

Potassium silicate optimizes the growth of naturally colored fiber cotton in the semi-arid

Abstract

Cotton is considered an important socioeconomic and environmental agricultural crop; its productive chain is the second economic activity in the world. The purpose of this research was to evaluate the growth of naturally colored fiber cotton cultivars under silicon foliar application. The experiment was carried out at EMBRAPA/Algodão, in Campina Grande county, Paraíba state, Brazil, using a completely randomized design, with 3 x 5 factorial scheme, which was composed by three cotton cultivars ('BRS Topázio', 'BRS Safira', and 'BRS Rubi'), five silicon concentrations (0, 50, 100, 150, and 200 mg L⁻¹), sprayed weekly on leaves, and four replicates. Growth data were submitted to analysis of variance, regression, correlation, and mean test. Treatments had a significant effect on growth variables. When calculating the effects of the factors, it was verified that the cultivars differed among them for the evaluated parameters. For 'BRS Topázio', silicon reduced plant height and increased the stem expansion rate. The application of silicon increased 'Safira BRS' plant height and growth rate. For 'BRS Rubi', silicon increased plant height and stem expansion rate.

Key words: *Gossypium hirsutum* L.; silicon; micronutrients; biometrics.

1. Introduction

Cotton (*Gossypium hirsutum* L. r. *latifolium* Hutch.) is a Malvaceae native of Mexico and Central America, stands out as one of the main crops grown in Brazil [1]. It should be observed that the country is the fifth largest producer in the world of this oil seed crop and, in the national market, cotton farming has significant importance for Brazilian agribusiness [2]. Currently, the largest Brazil's cotton production region is concentrated at Cerrado (Brazilian savana) but, according to Beltrão and Oliveira [3], Brazilian semiarid also has an edaphoclimatic conditions that favor growing this crop.

29 Naturally colored cotton developed and grown in Paraíba state has unquestionable
30 social, environmental and economic potentials. However, the production chain requires
31 the use of technologies to increase yield of this kind of cotton [4]. A viable alternative
32 to improve this kind of agricultural activity is growing colored fiber cotton cultivars
33 adapted to the semiarid climate and soil conditions. Researches involving plant growth
34 are important to support scientific and technological development, mainly with the
35 purpose of increasing crop efficiency and cotton production [2].

36 According to Floss [5], quantitative growth analysis is the first step to study plant
37 production and to obtain information about dynamics of plant biomass production.
38 Foliar application of silicon (Si) is another practice with potential for the optimization
39 of cotton production chain, especially due to the association of this nutrient to several
40 indirect effects such as increase of the photosynthetic capacity, reduction of respiration,
41 and the increase of cell mechanical resistance; those variables are directly related to
42 plants growth [6].

43 Currently, different studies show Si benefits to diverse agricultural crops such as rice
44 [7], corn [8], bean [9], soybean, and peanuts [10] among others. In spite of being not
45 regarded as an essential nutrient, Si has a crucial importance on plant/environment
46 relation, because the application of this nutrient is optimized when agricultural crops are
47 subjected to some type of stress [11].

48 Based on above considerations, this research aimed to evaluate the growth of
49 herbaceous cotton cultivars under silicon foliar applications on semiarid climate and soil
50 conditions in Paraíba state.

51 **2. MATERIAL AND METHODS**

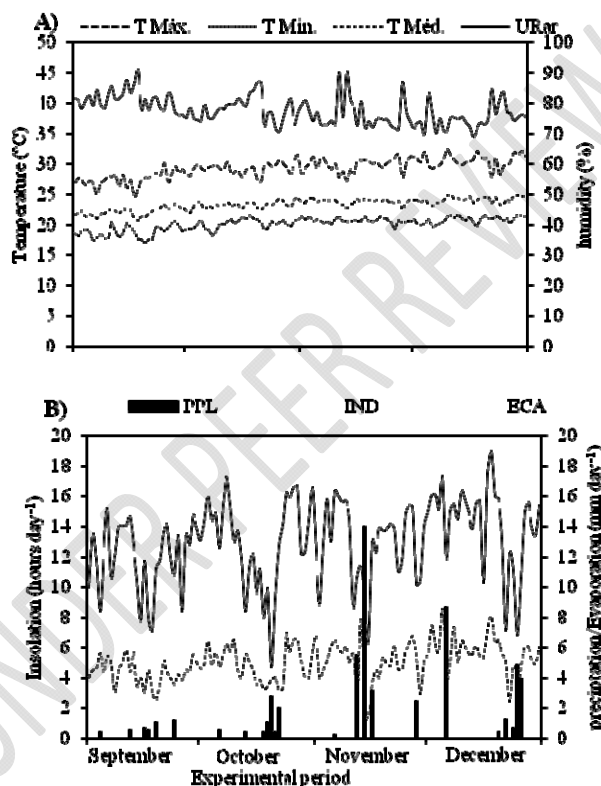
52 **2.1 Characterization of the Experimental Area**

53 The field experiment was carried out at experimental area of National Cotton Research
54 Center belonged to the Brazilian Agricultural Research Corporation
55 (CNPQ/EMBRAPA-Algodão) located in Campina Grande county (Paraíba state) and
56 geographical coordinates: latitude 07 ° 13'S, longitude 53 ° 31'W Greenwich. The city is
57 located at an altitude of 551 meters, with semiarid equatorial climate and average
58 temperature of 25°C, with relative humidity of 72-91%.

59 Climatic features were monitored daily through data collected at the automated agro-
60 meteorological station located 150 m from the experimental area. Features were:
61 maximum (T max °C), minimum (Tmin °C), and average temperature (Tavg °C),
62 relative humidity (RH%) (Figure 1A), daily insolation (IND Hours), Class A Tank
63 evaporation (ECA) (mm), and rainfall (PPL mm) (Figure 1B).

64

65



66

67 Fig. 1. Climatic variables, air temperature and humidity (A), insolation, rainfall, and evaporation (B)
68 observed throughout the experimental period

69

70 2.2 Treatments and Experimental Design

71 Treatments were established by combination of two factors: Three herbaceous cotton
72 cultivars (CV₁= 'BRS Topázio', CV₂= 'BRS Safira', and CV₃= 'BRS Rubi'), and five
73 silicon concentrations (0, 50, 100, 150, and 200 mg L⁻¹). The experimental design was a

completely randomized, in a 3 x 5 factorial scheme, and four replications. The experimental unit consisted of a cotton plant, totalizing a final stand of 60 experimental plants. 'BRS Topázio', 'BRS Safira', and 'BRS Rubi' cultivars were developed by CNPA/EMBRPA. 'BRS Topázio' was obtained by genealogical selection applied to a population derived from the cross between 'Suregrow 31' with 'Delta Opal' cultivars [12].

