J. Bamboo Rattan (2022) 21(3):113-124
https://doi.org/10.55899/09734449/jbr021303 www.jbronline.org
RESEARCH ARTICLE

Influence of silicon on the growth of *Guadua angustifolia* Kunth seedlings

M. Saavedra[1] . G. Fonthal[1*] . P. Cardona Olarte[2] . H. Ariza Calderon[1]

Received: 5 September 2022Accepted: 11 January 2023
Published online 2 June 2023

Abstract: An experiment was carried out in a nursery with 220 seedlings of *Guadua angustifolia Kunth*, by adding silicon (Si) in a commercial fertilizer. Eleven treatments, including the no silicon-control were applied, with concentrations progressively increasing in 600 mg Si up to 6000 mg Si kg^{-1}-dried. We found that, Si was beneficial to the seedling's growth in terms of their stem height, stem base area, leaf area, root length, stem biomass, leaves, roots and total biomass. However, this benefit reached a peak at about 4200 mg Si kg^{-1}, and after this concentration the plants did not show any benefit, but instead they stopped absorbing silicon as the inner silicon decreased when the Si in the soil was equal or higher of 2400 mg kg^{-1}. The supplied fertilizer also contained phosphorus (P), but this mineral did not affect the previous variables, nor the absorption of Si.

Keywords: Guadua angustifolia Kunth, Si absorption, plant growth, mineral absorption, bamboo growth, plant biomass

Introduction

Silicon (Si) is considered the second most abundant chemical element in the lithosphere after oxygen. It is also recognized as a "beneficial nutrient element" in plants (Xu *et al*., 2018; Ya,. Moroslav., Ye, Xiao & Liang, 2018). However, the real impact of adding silicon in agricultural practices has hardly begun to be studied (Klotzbüchera, Klotzbücher., Kaiser, Merbach & Mikutta, 2018), although in several countries such as China, Japan, Korea, Brazil and the United States it is a common practice supplying Si as an additional fertilizer in cropland (Yan, Moroslav., Ye, Xiao. & Liang, 2018).

It is already known that the concentration of Si in the plant depends on the plant type, varying between 0.1 to 10% of Si in dry weight (Ma & Yamaji, 2006; Currie & Perry, 2007). The grasses, one of the most important families of the vegetable kingdom, have been regarded as high silicon accumulators, depositing this mineral in their tissues in greater quantities than any other inorganic element. Silica content can be found in bamboo sprouts and leaves up to 41% dry weight, for example, in *Sasa veitchii* Carrière (Motomura, Mita, & Suzuki, 2002).

Silicon helps plants to overcome multiple stress situations, which can be either biotic or abiotic. This mineral element plays a very important role in the resistance of plants to pathogens (Ma & Yamaji, 2006), herbivores (Bauera, Elbaum & Weiss, 2011) and pests (Bakhat, *et al*., 2018). It also helps withstand abiotic stresses such as salinity, metal toxicity (Ma *et al*., 2022; Mandlik, *et al*., 2020), drought, radiation damage, nutrient imbalance, high temperature and freezing (Mitani & Ma, 2005; Hernandez-Apaolaza, 2014). In an experiment, the application of Si to the soil resulted in a smaller insertion angle of the leaf, a higher Si content in leaves and roots and a higher biomass production in rice (Zanao Junior, Ferreira Fontes, Korndorfer, Tavares de Avila & Pereira Carvalho- Zanao, 2010) . In another set of experiments,

**Corresponding Authors*

[1] Instituto Interdisciplinario de las Ciencias - Universidad del Quindío – Colombia

[2] Program of Natural Science Education - Universidad del Quindío – Colombia
✉ gfonthal@uniquindio.edu.co

Collin *et al.,* 2012 reported a greater growth of bamboo plants, Korndörfer *et al*., 2001, found taller stems of sugar cane (*Saccharum officinarum*), higher growth and yield in jute (*Corchorus capsularis*) and cucumber (*Cucumis sativus*) (Korndorfer & Lepsch, 2001), while Collin *et al*., 2013 detected no change in the architecture of hydroponic bamboos (*Bamboo gigantocloa*). Accordingly, Currie and Perry (Currie & Perry, 2007), assert that Si is the only nutrient that is not harmful when the plant collects it in excess.

Guadua angustifolia Kunth , stands out among the 20-bamboo species included in the "bamboo priority species", for it is the most useful one in Latin America. It is native to Colombia, Venezuela and Ecuador (González, Fonthal & Ariza-Calderon, 2014; Kleinn & Morales-Hidalgo, 2006; Parsons, 1991). This American bamboo is an excellent sustainable resource, self-renewable, fast growing, versatile, light weight, flexible, durable and easy to use (Ingram, Tieguhong, Nkamgnia, Eyebe & Ngawel, 2010). The economic importance of this giant grass is manifested in the industries of construction, furniture and crafts. In addition, it is a low-maintenance plantation and it is regenerated with high yields per hectare and it is harvested in short time periods (González, Fonthal, & Ariza-Calderón, 2014; Kleinn & Morales-Hidalgo, 2006; Parsons, 1991). It is also used by many farmers to obtain international environmental certificates or certificates of low carbon footprint, and as a soil protector, contributor of organic matter, erosion controller and host of wildlife. It should also be mentioned that *G. angustifolia* has a broad geographical distribution due to its adaptability to diverse bio-physical conditions, including different climates and soil conditions (González, Fonthal, & Ariza-Calderón, 2014; Kleinn & Morales-Hidalgo, 2006; Parsons, 1991).

In this work a systematic study on the effect of silicon addition to Si on *G. angustifolia* seedlings to assess on their below- and belowground growth, as well as their effects on mass and area, since their great capacity to uptake of this nutrient.

