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Effects of Soluble Silicate and Nanosilica Application on Rice Nutrition in an Oxisol

Rita de Cassia FÉLIX ALVAREZ[1,*], Renato de Mello PRADO[2], Guilherme FELISBERTO[2], Angélica Cristina FERNANDES DEUS[2] and Raimundo Leonardo LIMA DE OLIVEIRA[2]

[1] *Federal University of Mato Grosso do Sul, Chapadão do Sul 79560-000 (Brazil)*
[2] *University of the State of São Paulo, UNESP, School of Agronomic Sciences, Department of Soils and Fertilizers, Jaboticabal 14884-900 (Brazil)*

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ABSTRACT

Silicon (Si) has been supplied to plants *via* application of calcium silicate to soil; however, high doses of calcium silicate are required because of its low solubility. Nanoparticles can reduce Si doses and be applied to seeding furrows. This study investigated the effects of liquid Si sources, *i.e.*, highly soluble silicate (115.2 g L^{-1} Si and 60.5 g L^{-1} Na_2O) and nanosilica (< 200 nm), on Si uptake by rice plants, plant lignification, plant C:N:P stoichiometry, plant physiology, and grain yield using an Oxisol under greenhouse condistions. The treatments included the application of nanosilica and soluble silicate to seeding furrows at Si doses of 0, 605, 1 210, and 2 420 g ha^{-1}. Plant uptake and treatment effects were evaluated by measuring C and lignin contents, Si, N, and P accumulation, physiological characteristics, and grain yield of rice. The deposition of silica bodies and amorphous silica in the flag leaves was analyzed using scanning electron microscopy. Application of liquid Si increased Si accumulation in rice by 47.3% in relation to the control (0 g ha^{-1} Si), regardless of the Si sources used. Nanosilica application increased leaf lignin content by 112.7% when compared to that in the control. Silicon moderately affected the net C assimilation (increased by 1.83%) and transpiration rates (increased by 48.3%); however, Si influenced neither plant growth nor grain yield of rice. These results are explained by the lack of biotic or abiotic stress in rice plants during the experiment. To the best of our knowledge, in Brazilian agriculture, this is the first report on the use of nanosilica as a Si fertilizer and its effect on plant nutrition. This study provides evidence that rice plants absorb and accumulate nanoparticles; however, further studies are required to investigate the use of nanoparticles in other plant species.

Key Words: C:N:P stoichiometry, grain yield, leaf lignin, net C assimilation, plant physiology, silicon source

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Silicon (Si) is classified as a beneficial or useful element for plant growth (Marschner, 1995; Mendes *et al.*, 2011). The beneficial effects of Si on crops include yield gain, increased resistance to pests and diseases (biotic factors), and the mitigation of metal toxicity, salt stress, and drought stress (abiotic factors), among others (Epstein, 2001). Rice (*Oryza sativa* L.) accumulates Si (Mengel and Kirkby, 1987; Ma *et al.*, 2001; Mendes *et al.*, 2011), leading to improved crop nutrition and induction of the formation of organosilicon in the leaves, which cooperate to improve crop yield under biotic or abiotic stress. The benefits of Si application to rice may vary. Some studies indicate a lack of response of rice plant to Si (Ramos *et al.*, 2012; Artigiani *et al.*, 2014) because of the absence of stressors. Other reports claim grain yield increase in response to Si application in the presence of stressors (Korndörfer *et al.*, 1999b; Guimarães *et al.*, 2013; Moro *et al.*, 2015). The increase of rice sheath lignification is one of the beneficial effects of Si. Element Si is associated with the lignin-carbohydrate complex in leaf epidermal cell walls and increases lignification in these structures, consequently improving resistance to pests and pathogens (biotic factors) (Schurt *et al.*, 2013). The presence of Si in the leaf blades, sheaths, and stems reduces the C content present in these parts of the plant. Thus, metabolic costs are lowered since Si compounds are energetically cheaper to form compared with C compounds. Moreover, higher Si supply increases shoot growth of *Phragmites australis* by altering the C:N:P stoichiometry in plant tissues (Schaller *et al.*, 2012).

The most common Si source in agriculture is calcium silicate, some of which is derived from industrial or mining waste, such as steel slag. In this case, calcium silicate is likely to be contaminated with phytotoxic heavy metals (Prado *et al.*, 2001). Other Si

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[*] Corresponding author. E-mail: ritacfalvarez@gmail.com.

sources include wollastonite, a naturally occurring rock of limited availability, and manufactured sources such as potassium silicate. Relatively high doses of Si (960 kg ha^{-1}) have been used in some rice crop studies (Korndörfer *et al.*, 1999a), since it can be lost (rendered unavailable to plants) due to polymerization reactions after the incorporation into soil. Silicon can be applied in planting furrows in the form of nanoparticles to decrease its doses applied to soil while maintaining efficacy. This method favors plant nutrition because the nanoparticles have a large specific surface area (Nair *et al.*, 2010). Nevertheless, further studies are needed to understand the effect of nanoparticles on plants (Tripathi *et al.*, 2015), as their use in nutrient solutions is limited (Janmohammadi and Sabaghnia, 2015).