'BRS Safira' was obtained by crossing between a US introduced material, that had dark brown fiber coloration, with the 'CNPA 87-33', a white fiber cultivar [13]. 'BRS Rubi' was obtained by crossing between a US introduced material, which had dark brown fiber coloration, with the 'CNPA 7H' cultivar that has white color fiber [14].

A commercial potassium silicate was used as silicon source with the following chemical characteristics: Silicon (Si) = 12.0%; potassium (K) = 15.0%; saline index = 26; electrical conductivity = 1.93 dS m⁻¹; density = 1.40 g L⁻¹; pH = 10.96; physical nature = liquid. Silicon concentrations, corresponding to each treatment applied, were obtained by diluting the liquid silicate into distilled water.

2.3 Growing Environment

Each experimental unity was composed by a pot of synthetic polymeric organic material with volumetric capacity of 200 dm³, which was placed on a masonry support. All pots had their lower part filled with 10 L of gravel for water drainage; the remainder of the pot volume was filled with soil. The soil was classified as sandy-loam which was collected on Campina Grande County. Its chemical and physical characteristics were determined according to EMBRAPA (Table 1) [15].

Table 1. Chemical and physical characteristics of the soil used in the experiment

Chemical									
pH	K ⁺	Na ⁺	Ca ²⁺	Mg ²⁺	H+Al	T	V	N	OM
			(mmol _c dm ⁻³)				(%)		(g kg ⁻¹)
5.1	0.5	0.4	3.7	6.5	28.9	40	28.0	0.0	3.6
Physical									
Sand	Silt	Clay	Porosity	Particle density		Soil density		Water available	
	(%)		(%)			(g cm ⁻³)		(%)	
81.44	13.79	4.77	46.67	2.85		1.52		1.43	

* pH – pH in H₂O; K⁺ – potassium; Na⁺ – sodium, Ca²⁺ – calcium; Mg²⁺ – magnesium; H+Al – hydrogen + aluminum; T – cation exchange capacity at pH 7,0; V – base saturation percentage; N – nitrogen; OM – organic matter; AssP – assimilable phosphorus

2.4 Cultural Practices

Liming (dolomitic limestone) was applied based on soil analysis, whose quantity was estimated by exchangeable soil aluminum as well as limestone relative total neutralization power (RTNP). After applying limestone and before sowing of seeds, the soil remained incubated for 60 days as well submitted to weekly inverting and irrigation.

According to cotton requirements and soil analysis, corrective and maintenance fertilizations were carried out with nitrogen (N), phosphorus (P), and potassium (K), as the following commercial sources (N = urea, P = single superphosphate, and K = potassium chloride) which were applied in a fractional way 15 days before sowing. The remaining one was applied twice until full bloom [2].

45 days after sowing of seeds (DAS), 300 mL of complete nutrient solution was applied to the soil at each experimental unit (Table 2).

Table 2. Complete nutrient solution applied to the plots at 45 days after sowing

Chemical substances	Quantity (g L ⁻¹)
CaCl ₂ 0.025M	27.75
Ca (NO ₃) ₂ . 4H ₂ O 1M	236.15
KNO ₃ 0.5M	50.55
NH ₄ NO ₃ 0.5M	40.025
K ₂ SO ₄ 1M	174.28
Mg SO ₄ . 7H ₂ O 1M	246.470
Ca ₃ (PO ₄) ₂ 0.333M	103.297
Ca (H ₂ PO ₄) ₂ . H ₂ O 0.5M	126.045
Ca HPO ₄ . 2H ₂ O 0.5M	203.53

Zn SO ₄ . 2H ₂ O 1.21Mm	0.0348
Cu SO ₄ . 5H ₂ O 0,12Mm	0.030
Mn S ₂ O ₄ . H ₂ O 1,25mM	0.2118
(NH ₄) ₆ Mo ₇ O ₂₄ . 4H ₂ O 0.0033Mm	0.0042
H ₃ Bo ₃ 3.61Mm	0.2232
Fe SO ₄ . 7H ₂ O	6.291

114

115 At 75 days after soil liming, and at 15 days after soil fertilization, five seeds were sowing
 116 per experimental unit, at a depth of 0.03 m from soil surface. At this time, the pH was in
 117 the ideal rate, nutrients available, and soil in the field capacity. At 15 days after emergence
 118 (DAE), seedlings were thinning and the best one was chosen.

119 At the beginning, irrigations were applied to raise the soil moisture up to the level
 120 corresponding to the field capacity. The replacement of evapotranspired water by
 121 plants (ETc) occurred as a result of class 'A' tank evaporation (ECA), and crop
 122 coefficient (Kc) at different phenological stages of plants [16]. Data, referring to the
 123 reference evapotranspiration, were collected in class 'A' tank located in the
 124 agrometeorological station next to the experimental area.

125 Weeds were controlled manually throughout experimental period to eliminate
 126 interspecific competition for water and nutrients and to promote the full development of
 127 the crop. Pest and disease controls was carried out with preventive applications of
 128 commercial pesticides (Pyrethroid, neonicotinoid fungicide), by hand sprayer.

129 2.5 Treatments application

130 15 days after the emergence of the seedlings, time for establishment of the plants in the
 131 experimental plot, weekly a silicate solution was sprayed on the leaves by a hand
 132 sprayer at the abaxial and adaxial surfaces of the cotton leaves up to drainage of the

133 solution. Surfactant was used in the spray solution to improve efficiency contact of the
134 silicon on leaf surface [17].

135 **2.6 Plant growth**

136 Biometric parameters were evaluated at intervals of 20 days, beginning on fifth day of
137 seedlings emergence according to Beltrão [18]. During these intervals the following
138 growth variables were assessed: plant height (PH cm) and stem diameter (SD mm).
139 With these data, it was possible to establish the absolute growth rate (AGR cm^{-1}) and
140 the relative growth rate (RGR $\text{cm}^{-1} \text{ day}^{-1}$) in relation to plant height, which was
141 obtained through the relationships presented in [19] and [5]:

$$142 \quad TCA = \frac{M2 - M1}{T2 - T1}$$

143 Where AGR (absolute growth rate); M1 corresponds to the height of plant in season one
144 (T1); M2 measurements carried out at intervals until the last evaluation (T2).

$$145 \quad TCR = \frac{\ln M2 - \ln M1}{T2 - T1}$$

146
147 Where RGR (relative growth rate), ln (Napierian logarithmic of plant height measurement
148 at season one - T1), and measurements taken at intervals up to the last evaluation (T2).
149 Following the relations proposed by these authors, it was also possible to determine the
150 absolute expansion rate (AER mm day^{-1}), as well as the relative expansion rate (RER mm
151 day^{-1}) based on stem diameter:

$$152 \quad TEA = \frac{D2 - D1}{T2 - T1}$$

153 Where AER (absolute expansion rate of stem diameter); D1 corresponds to the stem
154 diameter in season one (T1); D2 corresponds to the measurements carried out at intervals
155 up to the last evaluation (T2):

$$RER = \frac{\ln D2 - \ln D1}{T2 - T1}$$

156

157 Where RER (relative expansion rate); ln (Napierian logarithm of the stem diameter at
158 time one (T1); measurements taken at intervals up to the last evaluation (T2).