Materials and methods

Seedling acquisition and overall experimental layout

The study was carried out through a nursery experiment with *G. angustifolia* seedlings (hereafter referred as "chusquines") evenly distributed in 11 treatments. These plants were acquired at the Centro Nacional de la Guadua, located in Córdoba (Quindío - Colombia), at 1,240 meters above sea level, average annual temperature 22.5° C (maximum of 29°C and minimum 16°C). The nursery facility is located at the Universidad del Quindío, Armenia (04° 33′ N, 75° 39′W), at 1490 MASL, annual temperature between 15°C to 24°C and an average relative humidity of 65-75%). Light conditions were not controlled inside the facility but the ambient light was measured and varied from an average of 608 lux in the afternoon to an average of 243 lux in the morning.

At the planting, the "chusquines" were 2 months old, and from 8 to 15 cm tall. They were planted in poly-ethylene bags (volume of 1.2 L, equivalent to 2 kg of dry soil) with sandy loam soil acquired in the "Bosque Tropical" nursery, located in Armenia, Quindío - Colombia. The initial soil chemical characteristics (Table 1) was determined in Laboratorio de Química at the Universidad Nacional de Colombia for silicon, and in the Universidad del Quindío for the other chemical variables. Initially, this soil was slightly acidic, its silicon concentration was relatively high, the amount of organic matter content seemed to correspond to a relatively carbon-poor soil (carbon/ nitrogen ratio was rather low), and the phosphorus content was in excess relative to nitrogen.

Plants were watered by using a semiautomatic irrigation system, which was weekly checked to ensure a homogeneous spray, whereby each seedling received an average of 4.8 ml of water each 20 minutes for 19 hours each other day.

Plant soil was enriched with a commercial fertilizer Agromil Llanero-Zeo, which contained 75.0% total silicon (SiO_2), 7.0% of total phosphorus (P_2O_5), and 3.0% total sulfur. The amount silicon added to each treatment is shown in Table 2. The dose was obtained by adding the corresponding amount dissolved in 150 ml of distilled water.

Experimental design

We conducted an experiment to assess the effect of silicon on *G. angustifolia* seedlings by using a completely randomized design. All experimental units (the "chusquines") were set on top of three nursery beds raised 50 cm from the ground. Eleven silicon treatments (including the no extra silicon added; Table 2) with 10 replicates each (total 110 "chusquines") were randomly distributed in 10 blocks

Table 1. Treatments with fertilizers applied to the soil of the chusquines.

Treatment	Concentration (mg of Si / bag)	Concentration (mg of P / bag)
T_1	0	0
T_2	600	56
T_3	1200	112
T_4	1800	168
T_5	2400	224
T_6	3000	280
T_7	3600	336
T_8	4200	392
T_9	4800	448
T_{10}	5400	504
T_{11}	6000	560

T_1 = control

Table 2. Physical and chemical characteristics of the soil used at the time of sowing the chusquines

Variables	Units	Amounts
Silicon	%*	17.99
pH	-	5.1
Organic material	% $^{\infty}$	10.7
phosphorous	mg kg^{-1}	21.8
Potassium	mg kg^{-1}	2.53
Calcium	mg kg^{-1}	22.14
Magnesium	mg kg^{-1}	1.20
Aluminum	meq/100	0.2
Nitrogen	mg kg^{-1}	0.9095
Density	g cm^{-3}	0.9
Carbon	% *	6.2064
Carbon Nitrogen Ratio		11.6
Carbon + Magnesium / Potassium Ratio		11.80

*Percentage of weight per dry weight, $^{\infty}$ Percentage in ashes.

of 11 plants each (every block contained one replicate of each treatment, which was allotted randomly within the block). Once established and aimed at characterizing the light environment, the amount of ambient light reaching every plant was recorded during two sunny days and two cloudy days at different times of the day (8:00, 13:00 and 17:00 respectively). Ambient light levels ranged from an average of 243 lux in the morning and afternoon to 608 lux at 13:00.

Plant variables

To determine the growth of "chusquines", they were allowed to grow for a period of eight months. At the beginning of the experiment plants were measured for height, then and on monthly basis they were monitored for height, stem diameter, leaf and stem counts. Senescent leaves were collected during the experiment to add their weigh in the total leaf biomass. At the end of the experiment, all plants were harvested and separated into stems, leaves and roots. Fresh measurements were taken for stem and root length, stem diameter, leaf area, stem (ramets) count. Pictures of the fresh leaves were processed with Paint Net to obtain their area. All plants parts were oven-dried 72 hours at 40 ° C until constant weight and then subsequently the samples were separated into parts such as; leaves roots and reeds (including branches, stem and thorns) and then weighed. In this way the biomass of leaves, stems, roots and total biomass was determined. From these data we calculated the root/ shoot mass ratio. Silicon and phosphorus concentration in plant tissues were determined by using spectro-photometry analysis in the Laboratorio de Analisis Instrumental at the Universidad del Valle (Cali, Colombia).

Statistical analysis

Data were initially run with 2- way ANOVAs after checking for normality and homoscedasticity, with silicon treatments and blocks as the variation sources. Because in all analyses the block effect tested as non-significant ($p>0.05$), in subsequent analyses this factor was removed and 1-way ANOVAs were applied. Multiple comparisons after ANOVA were run by using the Fisher LSD test. On the other hand, to test for the effect of silicon and phosphorus content in the plant tissues, simple correlation analyses were run between silicon vs. phosphorus in these tissues, and between soil silicon vs. silicon content in plant tissues. Statistical analyses were accomplished by using the Statgraphics Centurion® package.

