486494\ B - 0.188270^{\circ}\ B^2 + 0.018015^{\circ}\ B^3$	0.682
	Number of abscised fruiting structures per plant	
'CNPA 8H'	$\hat{y} = \bar{y} = 10.0$	
'BRS Aroeira'	$\hat{y} = \bar{y} = 6.7$	
'BRS Antares'	$\hat{y} = \bar{y} = 9.4$	
'BRS Ipe'	$\hat{y} = \bar{y} = 6.1$	
'BRS Sucupira'	$\hat{y} = \bar{y} = 8.3$	
	B concentrations in the leaf (mg kg^{-1})	
'CNPA 8H'	$\hat{y} = 21.3 + 6.94238^{**}\ B$	0.874
'BRS Aroeira'	$\hat{y} = 21.7 + 8.80752^{**}\ B$	0.889
'BRS Antares'	$\hat{y} = 19.8 + 25.938^{**}\ B - 6.41581^{**}\ B^{0.5}$	0.996
'BRS Ipe'	$\hat{y} = 33.9 + 11.54476^{**}\ B - 2.361108^{\circ}\ B^2$	0.834
'BRS Sucupira'	$\hat{y} = 28.2 + 22.7676\ B - 7.39556^{**}\ B^2$	0.914

[1]Equations adjusted with data transformed for $\sqrt{x}$.
[0]Significant at the 10% probability level.
*Significant at the 5% probabilitylevel.
**Significant at the 1% probability level.

was dependency between the leaf B concentration and the doses of B applied to the soil, verified by the R^2 values (above 0.830).

CONCLUSIONS

In the sandy soil studied the leaf B concentrations of the cotton plants and the B availability in the soil increase as a function of the soil fertilization with B.

A differential efficiency of B utilization by the cultivars ('BRS Aroeira' > 'CNPA 8H' = 'BRS Antares' > 'BRS Sucupira' > 'BRS Ipe') seems to occur among the cultivars studied.

Among the cultivars studied, 'BRS Aroeira' has greatest potential to respond positively to the applications of B to the soil.

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