159 2.7 Statistical Analysis

160 Data were submitted to analysis of variance by Fisher's test (F) at 5% of error probabilities.
161 For significant variables (P <0.05), the regression analysis was performed to quantitative
162 factor (silicon concentrations). The choice of regression models, for each variable, was
163 based on the significance of the regression parameters (t-test). For cultivars, the means
164 were compared using Tukey test [20]. Statistical analysis (SAEG 9.1), and Table Curve 2D
165 software were used.

166 3. Results

167 All treatments had a significant effect (P <0.01) for biometric variables such as plant
168 height (PH), absolute growth rate (AGR), relative growth, and absolute expansion rate
169 (AR) (P <0.05). When treatments effect was isolated, it was observed that Si had
170 significant effect (P < 0.05) for variables: Plant height, absolute growth rate, absolute
171 expansion rate, and relative expansion rate.

172 After analyzing the effects of the factors, it was also possible to verify that cultivars
173 presented differences (P < 0.01) for plant height and absolute growth rate variables. It was
174 also observed that silicon x cultivar interaction had a significant effect for absolute growth
175 rate (P <0.05) and relative growth rate variables (P <0.01) (Table 3).

176 **Table 3. Summary of analysis of variance for variables: plant height (PH cm), stem**
177 **diameter (SD mm), absolute growth rate (AGR cm⁻¹) in relation to plant height,**

relative growth rate (RGR cm cm⁻¹ day⁻¹) in relation to plant height, absolute expansion rate (AER mm dia⁻¹) in relation to stem diameter, and relative expansion rate (RER mm mm⁻¹ day⁻¹) in relation to stem diameter in cotton cultivars under silicon spray

S.V.	F.D.	Medium Squares					
		PH	SD	AGR	RGR	AER	RET
Treatments	(14)	237.554 ^{**}	3.853 ^{ns}	0.020 ^{**}	0.36E-5 ^{**}	0.58E-3 [*]	0.5E-5 ^{ns}
Silicon (Si)	4	285.010 [*]	3.572 ^{ns}	0.014 [*]	0.25E-5 ^{ns}	0.86E-3 [*]	0.1E-4 [*]
Linear	1	467.285 [*]	4.641 ^{ns}	0.1E-4 [*]	0.5E-6 ^{ns}	0.18E-2 [*]	0.3E-4 ^{**}
Quadratic	1	493.714 [*]	1.885 ^{ns}	0.055 ^{**}	0.1E-5 ^{ns}	0.88E-3 ^{ns}	0.5E-5 ^{ns}
Cubic	1	160.083 ^{ns}	4.880 ^{ns}	0.1E-2 ^{ns}	0.2E-5 ^{ns}	0.73E-3 ^{ns}	0.6E-5 ^{ns}
Cultivar (G)	2	583.480 ^{**}	7.269 ^{ns}	0.065 ^{**}	0.5E-5 ^{ns}	0.28E-3 ^{ns}	0.5E-5 ^{ns}
Int. Si x G	8	127.344 ^{ns}	3.140 ^{ns}	0.012 [*]	0.37E-5 ^{**}	0.51E-3 ^{ns}	0.25E-5 ^{ns}
Residual	45	79.283	3.750	0.005	0.13E-5	0.41E-3	0.34E-5
C.V. (%)		15.191	12.365	23.726	22.993	12.248	15.087
Averages of cultivars							
BRS Topázio		53.280 b	15.227a	0.262 b	0.471E-2a	0.161a	0.012a
BRS Safira		64.080a	16.350a	0.371a	0.561E-2a	0.167a	0.011a
BRS Rubi		58.475ab	15.407a	0.287 b	0.522E-2a	0.168a	0.012a
DMS		6.822	1.483	0.055	0.91E-3	0.015	0.001

S.V. – Source of variation; C.V. – Coefficient of variation; F.D. – Freedom degree; Int. – Interaction **, * -

Significant at 1 and 5% respectively; ^{ns} – Not significant by F test at 5% of probability.

182

183 3.1. Plants height

184 The effect of Si concentration, on each cotton cultivar, showed that 'BRS Topázio' had
 185 29.2% reduction in its height when Si concentration was increased (Fig. 2A). In contrast,
 186 there was an increase in 'Safira BRS' height, with a higher estimated value of 69.53 cm,

187 which was obtained with the application of 94.3 mg L⁻¹ of Si. In addition, there was an
188 increase of 13.8% in relation to Si control treatment (0 mg L⁻¹). From plant height, it was
189 observed that there was a significant reduction of 18.4% up to the concentration of 200 mg
190 L⁻¹ of Si, with plants presenting 56.7 cm height (Fig. 2B)

191 The highest height (67 cm) was achieved by the application of 88.2 mg L⁻¹ of Si (increase
192 of 21.5% in 'BRS Rubi' height), when compared to the value of 52.6 cm obtained in the
193 treatment with 0 mg L⁻¹ of Si. On the other hand, after the maximum point of the curve, a
194 reduction of 23.7% was observed in relation to the critical value (51.1 cm) of plant height,
195 obtained with Si concentration of 200 mg L⁻¹ (Fig. 2C).

196 It is noted that, as the cotton cultivars reached a significant height, there was a directly
197 proportional gain in stem diameter for 'BRS Topázio', 'BRS Safira,' and 'BRS Rubi',
198 respectively (Fig. 2D, E, and F).