Results and Discussion

Overall, most plant variables (except leaf count, stem and leaf count and root/shoot ratio) showed significant effects from enriching the soil with silicon (Table 3). In particular, silicon enhances plant growth in terms of plant height (Fig. 1) up to approximately in 38%, in treatment T_{10} (5400 mg of Si kg^{-1} of dry soil), which could indicate that above this concentration the demand for silicon is exceeded in G. *angustifolia* seedlings. Increased growth stem length after adding this nutrient was also observed in the Colombian coffee variety (*Coffea arabica L.*) by Caicedo and Chavarriaga (2007) and forage oats (*Avena sativa L.*) by Borda *et al.*, 2007.

Table 3. ANOVA table depicting the soil silicon effects on *G. angustifolia* seedlings

Plant variable	**F**(10, 109 df)	p-value
Plant height	0.277	0.006
Stem basal area	0.113	0.024
Root length	0.761	0.0001
Stem biomass	0.224	<0.0001
Root biomass	2.250	0.024
Leaf biomass	0.267	<0.0001
Average leaf area	0.053	<0.0001
Total plant biomass	0.077	<0.0001
Stem count	-	0.83
Leaf count	-	0.18

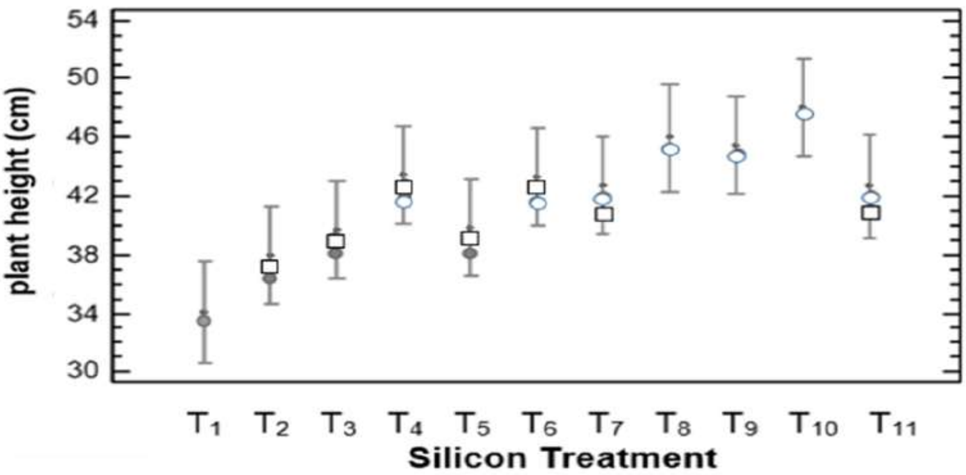

Fig.1. Relationship between plant height and the silicon treatments. The geometric shapes indicate comparisons between treatments; showing that the points of the same form do not have a significant difference. T_1 is the control treatment

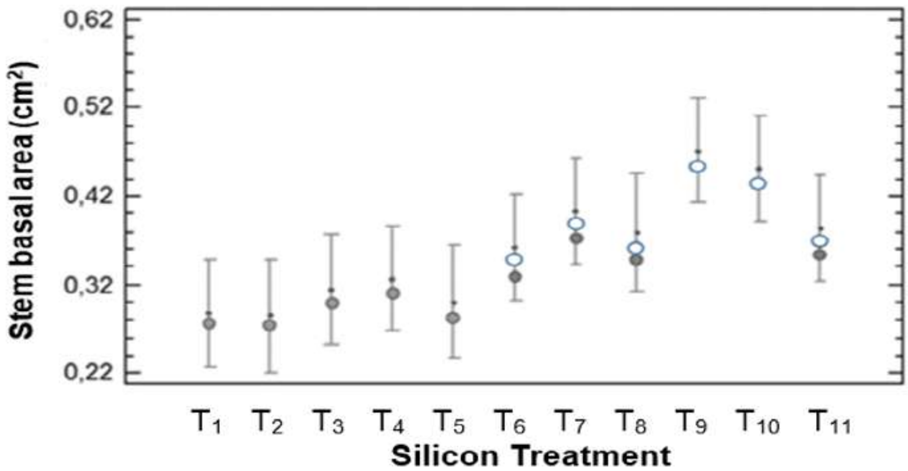

Fig. 2. Relationship between the stem basal area and the silicon treatments. Geometric points of the same form do not have a significant difference. T_1 is the control treatment.

The most efficient treatments in increasing stem thickness (i.e., diameter; Fig. 2) was treatment T_9 (4800 mg Si kg^{-1} dry soil) and T_{10}, with an increase between 70 to 76 % compared to treatment T_1 (control). Similarly, treatment T_{11} decreases stem diameter, as it did with plant height, which could indicate that this concentration exceeds the demand of *G. angustifolia.* A larger stem diameter can make the plant physically stronger when transplanted to the field. Furthermore, since *G. angustifolia* is a clonal plant, stem thickening does not take place at the individual but at the generational level, that is, it does not grow crosswise but its diameter remains the same in each culm throughout its life, instead the stem thickness increases only with the emergence of a new culm, which results at the population level the next generation could reach much faster harvest diameters. Similar results have been also observed in forage oats with an increase of 20% compared to the control when applying monosilicic acid (Borda, Baron, & Gómez, 2007), in coffee of 37% (Caicedo & Chavarriaga, 2007), and in cucumber with an increase from 7 to 9% (Parra-Terraza, *et al.,* 2004).

