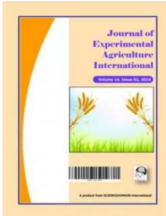

Journal of Experimental Agriculture International

17(4): 1-14, 2017; Article no.JEAI.36260
Previously known as American Journal of Experimental Agriculture
ISSN: 2231-0606

Potassium Silicate Optimizes the Growth of Naturally Colored Fiber Cotton in the Semi-arid

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Authors' contributions

This work was carried out with the collaboration of all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JEAI/2017/36260
Editor(s):
(1) Celerino Matias Quezada Landeros, Departamento de Suelos y Recursos Naturales, Facultad de Agronomia, Universidad de Concepcion, Chile.
Reviewers:
(1) Joseph A. Orluchukwu, University of Port Harcourt, Nigeria.
(2) Shaon Kumar Das, ICAR-National Organic Farming Research Institute, India.
Complete Peer review History: http://www.sciencedomain.org/review-history/20985

Original Research Article

Received 21st August 2017
Accepted 10th September 2017
Published 14th September 2017

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ABSTRACT

Potassium silicate optimizes the growth of naturally colored fiber cotton in the semi-arid of Paraíba state, Brazil. 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 in the experimental area of Embrapa / Algodão, in the Northeast region of 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 'BRS Safira' plant height and growth rate. For 'BRS Rubi', silicon increased plant height and stem expansion rate.

Keywords: 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.

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

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

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

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

2. MATERIALS AND METHODS

2.1 Characterization of the Experimental Area

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

Climatic features were monitored daily through data collected at the automated agro-meteorological station located 150 m from the experimental area. Features were: maximum (T max ºC), minimum (T min ºC), and average temperature (T avg ºC), relative humidity (RH%) (Fig. 1A), daily insolation (IND Hours), Class A Tank evaporation (ECA) (mm), and rainfall (PPL mm) (Fig. 1B).

2.2 Treatments and Experimental Design

Treatments were established by combination of two factors: Three herbaceous cotton cultivars (CV_1= 'BRS Topázio', CV_2= 'BRS Safira', and CV_3= 'BRS Rubi'), and five 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].

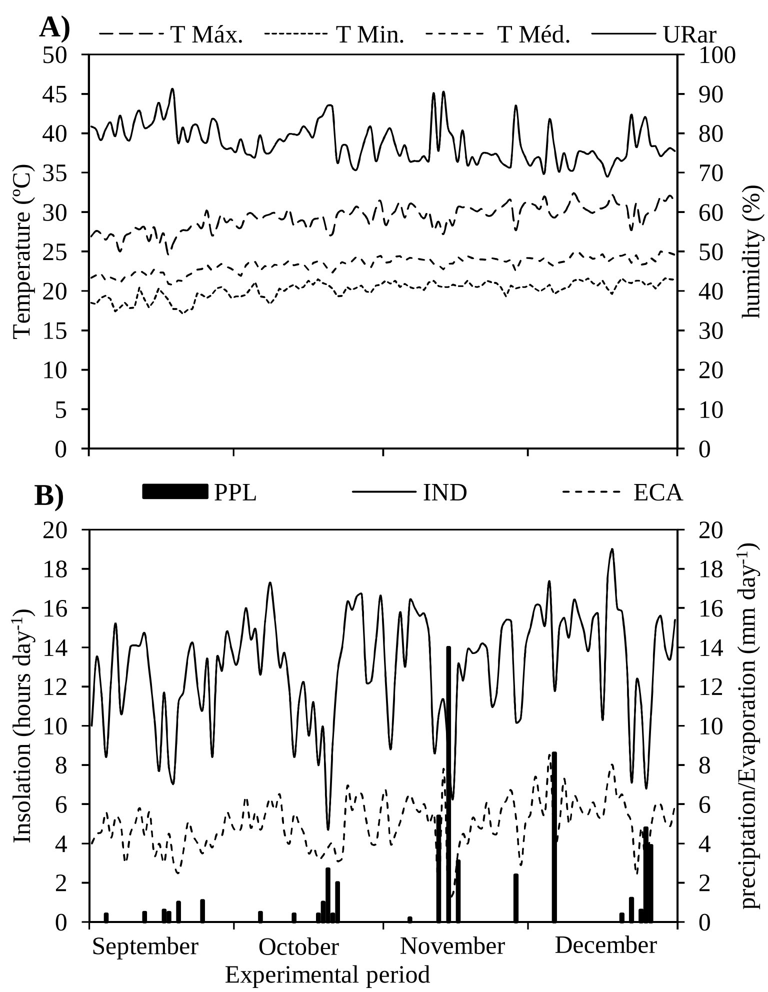


Fig. 1. Climatic variables, air temperature and humidity (A), insolation, rainfall, and evaporation (B) observed throughout the experimental period

A commercial potassium silicate (Sifol®) 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 = Silicon concentrations, corresponding to each treatment applied, were obtained by diluting 36, 72, 108 and 144 ml of Sifol®, respectively, in one liter of distilled water.