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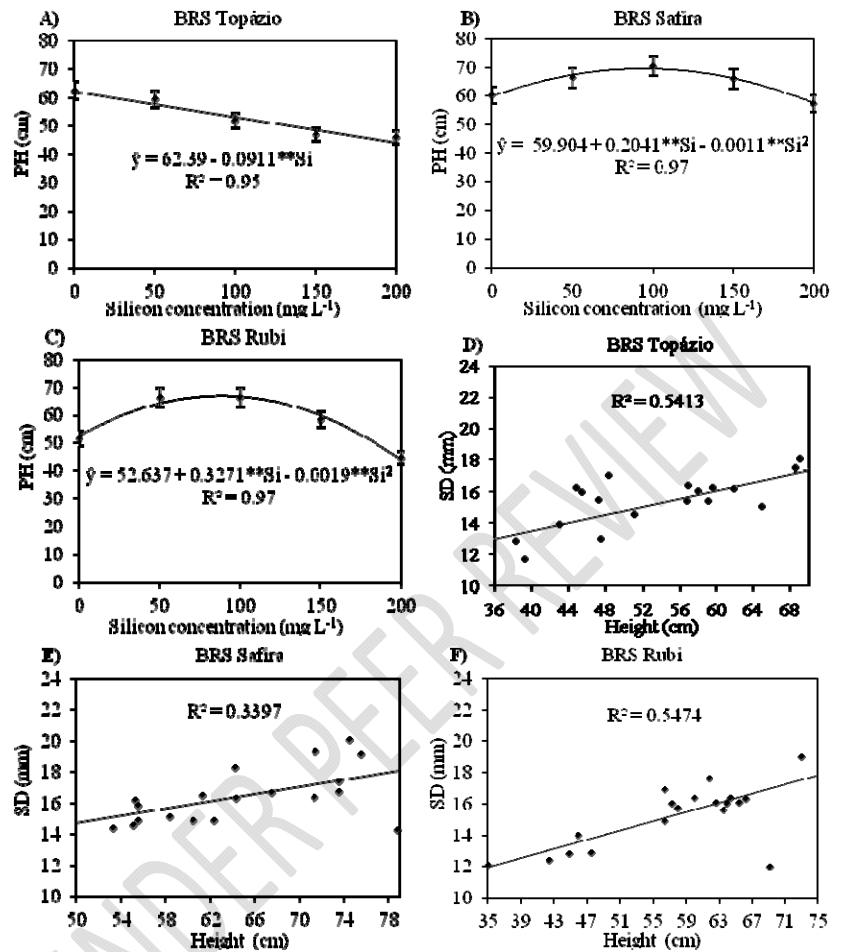


Fig. 2. 'BRS Topázio' (A), 'BRS Safira' (B), and 'BRS Rubi' (C) plants height (PH), Pearson's linear correlation for plant height variable (PH), and 'BRS Topázio' (D), 'BRS Safira' (E), and 'BRS Rubi' (F) stem diameter (SD) grown under silicon foliar application

Among the cultivars, regardless of Si concentration, 'BRS Safira' showed higher plant height (64.1 cm) as well exceeded 'BRS Topázio' and 'BRS Rubi' cultivars with the percentages 16.8 and 8.7% respectively (Table 3). When the isolated effect of cultivars was

209 calculated separately at each concentration of Si at 50 mg L⁻¹ and 200 mg L⁻¹ (without 0
210 mg L⁻¹), the cultivars did not differ among them (Fig. 3A, B, and E).

211 On the other hand, it is possible to observe differences among cultivars at 100 and 150 mg
212 L⁻¹ of Si concentration. At 100 mg L⁻¹ of Si, 'BRS Safira' showed the highest height (70.5
213 cm), and differed with 'BRS Topaz' which presented 51.9 cm. The estimated percentage
214 difference between 'BRS Safira' and 'BRS Topázio' was 26.4%. 'BRS Rubi' had
215 intermediate height (66.4 cm) and did not differ statistically from the other ones (Fig. 3C).

216 The highest plant height (65.9 cm) was verified to 'Safire BRS' at the concentration of 150
217 mg L⁻¹ of Si, although this value did not differ significantly from 53.5 cm observed to 'BRS
218 Rubi'.

219 Nevertheless, when the contrast between the value obtained by 'Safira BRS' with that one
220 expressed by 'BRS Topaz' (46.9 cm), there was a significant difference, with 'BRS Safira'
221 28.8% higher than 'BRS Topaz'. It should be noted that the value achieved in 'BRS Rubi'
222 did not differ statistically from the value observed in 'BRS Topázio' (Fig. 3D). There was
223 no significant interaction between silicon (Si) and cultivar (G) factors with regard to the
224 plant height variable (Fig. 3F).

225 Among these cultivars, regardless of Si concentration, 'BRS Safira' expressed higher plant
226 height (64.1 cm) which was higher than 'BRS Topázio' and 'BRS Rubi' at 16.8 and 8.7%
227 respectively (Table 3). When the isolated effect of cultivars, in each concentration of Si is
228 observed, cultivars did not differ at 50 mg L⁻¹ and 200 mg L⁻¹ concentrations (Figure 3A,
229 B, and E).

230 Otherwise, it is possible to observe differences among these cultivars at 100 and 150 mg L⁻¹
231 of Si concentration. Using 100 mg L⁻¹ of Si concentration, 'BRS Safira' was the cultivar
232 that expressed the higher height (70.5 cm), contrasting with 'BRS Topázio' which

233 expressed 51.9 cm. The estimated percentage difference between 'BRS Safira' and 'BRS
234 Topázio' was 26.4%. The 'BRS Rubi' plants had intermediate height (66.4 cm), and did not
235 differ statistically from the other ones (Fig. 3C).

236 At 150 mg L⁻¹ Si concentration, 'BRS' Safira showed the greater height (65.9 cm),
237 although this value did not differ significantly from 53.5 cm observed in 'BRS Rubi'.
238 However, when the contrast between the values obtained by 'BRS Safira' and 'BRS
239 Topázio' (46.9 cm), a significant difference was verified, where 'BRS Safira' was higher at
240 28.8 % when compared to 'BRS' Topázio. It may be noted that the value obtained by 'BRS
241 Rubi' did not differ statistically from the value observed to 'BRS Topázio' (Fig. 3D). There
242 was no significant interaction between the factors silicon (Si) and cultivars (G) for plant
243 height variable (Fig. 3F).