The average leaf area was also influenced by silicon application (Fig. 3). For instance, in treatment T_{11} leaf size increased 36% compared to T_1. Similar results were also obtained in sugarcane (Sánchez, 1981). Epstein (1994) in a review, reports growth in the leaves of rice, sugar-cane and cucumber. Leaf size increments could improve the photosynthesis yield, as shown by Zhang et al (2018) in tomato plants.

Figure 4 shows that silicon addition also promotes root growth. The most efficient silicon concentration in soil seemed to be in treatment T8 (4800 mg Si/kg dry soil), in which compared to the control treatment, roots were 67% longer. Matichenkov *et al*., (1999) also found that root growth in citrus plants after silicon addition to the soil, and Caicedo and Chavarriaga (2007) found this same pattern in coffee plants. Root growth resulting from silicon addition can produce a great benefit to the chusquines, since by having a longer roots, more rootlets and hair roots, these plants can improve nutrient uptake and plant anchoring to the soil, thus decreasing the possibility of plant overturning.

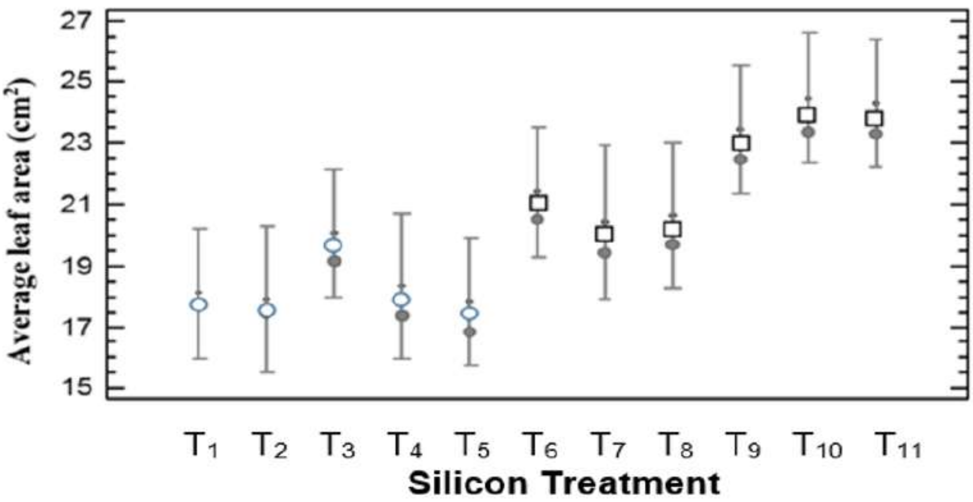

Fig. 3. Relationship between the average leaf area and the silicon treatments. Geometric points of the same form do not have a significant difference. T_1 is the control treatment.

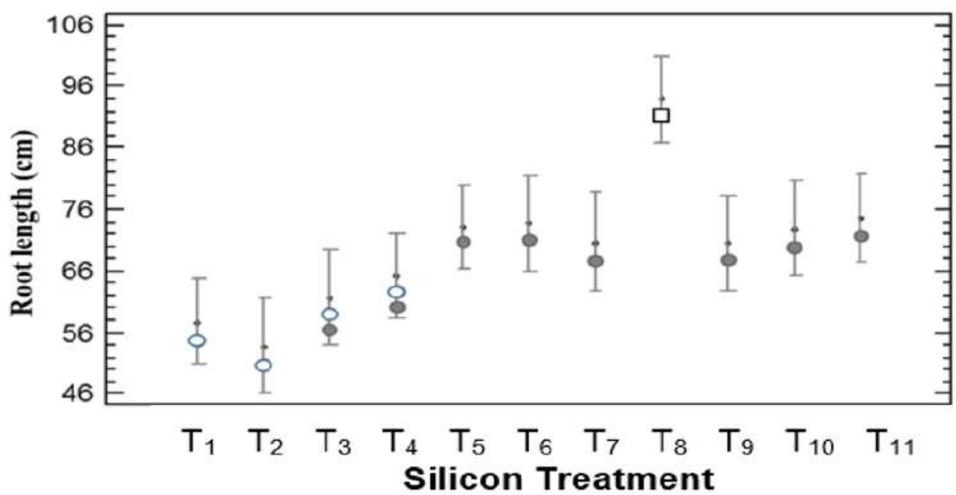

Fig. 4. Relationship between the length of the root and the silicon treatments. Geometric points of the same form do not have a significant difference. T_1 is the control treatment.

Stem biomass was also increased from silicon addition (Fig, 5). However, it peaked at treatment T_7 (3600 mg Si kg^{-1} dry soil), stem biomass started to decrease. Compared to the control treatment, this stem mass increased 100%, which was linked to the increase in plant height and diameter. This finding is encouraging because the stem (culm) is the most useful plant organ by *G. angustifolia* farmers, so that the maturation time of this bamboo plantation could be reduced by making an adequate silicon fertilization. Sugar cane is another species whose main product is the stem and also benefits when fertilized with silicon, as have been reported by Yan *et al*., 2018, Epstein (1994) and Korndorfer *et al.,* 2001.

Leaf biomass (Fig. 6) also increased as a result of silicon addition. This situation peaked at treatment T_9, where the value was 71% higher compared to the control treatment (T_1) increase. Caicedo and Chavarriaga (2007) have also reported the increase, in the coffee leaves.