2.3 Growing Environment

Each experimental plot was composed by a pot of synthetic polymeric organic material with volumetric capacity of 200 dm^3, which was placed on a masonry support. All pots had their lower part filled with 10 L of gravel, forming a 10 cm layer, 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].

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).

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

At the beginning, irrigations were applied to raise the soil moisture up to the level corresponding to the 80-100% field capacity. The replacement of evapotranspirated water by plants (ETc) occurred as a result of class 'A' tank evaporation (ECA), and crop coefficient (Kc) at different phenological stages of plants [16]. Data, referring to the reference evapotranspiration, were collected in class 'A' tank located in the agrometeorological station next to the experimental area.

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

2.5 Treatments Application

15 days after the emergence of the seedlings, time for establishment of the plants in the experimental plot, weekly a silicate solution was sprayed on the leaves by a hand sprayer at the abaxial and adaxial surfaces of the cotton leaves up to drainage of the solution. Surfactant was used in the spray solution to improve efficiency contact of the silicon on leaf surface [17].

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	AssP
	($cmol_c$ dm^{-3})						(%)	(g kg^{-1})		(mg dm^{-3})
5.1	0.05	0.04	0.37	0.65	2.89	4.00	28.00	0.0	3.6	0.3

Physical					
Sand	Silt	Clay	Porosity	Soil density	Water available
(%)			(%)	(g cm^{-3})	(%)
81.44	13.79	4.77	46.67	1.52	1.43

** pH – pH in H_2O; K^+ – potassium; Na^+ – sodium, Ca^{2+} – calcium; Mg^{2+} – magnesium; H+Al – hidrogen + aluminum; T – cation exchange capacity at pH 7,0; V – base saturation percentage; N – nitrogen; OM – organic matter; AssP – assimilable phosphorus*

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 $(NO_3)_2 . 4H_2O$ 1M	236.15
KNO_3 0.5M	50.55
$NH_4 NO_3$ 05M	40.025
K_2SO_4 1M	174.28
Mg $SO_4 . 7H_2O$ 1M	246.470
$Ca_3 (PO_4)_2$ 0.333M	103.297
Ca $(H_2PO_4)_2 . H_2O$ 0.5M	126.045
Ca $HPO_4 . 2H_2O$ 0,5M	203.53
Zn $SO_4 . 2H_2O$ 1.21Mm	0.0348
Cu $SO_4 . 5H_2O$ 0,12Mm	0.030
Mn $S_2O_4 . H_2O$ 1,25mM	0.2118
$(NH_4)_6 Mo_7O_{24} . 4H_2O$ 0.0033Mm	0.0042
H_3Bo_3 3.61Mm	0.2232
Fe $SO_4 . 7H_2O$	6.291

2.6 Plant Growth

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

$$\mathrm{AGR} = \frac{\mathrm{M2} - \mathrm{M1}}{T2 - T1}$$

Where AGR (absolute growth rate, cm day^{-1}); M1 corresponds to the height of plant in season one (T1); M2 measurements carried out at intervals until the last evaluation (T2).

$$\mathrm{RGR} = \frac{\ln \mathrm{M2} - \ln \mathrm{M1}}{T2 - T1}$$

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

$$\mathrm{AER} = \frac{\mathrm{D2} - \mathrm{D1}}{T2 - T1}$$

Where AER (absolute expansion rate of stem diameter, mm day^{-1}); D1 corresponds to the stem diameter in season one (T1); D2 corresponds to the measurements carried out at intervals up to the last evaluation (T2):

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

Where RER (relative expansion rate, mm mm^{-1} day^{-1}); ln (Napierian logarithm of the stem diameter at time one (T1); measurements taken at intervals up to the last evaluation (T2).