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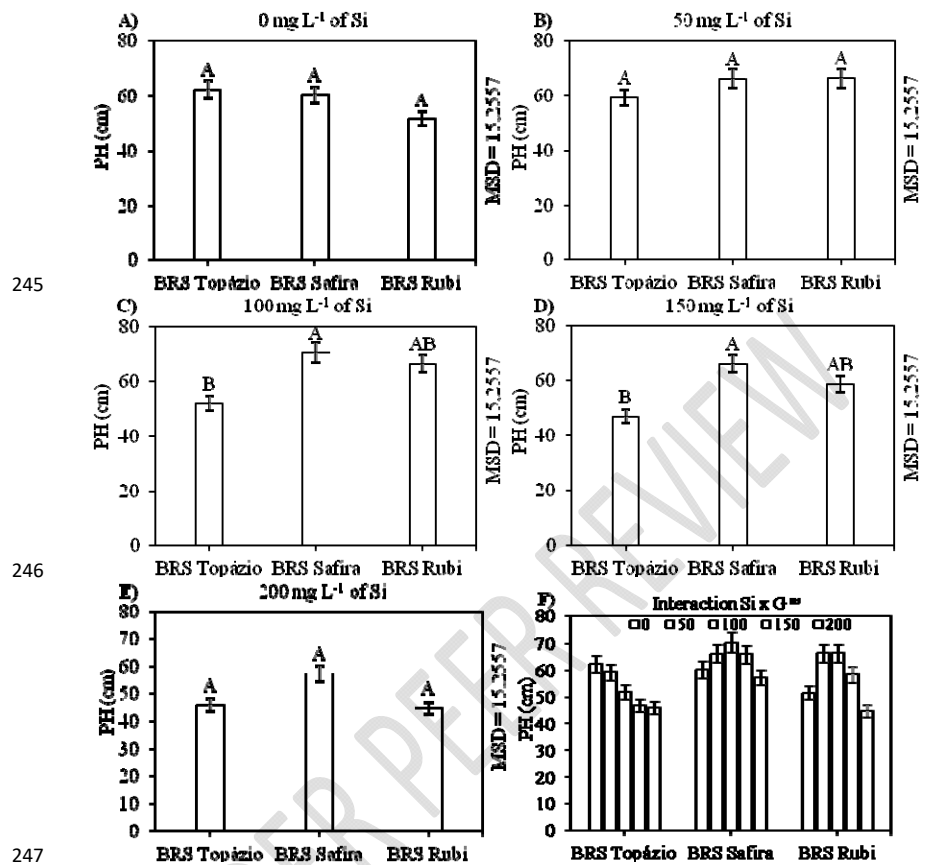
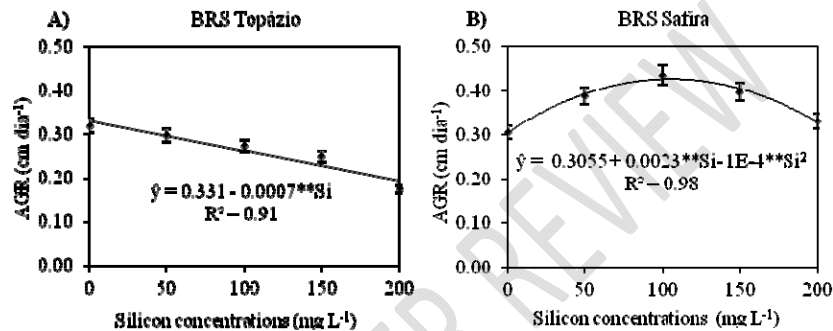


Figure 3. Cotton cultivars 'BRS Topázio', 'BRS Safira', and 'BRS Rubi' Plant height (PH) grown under foliar silicon spraying at concentrations 0 (A), 50 (B), 100 (C), 150 (D), and 200 (E) and the interaction Si x G (F)

3.2 Absolute Growth Rate

A sharp linear reduction of 42.6% for 'BRS Topázio' absolute growth rate was observed, when the value (0.19 cm day⁻¹), obtained in plants submitted to the application of 200 mg L⁻¹, was compared to the value of 0.33 cm day⁻¹ obtained by plants that did not receive silicate foliar fertilization. The means were adjusted to the simple linear model with higher coefficient of determination ($R^2 = 0.91$) (Fig. 4A).

257 'BRS Safira' absolute growth rate had an adjustment to the quadratic polynomial model,
 258 with estimated maximum value (0.43 cm day⁻¹) which it was obtained at Si of 105.4 mg L⁻¹
 259 concentration. Also, it was observed an increase of 30.2% in relation to plants grown with
 260 0 mg L⁻¹ of Si. For that cultivar, Si increase, from 105.4 mg L⁻¹ to 200 mg L⁻¹, decreased
 261 the absolute growth rate of plants by 15.2% (Fig. 4B).



262
 263 Fig. 4. Absolute growth rate in relation to the plant height (AGR) of cotton cultivars BRS Topázio (A)
 264 and BRS Safira (B) grown under foliar application of silicon

265 According to the average data related to the joint analysis of the absolute growth rate
 266 (Table 3), regardless of Si concentration, 'BRS Safire' expressed an average value of 0.37
 267 cm day⁻¹, which was higher than those recorded by 'BRS Topázio' (0.26 cm day⁻¹) and
 268 'BRS Rubi' (0.29 cm day⁻¹), with a percentage difference between 29.7 and 21.6%
 269 compared to 'Safire BRS'.

270 When it was calculated the isolated effect of cultivars, at each silicon concentration, it was
 271 found that, in the absence of this micronutrient (0 mg L⁻¹), 'BRS Topázio' and 'BRS Safira'
 272 presented a higher absolute growth rate of 0.32 cm day⁻¹ and 0.31 cm day⁻¹, respectively.
 273 These values were higher than 43.7 and 41.9% in relation to 0.18 cm day⁻¹ presented by
 274 'BRS Rubi' (Fig. 5A). There was no significant difference among absolute growth rate of

275 'BRS Topázio', 'BRS Safira', and 'BRS Rubi' at the concentration of 50 mg L⁻¹ of Si (Fig.
276 5B).

277 At 100 and 150 mg L⁻¹ Si concentrations, absolute growth rate significant values 0.43 cm
278 day⁻¹ and 0.4 cm day⁻¹ were recorded for 'BRS Safira'; these values did not differ from
279 those presented by 'BRS Rubi' (0.33 cm dia⁻¹) and (0.3 cm dia⁻¹). On the other hand, 'BRS
280 Safire ' growth rates, at concentrations of 100 and 150 mg L⁻¹, differed statistically from
281 0.27 cm day⁻¹ and 0.25 cm day⁻¹ for 'BRS Topázio' at related concentrations of leaf
282 fertilizer, with differences at estimated percentage of 34 and 37.5%. 'BRS Topázio' means
283 did not differ significantly from 'BRS Rubi' (Fig. 5C and D).

284 At 200 mg L⁻¹ Si concentration applied by foliar spray in the cotton, it was verified that
285 'BRS Safire' and 'BRS Rubi' were statistically different ($P < 0.05$) from 'BRS Topázio'.
286 'BRS Safira' showed the highest absolute growth rate (0.33 cm day⁻¹), which exceeded by
287 48.5% 'BRS Topázio' absolute growth rate (0.17 cm day⁻¹). 'BRS Rubi' presented an
288 absolute growth rate of 0.32 cm day⁻¹; rate 46.9% higher than that found for 'BRS
289 Topázio'. 'BRS Safira' and 'BRS Rubi' average values did not differ significantly from each
290 other (Fig. 5E). There was a significant interaction between silicon (Si) and cultivars (G)
291 factors. The highest absolute growth rate (0.43 cm day⁻¹) was observed at interaction 100
292 mg L⁻¹ with 'Safire BRS' (Fig. 5F).