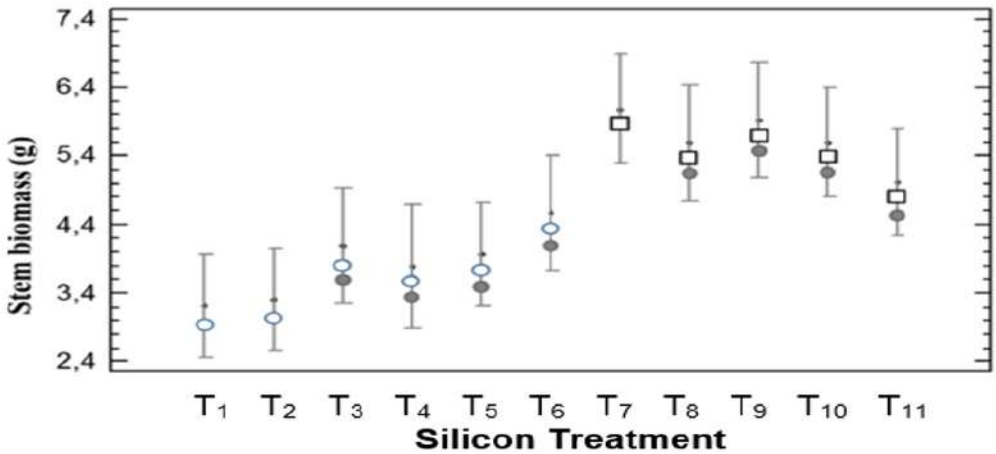

Fig. 5. Relationship between the biomass of the stems and the silicon treatments. Geometric points of the same form do not have a significant difference. T_1 is the control treatment.

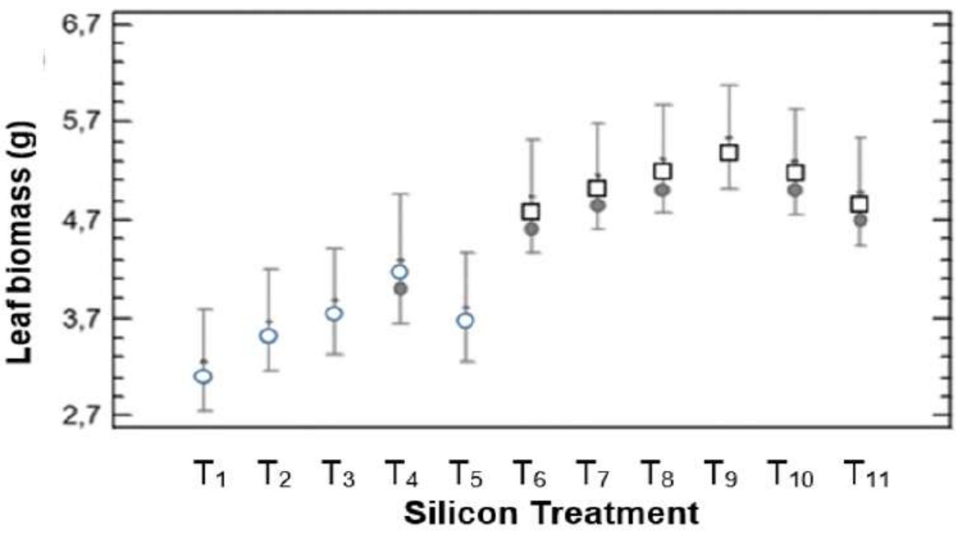

Fig. 6. Relationship between leaf biomass and silicon treatments. Geometric points of the same form do not have a significant difference. T_1 is the control treatment.

Similar to the previous plant variables, root biomass had a positive effect from addition of silicon addition (Fig. 7). The highest response took place at treatment T_8, wherein there was a 128% increase compare to the control treatment. Accordingly, Matichenkov, *et al.,* 1999 found increases in root biomass (between 50 and 200%) in citrus fruits, and Adatia and Besford (Adatia & Besford, 1986) reported that silicon enrichment of soil significantly increased the fresh and dry root mass in cucumber plants.

As shown in previous figures, biomass of plant parts peaked at treatments T_7 trough T_9. Plant total biomass had also a positive effect from silicon additions and peaked at T9. It seems that soil silicon concentrations higher than 4800 mg kg^{-1} dry-mass are excessive and detrimental to these bamboo seedlings. Collins *et al.,* (2013) have previously reported this situation in *bamboo Gigantocloa sp.* when high concentrations of Si are supplied to the seedlings in hydroponic culture.

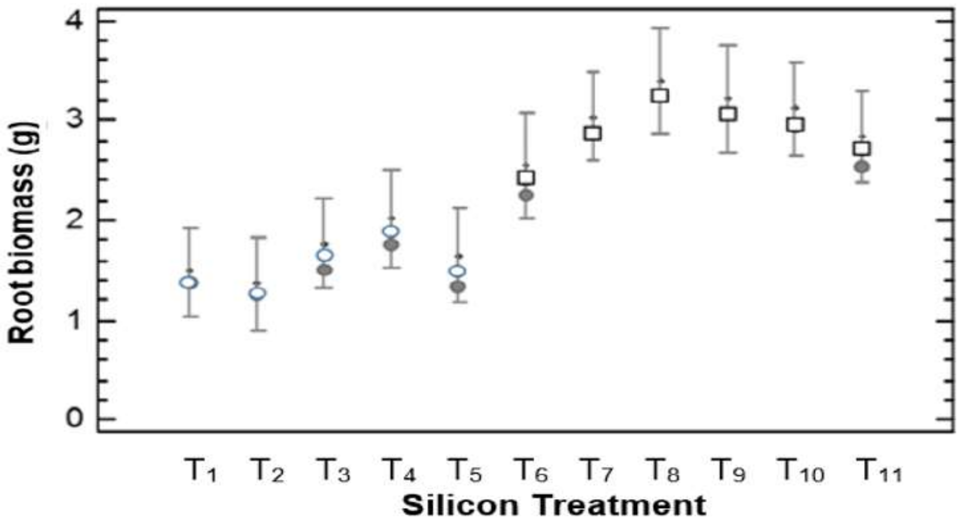

Fig. 7. Relationship between root biomass and silicon treatments. Geometric points of the same form do not have a significant difference. T_1 is the control treatment.