2.7 Statistical Analysis

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

3. RESULTS

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

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

Table 3. Summary of analysis of variance for growth variables in cotton cultivars under silicon spray in leaves

S.V.	F.D.	Medium squares					
		PH	SD	AGR	RGR	AER	RET
Treatments	(14)	237.554**	3.853ns	0.020**	0.36E-5**	0.58E-3*	0.5E-5ns
Silicon (Si)	4	285.010*	3.572ns	0.014*	0.25E-5ns	0.86E-3*	0.1E-4*
Linear	1	467.285*	4.641ns	0.1E-4*	0.5E-6ns	0.18E-2*	0.3E-4**
Quadratic	1	493.714*	1.885ns	0.055**	0.1E-5ns	0.88E-3ns	0.5E-5ns
Cubic	1	160.083ns	4.880ns	0.1E-2ns	0.2E-5ns	0.73E-3ns	0.6E-5ns
Cultivar (G)	2	583.480**	7.269ns	0.065**	0.5E-5ns	0.28E-3ns	0.5E-5ns
Int. Si x G	8	127.344ns	3.140ns	0.012*	0.37E-5**	0.51E-3ns	0.25E-5ns
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.*

3.1 Plants Height

The effect of Si concentration, on each cotton cultivar, showed that 'BRS Topázio' had 29.2% reduction in its height when Si concentration was increased (Fig. 2A). In contrast, there was an increase in 'Safira BRS' height, with a higher estimated value of 69.53 cm, which was obtained with the application of 94.3 mg L^{-1} of Si. In addition, there was an increase of 13.8% in relation to Si control treatment (0 mg L^{-1}). From plant height, it was observed that there was a significant reduction of 18.4% up to the concentration of 200 mg L^{-1} of Si, with plants presenting 56.7 cm height (Fig. 2B).