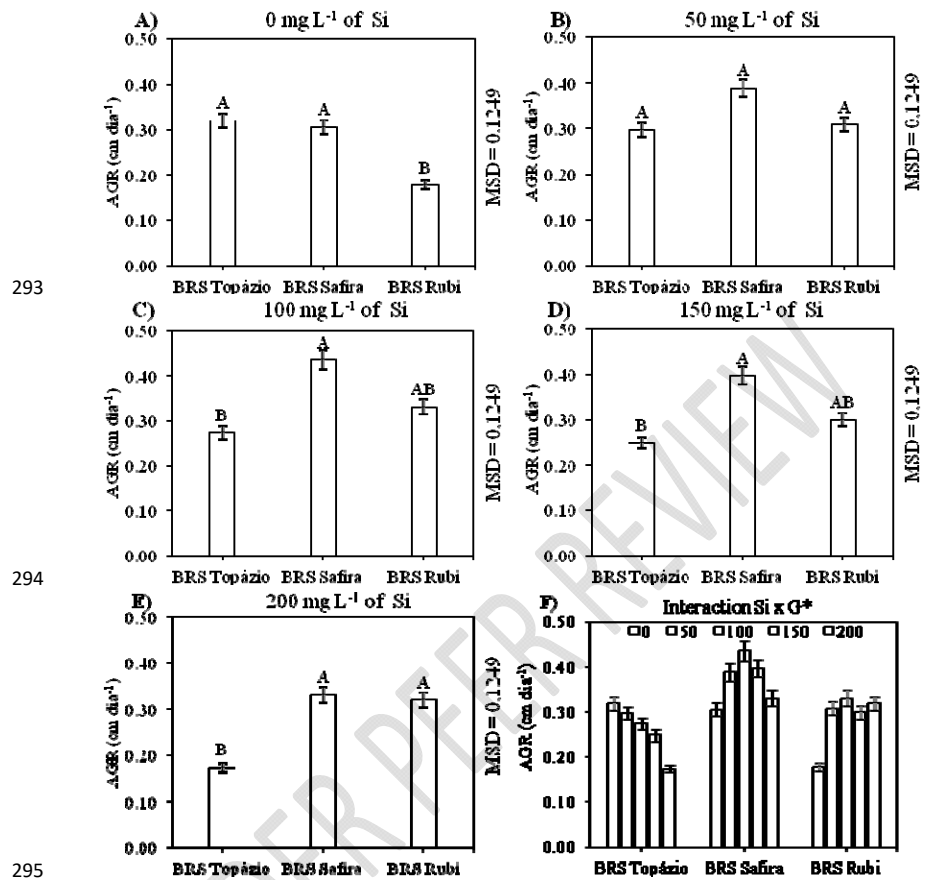
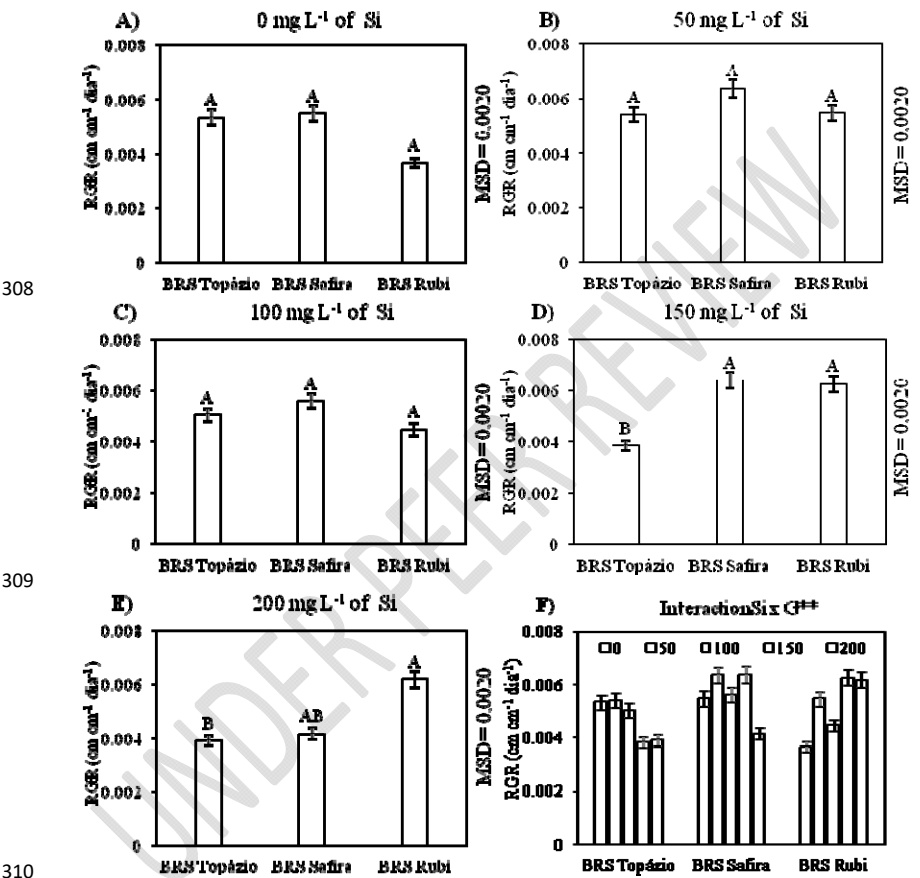


Fig. 5 Absolute growth rate in relation to plant height (AGR) of cotton ‘BRS Topázio’, ‘BRS Safira’, and ‘BRS Rubi’ grown under foliar application of silicon at 0 (A), 50 (B), 100 (C), 150 (D), and 200 mg L⁻¹ of Si (E), and Si x G (F) interaction

3.3 Relative Growth Rate

No significant differences were observed for relative growth rate among cotton cultivars in the absence of Si and under application of 50 and 100 mg L⁻¹ (Fig. 6A, B, and C). It was verified that, at 150 and 200 mg L⁻¹ Si application, ‘BRS Safira’ and ‘BRS Rubi’ showed a higher relative growth rate (0.0064 cm⁻¹ day⁻¹) and (0.0062 cm⁻¹ Day⁻¹), respectively (Fig. 6D and E).

305 There was a significant interaction among factors, in which the highest relative growth rate
 306 was obtained with the interaction of 'BRS Safira' under application of 150 mg L⁻¹ of silicon
 307 (Fig. 6F).

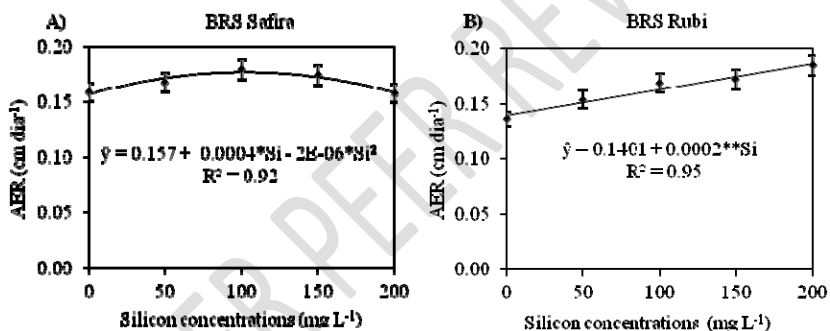


310 Fig. 6 Relative growth rate in relation to plant height (RGR) of cotton 'BRS Topázio', 'BRS Safira',
 311 and 'BRS Rubi' grown under foliar application of silicon at 0 (A), 50 (B), 100 (C), 150 (D), and 200 mg
 312 L⁻¹ of Si (E), and Si x G (F) interaction
 313

314 3.4 Absolute Stem Expansion Rate

316 'BRS Safira' absolute stem expansion rate was 0.16 cm day⁻¹, when did not receive Si
 317 solution application. However, when increasing Si concentrations up to the level of 101.98
 318 mg L⁻¹, the rate of expansion was 0.18 cm day⁻¹, with an increase of 11.1%. From the
 319 highest absolute expansion rate, the increase of silicate fertilization concentration up to 200
 320 mg L⁻¹ in the spray solution promoted a reduction of 12.8% of diameter in stem absolute
 321 expansion rate (Fig. 7A).