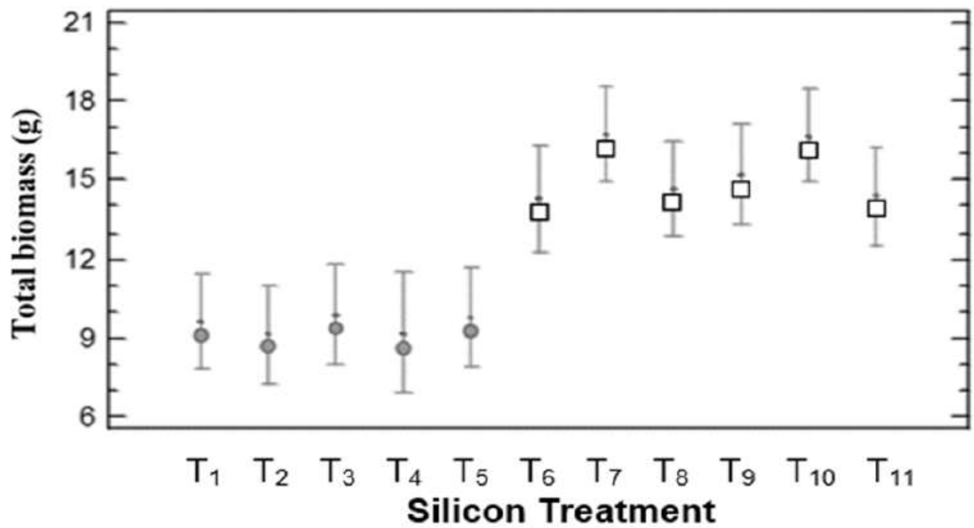

Fig. 8. Relationship between total biomass and silicon treatments. Geometric points of the same form do not have a significant difference. T_1 is the control treatment.

Table 4. Concentration of Si and P absorbed in stem, leaves and root.

Treatments	P (ppm) in Stem	Si (ppm) in Stem	P (ppm) in Leaf	Si (ppm) in Leaf	P (ppm) in Root	Si (ppm) in Root
T_1	1345,61	186,26	1512,36	191,19	1017,96	102,75
T_2	1119,80	215,69	1608,59	263,96	542,92	147,70
T_3	2090,90	285,60	1471,92	305,57	909,32	183,44
T_4	1680,95	296,81	1287,20	333,86	1035,58	208,42
T_5	1279,08	325,84	1209,16	392,24	614,62	373,62
T_6	1985,88	326,86	1932,47	396,92	898,97	438,00
T_7	1436,93	415,46	1872,53	512,52	962,00	600,32
T_8	2768,14	607,99	1159,68	514,00	1380,44	764,23
T_9	1427,10	675,85	1785,28	530,23	1258,36	1012,31
T_{10}	1671,44	694,75	1680,53	557,53	874,48	595,63
T_{11}	1472,75	576,81	1683,85	434,06	673,81	389,93

Silicon and phosphorus were differentially absorbed into plant tissues as their concentration varied in the soil (Table 4). However, it is important to stress that relative to the soil phosphorus, no significant correlation was detected between this variable and its concentration in stems, leaves and roots. Therefore, it can be argued that differences in soil phosphorus did not affect the plant responses to the varying concentrations of soil silicon.

Figure 9 shows the biomass of stems, leaves and roots as a function of the Si absorbed in each part of the seedling. In stem height, leaf area and root length, the result is similar.

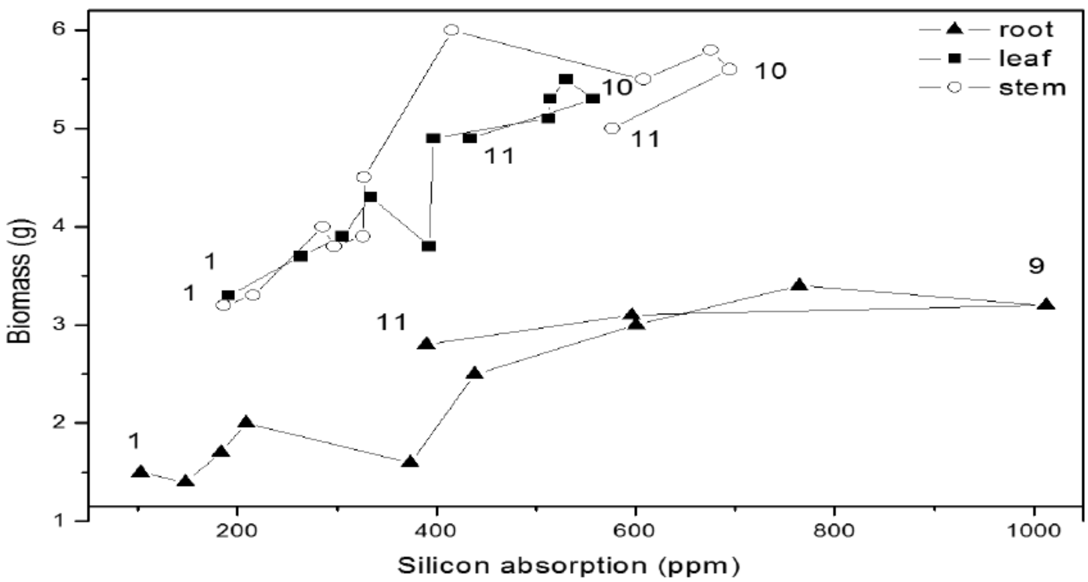

Fig. 9 Biomass of stems (circles), leaves (squares) and roots (triangles) as a function of Si absorption. The continuous line is an aid for the eyes from treatment 1 to 11