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

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

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

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

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

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

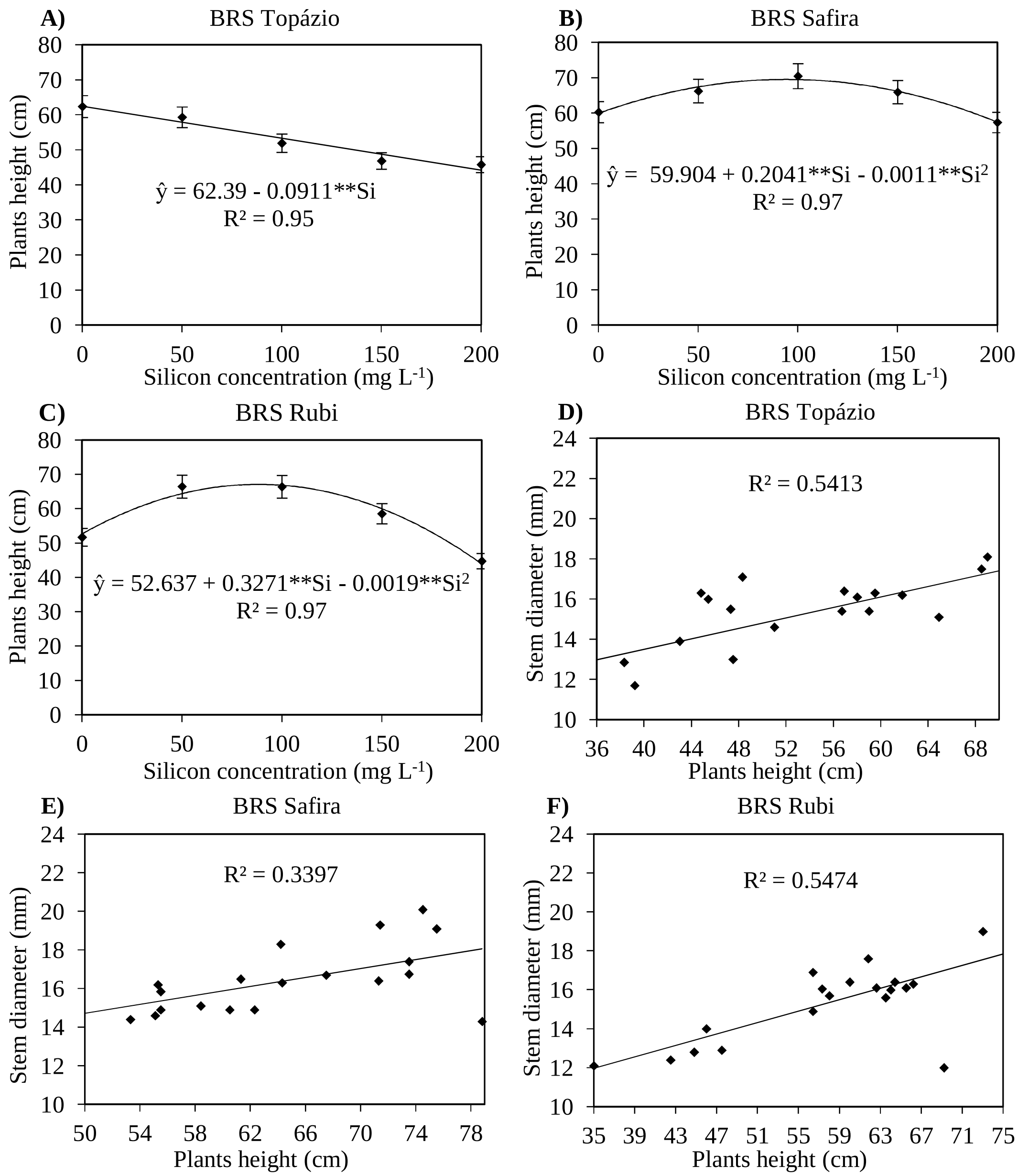


Fig. 2. 'BRS Topázio' (A), 'BRS Safira' (B), and 'BRS Rubi' (C) plants height (PH), Pearson's linear correlation for plant height variable (PH), and 'BRS Topázio' (D), 'BRS Safira' (E), and 'BRS Rubi' (F) stem diameter (SD) grown under silicon foliar application

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

Otherwise, it is possible to observe differences among these cultivars at 100 and 150 mg L^{-1} of Si concentration. Using 100 mg L^{-1} of Si concentration, 'BRS Safire' was the cultivar that expressed the higher height (70.5 cm), contrasting with 'BRS Topázio' which expressed 51.9 cm. The estimated percentage difference between 'BRS Safira' and 'BRS Topázio' was 26.4%. The 'BRS Rubi' plants had intermediate height (66.4 cm), and did not differ statistically from the other ones (Fig. 3C).

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

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).

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

According to the average data related to the joint analysis of the absolute growth rate (Table 3), regardless of Si concentration, 'BRS Safira' expressed an average value of 0.37 cm day $^{-1}$, which was higher than those recorded by 'BRS Topázio' (0.26 cm day^{-1}) and 'BRS Rubi '(0.29 cm day^{-1}), with a percentage difference between 29.7 and 21.6% compared to 'Safira BRS'.

When it was calculated the isolated effect of cultivars, at each silicon concentration, it was found that, in the absence of this micronutrient (0 mg L^{-1}), 'BRS Topázio' and 'BRS Safira' presented a higher absolute growth rate of 0.32 cm day^{-1} and 0.31 cm day $^{-1}$, respectively. These values were higher than 43.7 and 41.9% in relation to 0.18 cm day^{-1} presented by 'BRS Rubi' (Fig. 5A). There was no significant difference among absolute growth rate of 'BRS Topázio', 'BRS Safira', and 'BRS Rubi' at the concentration of 50 mg L^{-1} of Si (Fig. 5B).

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

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

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).