322 With variation of 0 to 200 mg L⁻¹, 'BRS Rubi' presented a linear increase of 26.3% for
 323 absolute stem expansion, with critical 0.14 cm day⁻¹ and maximum 0.19 cm day⁻¹ values,
 324 obtained at respective concentrations of this micronutrient (Fig. 7B).

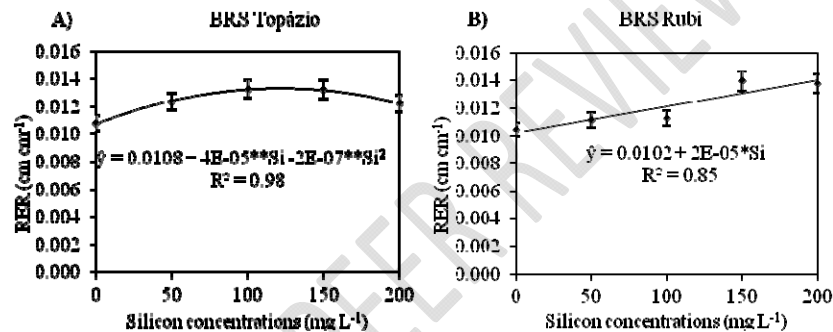


325
 326 Fig. 7. Absolute Expansion Rate (AER) at 'BRS Safira' (A) and 'BRS Rubi' (B) stem diameter grown
 327 under silicon foliar application

328 3.5 Relative Stem Expansion Rate

329 The averages of relative expansion rate of stem diameter had a quadratic polynomial
 330 adjustment, with the highest estimated value (0.013 cm⁻¹ day⁻¹) obtained with the
 331 application of 121.5 mg L⁻¹ of Si. An incremental rate of 18.8% was recorded in the
 332 average value of the relative expansion rate of 'BRS Topázio' stem.

333 This increase was verified at variation from 0 to 121.5 mg L⁻¹ of Si concentration.
 334 Increasing the concentration of this micronutrient up to 200 mg L⁻¹ resulted in a decrease
 335 of 15.4% in the relative expansion of the stem diameter with respect to the highest
 336 expansion rate obtained at the inflection point of the curve (Fig. 8A).
 337 'BRS Rubi' relative expansion rate of stem had a linear increase of 27.1% from 0 to 200
 338 mg L⁻¹ of Si, in which the values 0.010 and 0.014 cm⁻¹ day⁻¹ were estimated respectively
 339 (Fig. 8B).



340
 341 Fig. 8. Relative expansion rate (RER) at stem diameter of 'BRS Topázio' (A) and 'BRS Rubi' (B)
 342 grown under silicon foliar application

343 4. DISCUSSION

344 Records observed in Figures 2D, E, and F indicate symmetry for both aerial and root
 345 growth of cotton plants. Thus, when there is a significant correlation between two
 346 characters, it is possible to get gain in one of them by indirect selection of the other. This is
 347 worthwhile, especially, when a character of high economic value has low heritability
 348 and/or, difficult evaluation when compared to another character which is associated with it.
 349 Estimated correlations enabled to understand the associations among the characters, which
 350 provide important information about the establishment of a genetic improvement plan [21],
 351 which can be applied to optimize the productive chain of the cotton crop.

352 The behavior of 'BRA Topaz', in response to Si application, can be considered atypical
353 because the application of this nutrient increases photosynthetic capacity and reflects on
354 crop growth [22]. On the other hand, the increase observed for 'BRS Safira' and 'BRS Rubi'
355 height, in response to this element application on the leaves, is justified by the increase of
356 the nutrient concentration in the spray solutions, especially due to Si optimizes the opening
357 angle of leaves and promotes better use of light and the consequent conversion to energy
358 that is used into plant growth [23]. From the higher Si concentrations, it was observed that
359 there was a decreasing tendency, indicating that the excess of the element can exert a
360 phytotoxic effect, reducing the growth of the cotton.

361 Differences among cotton cultivars, under application of Si, may be associated to the
362 genetic intrinsic factors to each cultivar. In addition, Si, a beneficial element to plants [6],
363 may have maximized the characteristics of the cultivars, which justifies the differences in
364 plant height under application of 100 and 150 mg L⁻¹ of Si.

365 Lima et al. [9] reported that Si has a beneficial effect on the plant, mainly because it acts in
366 the optimization of biochemical and physiological processes and reflects the absolute
367 growth of agricultural crops. In this way, the increase in the absolute growth rate,
368 measured in 'BRS Safira', is linked to indirect effect of this nutrient on physiological
369 characteristics of the cotton [11], and these characteristics reflected at plants growth. On
370 the other hand, 'BRS Topázio' growth rate reduction, in response to the increase of Si
371 concentration, may be an indicative of sensibility of this cultivar to the excessive
372 accumulation of this micronutrient. Studying colored cotton fiber, Carvalho et al. [24]
373 emphasize there are divergent characteristics among colored cotton cultivars, which
374 justifies the fact that the cotton cultivars 'BRS Topázio', 'BRS Safira', and 'BRS Rubi' have
375 expressed significant differences for plant height.

376 Epstein and Bloom [25] reported that Si is not an essential element for all plants; however,
377 these authors mentioned that some plants should express differences in relation to those
378 grown in the absence of this element, mainly due to various metabolic effects that
379 indirectly influence growth. This information explains the increase in absolute stem
380 expansion rate of 'BRS Safira' and 'BRS Rubi' cultivars.

381 The effect of Si on plant becomes clear in plants grown under stress of biotic or abiotic
382 nature [26]. There is a natural tendency to optimize the growth process of plants under the
383 application of this element, mainly because it optimizes the increase of antioxidant
384 enzymes levels, photosynthetic capacity as well as by creating the conditions for full
385 growth and development of crops [27]. Therefore, although at absence of stress, it can be
386 inferred that the increase of relative expansion rate, in stem diameter, can be explained by
387 the increase of Si concentration in the spray solutions [28].

388 **5. CONCLUSION**

389 Potassium silicate optimizes the growth of naturally colored fiber cottons under semi-arid
390 conditions. For 'BRS Topaz', silicon reduced the height of plants and it increased the stem
391 expansion rate. Silicon application in 'Safira BRS' increased plant height and growth rate.
392 For 'BRS Rubi', silicon increased plant height and stem expansion rate.