Fig. 9 shows that as silicon was added to the soil of seedlings (sequenced from 1 to 11), they absorbed it with greater responses in low concentration treatments, decreasing this absorption in medium level treatments, and with a negative trend after a certain value of silicon depending on the plant organ assessed. As the root absorbs silicon, there must be a blockage in the cellular membrane transporters when there is too much of it in the soil. Borda et al. (2007)find this same pattern in the stem height in forage oats (*Avena sativa L*) and argued that this plant decrease silicon absorption at the high doses because the fertilizer they used also included phosphorus. They postulated that phosphorus is responsible for decreasing zinc absorption, which is known to contribute to cell elongation. However, in our experiment, the fertilizer used despite including phosphorus, did not show a detectable effect on the observed patterns of silicon absorptions, is different from what Borda et al. (2007)mentions. Cuyas et al. (2022) mention that several studies have reported that silicon nutrition increases the growth and yield of barley, rice, wheat, potato, and tomato plants, despite some phosphorus shortage in soil. Caicedo and Chavarriaga (2007) show this same phenomenon in root, leaf area and aerial biomass of coffee plants (variety Colombia) , but they do not mention why. Collin et al. (2013), show that in *Gigantocloa* sp (a bamboo) seedlings, the effect of decreasing silicon absorption becomes higher the higher its concentrations in water, and as the time goes by they absorb less silicon. In figure 9 when comparing treatment T_1 (control, i.e. no extra silicon added), we found that after eight months seedlings may have transported most silicon available from the root to up to the aerial part and therefore the its concentration must be much lower to the their roots. If looking into this same figure, the highest silicon concentration is observed for treatment, T_{10} leaves and stem, and the T_9 for roots, it is seen that after eight months, root contain more silicon that stems and leaves, indicating that silicon transport towards the aerial part has slowed down. At these treatments, 10 in stems and leaves and 9 in root, the amount of silicon absorbed decays despite its high concentration in the soil. There is a threshold limit in soil, below which seedling absorb this mineral and can be very beneficial for its growth. But above this value, seedling do not absorb it any more and its growth is impaired, contrary to what Currie and Perry (2007) defend that silicon is the only nutrient that is not harmful when the plant collects it in excess. Recently, Rivai *et al*., (2022) found that Si influences the genetics of sorghum, affecting the lignin content of the cell walls, which limits plant growth. We believe that Rivai's finding could be an explanation on why stem, leaf and root growth and biomass decreases after reaching certain threshold of silicon added to the soil where the seedlings were grown.

In a study by Liu and collaborators (Liu, et al., 2022) on the silicon biogeochemistry in *Bamboo mosso*, they took three different areas for the same soil type. They show that in the area where pure bamboo (BPF - bamboo-pure forest) stand, the accumulation of silicon in roots, stems, and leaves is lower than in those regions where there are other types of plants (BMF - bamboo-broadleaved mixed forest and EBF - evergreen broadleaved forest). These authors found that bamboo from the BPF zone accumulates more silicon in roots than in other plant parts, as we show in Figure 9. This indicates that silicon makes the biomass of *bamboo Mosso* increase more, but there is a saturation line in the plant and above it the plant biomass decreases.

Conclusions

The experiment provided useful data documenting that silicon addition to the soil enhances growth in *Guadua angustifolia* seedlings ("chusquines"). This increased growth is reflected in taller and thicker stems, bigger leaves, longer roots. Therefore, by adding silicon the biomass values for roots, stems and leaves become higher. However, at higher doses (from 2400 to 2700 mg Si kg^{-1} dry, dependent on the plant organ, mostly in roots) these seedlings stared to show an impaired growth.

Acknowledgements

The authors thank the Universidad del Quindío for the financial support for this project and subsequent publication.

References

Adatia , M. H., & Besford, R. T. (1986). The effects of silicon on cucumber plants grown in recirculating nutrient solution. *Annals of Botany, 58*, 343-351.

Bakhat, H. F., Bibi , N., Zia, Z., Abbas, S., Hammad, H. M., Fahadb, S., Saeed, S. (2018). Silicon mitigates *p Protection, 104*, 21–34.

Bauera, P., Elbaum, R., & Weiss, I. M. (2011). Calcium and silicon mineralization in land plants: Transport, structure and function. *Plant Science, 180*, 746–756.

Borda, O. A., Barón, F. H., & Gómez , M. I. (2007). El silicio como elemento benéfico en avena forrajera (Avena sativa L.): respuestas fisiológicas de crecimiento y manejo. *Agronomía Colombiana, 25*(2), 273-279.

Caicedo, L. M., & Chavarriaga, W. (2007). Efectos de la aplicación de dosis de silicio sobre el desarrollo en almácigo de plántulas de café variedad Colombia. *Revista Agronomica, 15*(1), 27 - 37.

Collin, B., Doelsch, E., Keller , C., Panfili, F., & Meunier, J. D. (2012). Distribution and variability of silicon, copper and zinc in different bamboo species. *Plant Soil, 351*, 377–387.

Collin, B., Doelsch, F., Keller , C., Panfili, F., & Meunier, J. D. (2013). Effects of silicon and copper on bamboo grown hydroponically. *Environmental Science and Pollution Research, 20*, 6482–6495.