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

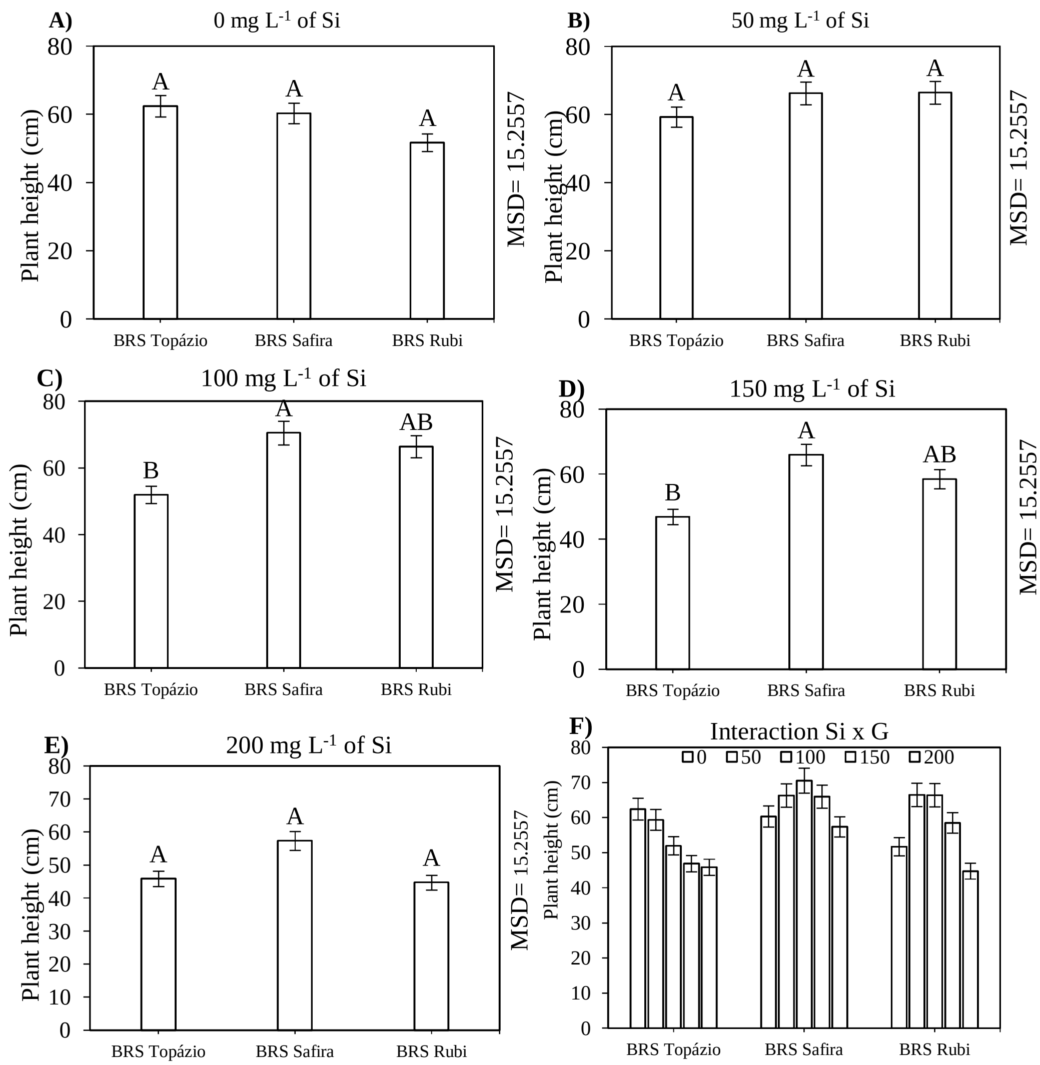


Fig. 3. Cotton cultivars 'BRS Topázio', 'BRS Safire', and 'BRS Rubi' Plant height (PH) grown under foliar silicon spraying at concentrations 0 (A), 50 (B), 100 (C), 150 (D), and 200 (E) and the interaction Si x G (F). MSD = minimal significant difference

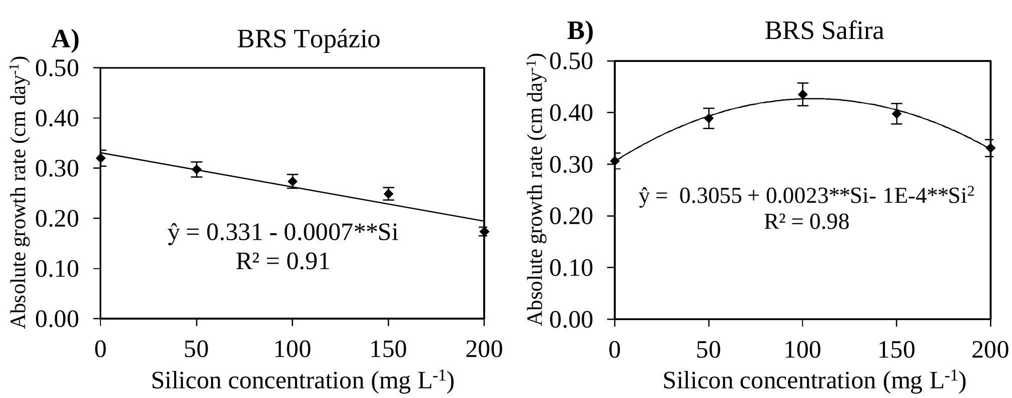


Fig. 4. Absolute growth rate in relation to the plant height (AGR) of cotton cultivars BRS Topázio (A) and BRS Safira (B) grown under foliar application of silicon