393 **REFERENCES**

- 394 1. Souza LP, Nobre RG, Barbosa JL, Lima GS, Almeida LLS, Pinheiro FWA.
395 Cultivation of cotton cv. BRS Topaz in saline-sodic soils with organic matter addition.
396 Spaces. 2017;38(14):17.

- 397 2. Oliveira FA, Medeiros JF, Oliveira FRA, Freire AG, Soares LCS. Production of
398 cotton as a function of salinity and treatment of seeds with growth regulator. *Agronomic*
399 *Science*. 2012;43(3):484-492.
- 400 3. Beltrão NEM, Oliveira MIP. Oilseeds and their Oils: Advantages and
401 Disadvantages for Biodiesel Production. Campina Grande: Embrapa Cotton. 2008.
- 402 4. ABA Brazilian Cotton Directory. Santa Cruz do Sul: Gazeta Santa Cruz Publishing
403 House. 2012. Available at:
404 <[http://www.gaz.com.br/tratadas/eo_edicao/7/2012/06/20120629_97763c201/pdf/3401_20](http://www.gaz.com.br/tratadas/eo_edicao/7/2012/06/20120629_97763c201/pdf/3401_2012_algodao_double_web.pdf)
405 [12_algodao_double_web.pdf](http://www.gaz.com.br/tratadas/eo_edicao/7/2012/06/20120629_97763c201/pdf/3401_2012_algodao_double_web.pdf). Accessed in: June, 2012.
- 406 5. Floss EL. Physiology of cultivated plants. Passo Fundo: Editor of UPF. 2004.
- 407 6. Guerrero AC, Borges LS, Fernandes DM. Effect of foliar application of silicon on
408 arugula cultivated in two types of soils. *Bioscience Journal*. 2011;27(4):591-596.
- 409 7. Ramos LA, Korndörfer GH, Nolla A. Silicon accumulation in rice plants of the
410 várzea ecosystem submitted to different sources. *Bragantia*. 2008;67(3):751-757.
- 411 8. Freitas LB, Coelho EM, Maia SCM, Silva TRB. Foliar fertilization with silicon in
412 maize crop. *Ceres*. 2011;58(2):262-267.
- 413 9. Lima MA, Castro VF, Vidal JB, Enéas Filho J. Application of silicon in maize and
414 string beans under salt stress. *Agronomic Science*. 2011;42(2):398-403.
- 415 10. Crusciol CAC, Soratto RP, Castro GSA, Costa CHM, Ferrari Neto J. Leaf
416 application of silicic acid stabilized in soybean, beans and peanuts. *Agronomic Science*.
417 2013;44(2):404-410.

- 418 11. Ferraz RLS, Beltrão NEM, Melo AS, Magalhães ID, Fernandes PD, Rocha MS.
419 Gaseous exchanges and photochemical efficiency of herbaceous cotton cultivars under
420 foliar silicon application. *Semina: Agrarian Sciences*. 2014;35(2):735-748.
- 421 12. Vidal Neto FC, Andrade FP, Silva Filho JL, Carvalho LP. *BRS Topaz*. 2p. 2010.
422 Available at: <[http://www.infoteca.cnptia.embrapa.br/bitstream/item/18954/1/Algodao-](http://www.infoteca.cnptia.embrapa.br/bitstream/item/18954/1/Algodao-Colorido-Topazio.pdf)
423 [Colorido-Topazio.pdf](http://www.infoteca.cnptia.embrapa.br/bitstream/item/18954/1/Algodao-Colorido-Topazio.pdf)>. Accessed in: june 2016.
- 424 13. Carvalho LP, Araújo GP, Costa JN. Folder 'BRS Rubi'. Campina Grande: Embrapa
425 Cotton. 2007;5.
- 426 14. Carvalho LP, Araújo GP, Vieira RM, Beltrão NEM, Costa JN. 'Folder BRS
427 Sapphire'. Campina Grande: Embrapa Cotton. 2009.
- 428 15. EMBRAPA. Manual of soil analysis methods. Rio de Janeiro: Soil Research
429 Center. 1997;2.
- 430 16. Bezerra MVC, Silva BB, Bezerra BG, Borges VP, Oliveira AS. Evapotranspiration
431 and coefficient of irrigated cotton crop from orbital sensor images. *Agronomic Science*.
432 2012;43(1):64-71.
- 433 17. Production of biomass and silicon content in forage grasses under different sources
434 of silicate. *Semina: Agrarian Sciences*. 2011;32(1):103-110.
- 435 18. Beltrão NEM, Almeida AO, Pereira JR, Fideles Filho J. Methodology for
436 estimation of fruit growth and absolute and relative volume of the cotton plant. *Brazilian*
437 *Journal of Oleaginous and Fibrous*. 2001;5(1):283-289.
- 438 19. Benincasa, M M P. Plant growth analysis. Jaboticabal: FUNEP. 2003.

- 439 20. Santos JW, Almeida FAC, Beltrão NEM, Cavalcanti FV. Applied Experimental
440 Statistics. Campina Grande: Embrapa Algodão / Federal University of Campina Grande.
441 2008.
- 442 21. Rodrigues HCA, Carvalho SP, Carvalho AA, Santos CEM, Carvalho Filho JLS.
443 Genotypic, phenotypic and environmental correlations among castor bean characters.
444 Science and Agrotechnology. 2010;34(6):1390-1395.
- 445 22. Borges LS, Guerrero AC, Fernandes DM. Foliar fertilization with silicon in the
446 growth of jambu plants. Cultivating Knowledge. 2010;3(1):160-170.
- 447 23. Avila FW, Beliza DP, Faquin V, Araújo JL, Ramos SJ. Interaction between silicon
448 and nitrogen in rice grown under nutrient solution. Agronomic Science. 2010;41(2):184-
449 190.
- 450 24. Carvalho LP, Andrade FP, Silva Filho JL. Cultivars of colorful cotton in Brazil.
451 Brazilian Journal of Oleaginous and Fibrous. 2011;15(1):37-44.
- 452 25. Epstein E, Bloom AJ. Mineral nutrition of plants: principles and perspectives.
453 Londrina: Editora Planta. 2006;2.
- 454 26. Currie HA, Perry CC. Silica in plants: biological, biochemical and chemical
455 studies. Annals of Botany. 2007;100:1383-1389.
- 456 27. Zuccarini P. Effects of silicon on photosynthesis, water relations and nutrient
457 uptake of *Phaseolus vulgaris* under NaCl stress. Biologia Plantarum. 2008;54:157-160.
- 458 28. Ferraz, RLS, Barbosa MA, Magalhães ID, Melo AS, Rocha MS, Costa PS.
459 Qualitative attributes of hydrocondicionadas cotton seeds in silicon solutions. Scientific.
460 2017; 45(1): 85-94.

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