Currie, H. A., & Perry, C. C. (2007). Botanical Briefing. Silica in Plants: Biological, Biochemical and Chemical Studies. *Annals of Botany, 100*, 1383–1389.

Cuyas, L., Jing, L., Pluchon, S., & Arkoun, M. (2022). Effect of Si on P-Containing Compounds in Pi-Sufficient and Pi-Deprived Wheat. *Journal of Soil Science and Plant Nutrition, 22*, 1873–1884.

Epstein, E. (1994). Review. The anomaly of silicon in plant biology. *Proceedings of the National Academy of Sciences of the United States of America, 91*, 11-17.

González , V. E., Fonthal , G., & Ariza-Calderón, H. (2014). Influence of Environmental Conditions on the DBH of *Guadua angustifolia* Kunth (Poaceae: Bambusoideae) in the Colombian Coffee Region. *Bamboo Science and Culture: The Journal of the American Bamboo Society, 27*(1), 27-35.

Hernandez-Apaolaza, L. (2014). 2014. ¿Can silicon partially alleviate micronutrient deficiency in plants?: A review. *Planta, 240*, 447–458.

Ingram, V., Tieguhong, J. C., Nkamgnia , E. M., Eyebe , J. P., & Ngawel , N. (2010). *Bamboo production to consumption system in Cameroon.* Amsterdam: CIFOR/ INBAR. http://hdl.handle.net/1 245/1.328

Kleinn, C., & Morales-Hidalgo, D. (2006). An inventory of Guadua (Guadua angustifolia) bamboo in the Coffee Region of Colombia. *European Journal of Forest Research, 125*(4), 361-368.

Klotzbüchera , T., Klotzbücher, A., Kaiser , K., Merbach, I., & Mikutta, R. (2018). Impact of agricultural practices on plant-available silicon. *Geoderma, 331*, 15–17.

Korndörfer, G. H., & Lepsch, I. (2001). *Effect of silicon on plant growth and crop yield. Silicon in agriculture* (Vol. Chapter 7). Elsevier Science B.V. doi 10.1016/ S0928-3420(01)80011-2

Liu, X., Fang, F., Xiong, Y., Peng, Q., Yu, Z., Luan, F., Liu, J. (2022). Assessment of the influence of bamboo expansion on Si pools and fluxes in a disturbed subtropical evergreen broadleaved forest. *Catena, 213*, 106136 - 106145.

Ma, H., Huang, Y., Wang, J., Hu, Q., Cheng, J., & Huang, L. (2022). Foliar and soil applications of nanosilicon affected the growth, metals accumulation, and volatile oils of Houttuynia cordata grown in contaminated soils. *Industrial Crops & Products, 178*, 114622 - 114631.

Ma, J. F., & Yamaji, N. (2006). Silicon uptake and accumulation in higher plants. *Trends in Plant Science, 11*(8), 392-397.

Mandlik, R., Thakral, V., Raturi, G., Shinde, S., Nikoli´c, M., Tripathi, D. K., Deshmukh, R. (2020). Significance of silicon uptake, transport, and deposition in plants. *J. Exp. Bot., 71*, 6703–6718.

Matichenkov, V., Calvert, D., & Synder, G. (1999). Silicon fertilizers for citrus in Florida. *Selected Proceedings of the Florida State Horticultural Society, 112*, 5-8.

Mitani , N., & Ma, J. F. (2005). Uptake system of silicon in different plant species. *Journal of Experimental Botany, 56*(414), 1255–1261.

Motomura, H., Mita, N., & Suzuki, M. (2002). Silica accumulation in long-lived leaves of Sasa veitchii (Carrière) Rehder (Poaceae: Bambusoideae). *Annals of Botany, 90*, 149-152.

Parra-Terraza, S., Baca-Castillo, G. A., Carrillo-González, R., Kohashi-Shibat, J., Martínez-Garza, A., & Trejo-López, C. (2004). Silicio y potencial osmótico de la solución nutritiva en el crecimiento de pepino. *TERRA Latinoamericana, 22*(4), 467-473.

Parsons, J. J. (1991). Giant American Bamboo in the Vernacular Architecture of Colombia and Ecuador. *Geographical Review, 81*(2), 131-152.

Rivai, R. R., Miyamoto, T., Awano, T., Yoshinaga, A., Chen, S., Sugiyama, J., Kobayashi, M. (2022). Limiting silicon supply alters lignin content and structures of sorghum seedling cell walls. *Plant Science, 321*, 111325 – 111340.

Sánchez, P. (1981). *Suelos del trópico* . San José de Costa Rica: IICA.

Xu, D., Gao, X., Mou, J., Li, J., Bu, H., Zhang, R., & Li, Q. (2018). Interactive effects of nitrogen and silicon addition on growth of five common plant species and structure of plant community in alpine meadow. *Catena, 169*, 80-89.

Yan, G. C., Moroslav, N., Ye, M. J., Xiao, Z. X., & Liang, Y. C. (2018). Silicon acquisition and accumulation in plant and its significance for agricultura. *Journal of Integrative Agriculture, 17*(10), 2138–2150.

Zanão Junior, I. A., Ferreira Fontes, R. L., Korndörfer, G. H., Tavares de Avila, V., & Pereira Carvalho- Zanão, M. (2010). Growth of rice plants in an Acrustox fertilized with silicon and manganese. *Ciencia Rural, Santa Maria, 40*(11), 2393-2397.

Zhang, Y., Shi , Y., Gong, H. H., Zhao, H. I., Li , H. L., Hu, Y. L., & Wang, Y. C. (2018). Beneficial effects of silicon on photosynthesis of tomato seedlings under water stress. *Journal of Integrative Agriculture, 17* (10), 2151–2159.