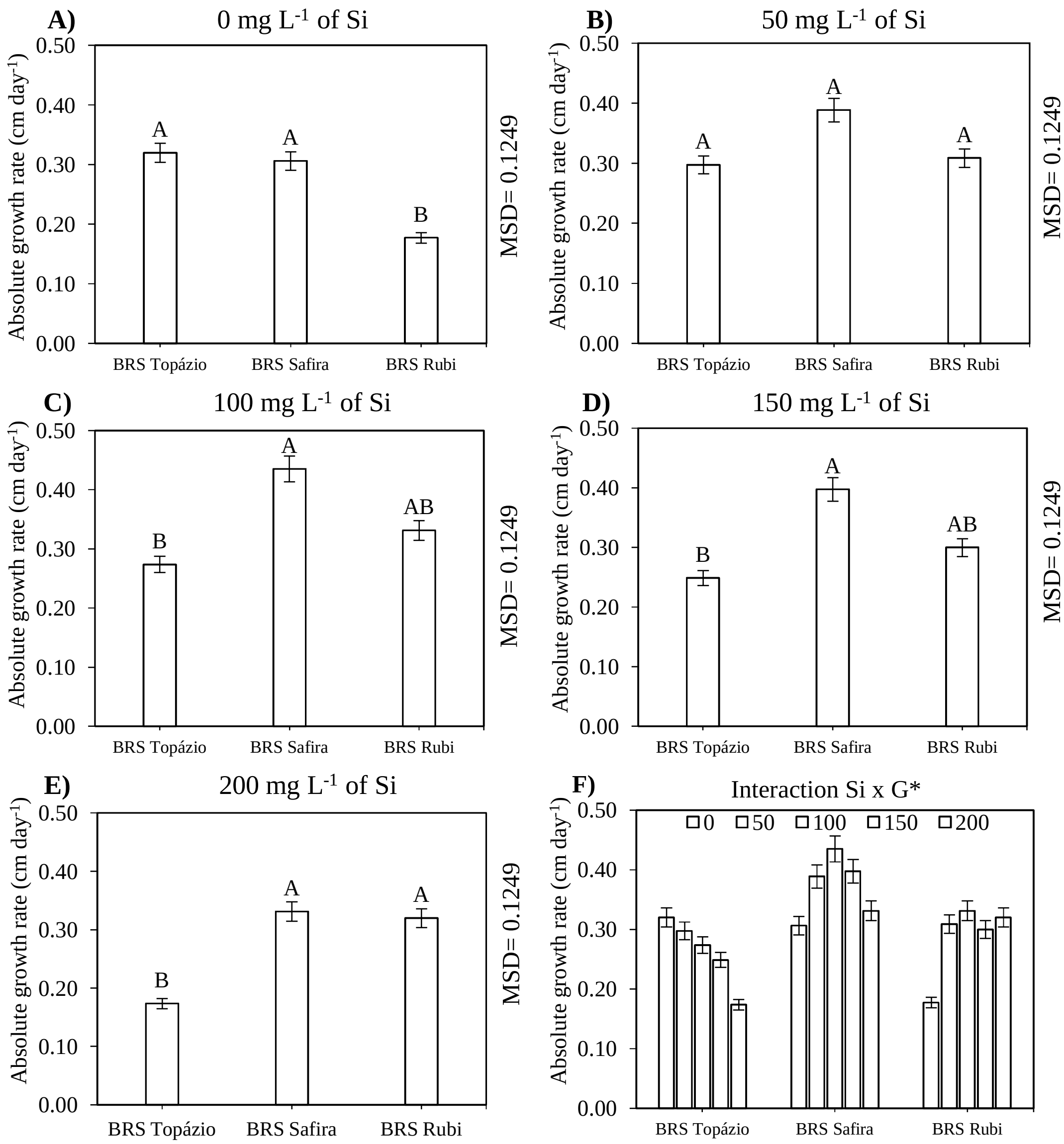


Fig. 5. Absolute growth rate in relation to plant height (AGR) of cotton 'BRS Topázio', 'BRS Safira', and 'BRS Rubi' grown under foliar application of silicon at 0 (A), 50 (B), 100 (C), 150 (D), and 200 mg L^{-1} of Si (E), and Si x G (F) interaction

3.4 Absolute Stem Expansion Rate

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

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

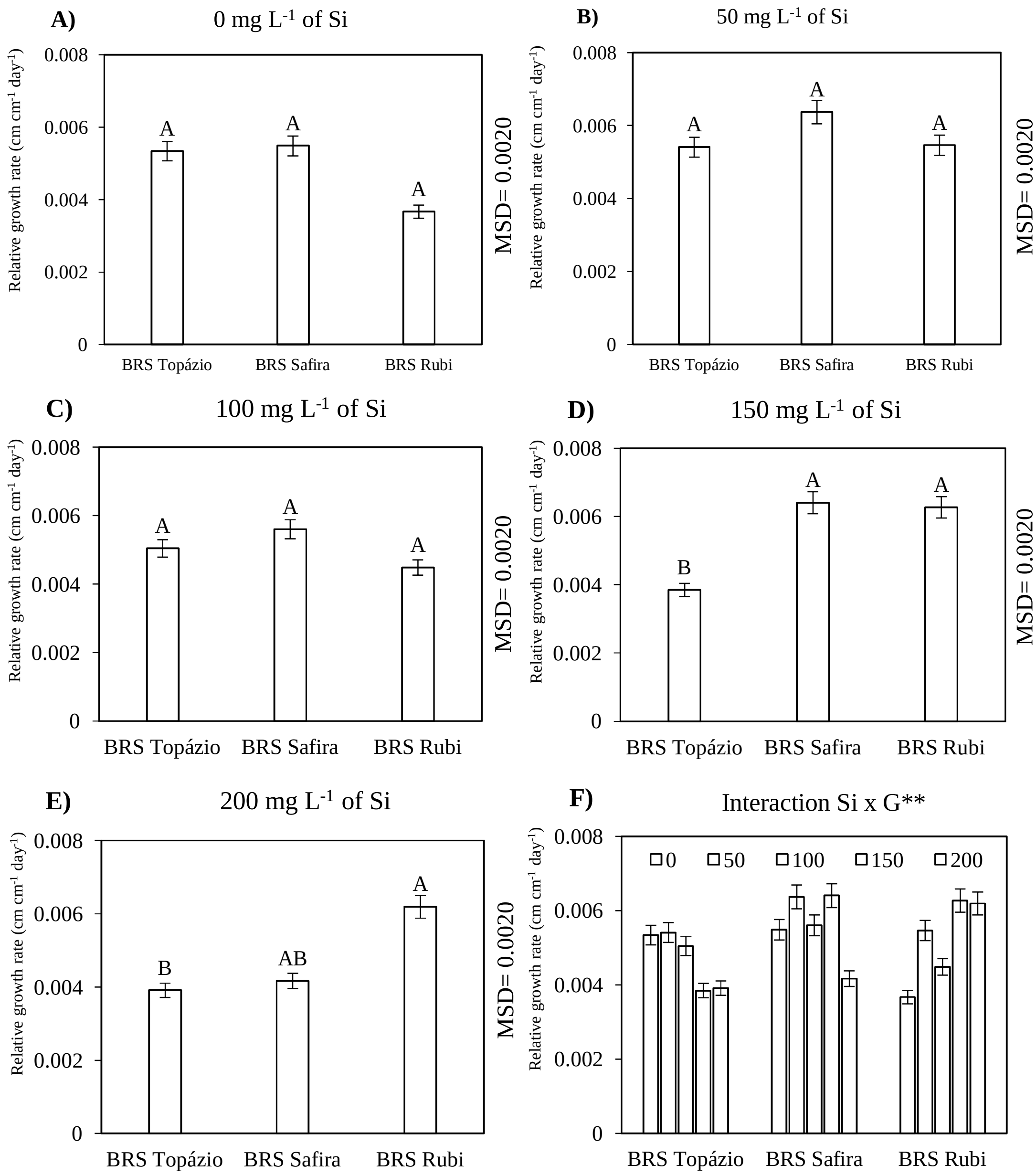


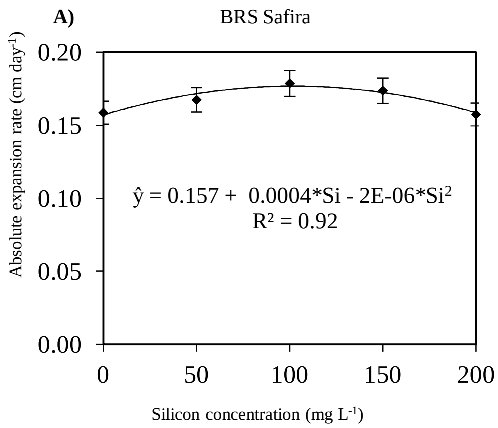
Fig. 6. Relative growth rate in relation to plant height (RGR) of cotton 'BRS Topázio', 'BRS Safira', and 'BRS Rubi' grown under foliar application of silicon at 0 (A), 50 (B), 100 (C), 150 (D), and 200 mg L^{-1} of Si (E), and Si x G (F) interaction

3.5 Relative Stem Expansion Rate

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

This increase was verified at variation from 0 to 121.5 mg L^{-1} of Si concentration. Increasing the concentration of this micronutrient up to 200 mg L^{-1} resulted in a decrease of 15.4% in the relative expansion of the stem diameter with respect to the highest expansion rate obtained at the inflection point of the curve (Fig. 8A).

'BRS Rubi' relative expansion rate of stem had a linear increase of 27.1% from 0 to 200 mg L^{-1} of



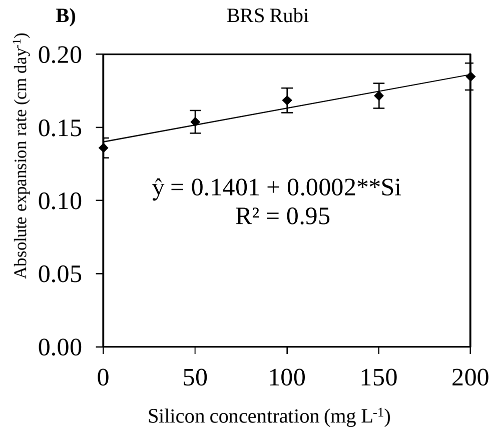
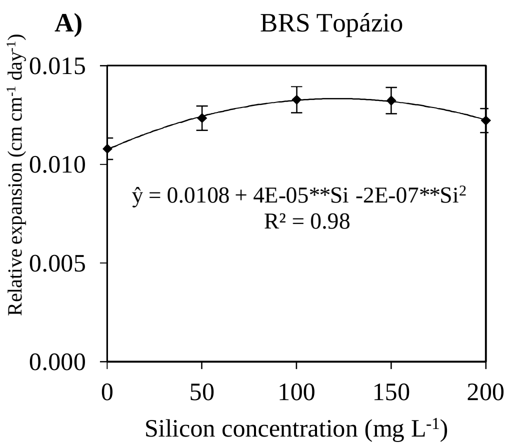


Fig. 7. Absolute expansion rate (AER) at 'BRS Safira' (A) and 'BRS Rubi' (B) stem diameter grown under silicon foliar application



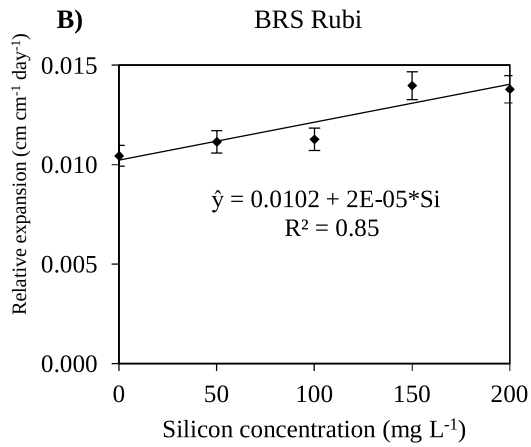


Fig. 8. Relative expansion rate (RER) at stem diameter of 'BRS Topázio' (A) and 'BRS Rubi' (B) grown under silicon foliar application

Si, in which the values 0.010 and 0.014 cm $^{-1}$ day^{-1} were estimated respectively (Fig. 8B).

4. DISCUSSION

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

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

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

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

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

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

5. CONCLUSION

Potassium silicate optimizes the growth of naturally colored fiber cottons under semi-arid conditions. For 'BRS Topázio', silicon reduced the height of plants and it increased the stem expansion rate. Silicon application in 'BRS Safira' increased plant height and growth rate. For 'BRS Rubi', silicon increased plant height and stem expansion rate. Based on this information, it is recommended to use silicon as an alternative for cultivation of naturally colored cotton fiber in arid and semi-arid regions, which may increase farmers' income.

ACKNOWLEDGEMENTS

The authors thank to Graduate Program in Agricultural Sciences of State University of Paraíba - UEPB, to National Center for Cotton Research - EMBRAPA/CNPA. To Coordination of Improvement of Higher Level Personnel - CAPES, and to National Council of Scientific and Technological Development - CNPq.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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