Studies on soluble Si sources supplied to rice crops, especially potassium silicate, have focused on foliar applications (Pawar and Hegde, 1978; Hegde and Pawar, 1981). No research has been reported on silicate application to soil, while few studies have addressed the use of Si nanoparticles in agriculture. The investigation of the use of Si nanoparticles is an important first step to expand Si application to rice crops. Nevertheless, the effect of new Si sources on rice crops, aiming to meet crop demands, increase the production of basic organic compounds, and boost yield, may be more prominent under biotic and/or abiotic stresses. One hypothesis is that nanosilica will perform better compared with other soluble Si sources, regarding Si uptake by plants, lignin biosynthesis, C:N:P stoichiometry, and grain yield in rice. The objective of this study was to evaluate the effects of highly soluble silicate and nanosilica, applied to rice seeding furrows, on plant Si uptake, lignin content, C:N:P stoichiometry, physiological attributes, and grain yield of rice.

MATERIALS AND METHODS

Experimental site and soil

The experiment was carried out between January and April 2016 under greenhouse conditions at São Paulo State University (UNESP), Jaboticabal, Brazil. The minimum and maximum temperatures and relative humidity during the experimental period were 21 °C, 37 °C, and 43%, respectively (Fig. 1). Environmental conditions were favorable for rice crop development. The soil was classified as Oxisol (Embrapa, 2013), with a clayey texture (15.6% sand, 26.9% silt, and 57.5% clay) at 0–20 cm depth. Soil samples were air-dried and sieved through a 2-mm mesh sieve. Random samples were taken to determine chemical properties (Van Raij *et al.*, 2001): pH 6.6 (in 1 mol L^{-1} CaCl$_2$), organic matter 6.0 g kg^{-1}, P extracted by Mehlich-1 extractant 2.0 mg dm^{-3}, H + Al 15.0 mmol$_c$ dm^{-3}, K 0.5 mmol$_c$ dm^{-3}, Ca 27.0 mmol$_c$ dm^{-3}, Mg 5.0 mmol$_c$ dm^{-3}, cation exchange capacity 47.5 mmol$_c$ dm^{-3}, and base saturation 68.4%.

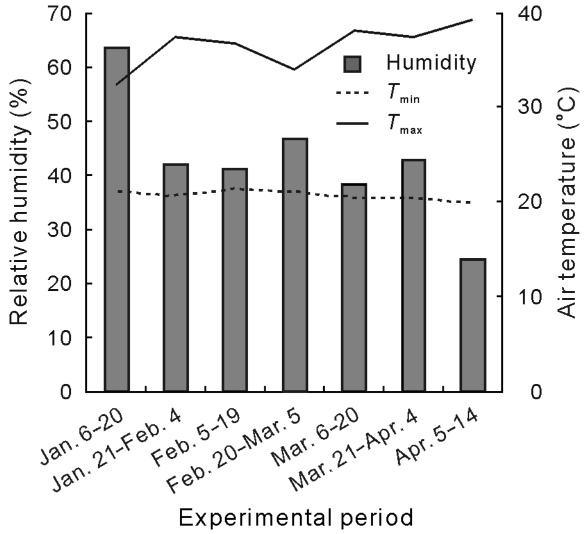

Fig. 1 Minimum and maximum temperatures ($T_{\min}$ and $T_{\max}$, respectively) and relative humidity inside the greenhouse during the experimental period.

Experimental design

The experimental design was completely randomized and consisted of a 2 × 4 factorial scheme (two sources and four doses of Si) with four replications. The treatments included the application of nanosilica (Si = 106.0 g L^{-1}) and soluble silicate (Si = 115.2 g L^{-1}, Na$_2$O = 60.5 g L^{-1}) to seeding furrows at Si doses of 0, 605, 1 210, and 2 420 g ha^{-1}. The used nanosilica (Cab-O-Sperse, PG 022) was supplied by Cabot Brasil Industria e Comercio Ltda., São Paulo, Brazil and had a particle surface area of 200 m^2 g^{-1} with particle size 10% < 200 nm, 70% < 100 nm, and 20% 100–199 nm. Seeds were sprayed with treatment solutions so that Si would be deposited under the seed. This technique simulates seeding furrow spraying in the field. Half the soil was added to a pot, and solutions were sprayed onto the soil. The remaining soil was then added to the pot, and the seeds were sown in furrows of approximately 5 cm in depth. Treatment solutions were applied using a hand-held sprayer at 200 L ha^{-1}, considering the surface areas of the pots to ensure uniform product distribution. At the time of application, the temperature was 28.9 °C and the relative humidity was 62%.

Before sowing and spraying, fertilizers were macerated and set aside for each pot, and then mixed into the entire soil volume before rice planting. The following fertilizer doses were used for 1 dm^3 of soil: 80 mg N, 200 mg P, 150 mg K, 10 mg Zn, 0.5 mg B, 10 mg Mg, and 5 mg Mn, in the forms of urea, superphosphate, potassium chloride, zinc sulfate, boric acid, magnesium sulfate, and manganese sulfate, respectively. Fertilization was carried out according to the recommendations of Malavolta (1981). Nitrogen was applied at the doses of 20 mg dm^{-3} at sowing, 30 mg dm^{-3} at the beginning of tillering (20 d after emergence, DAE), and 30 mg dm^{-3} at the initiation of panicle primordial (55 DAE). The form and amount of N used were based on the recommendations of Fageria (2001). Twelve BRS-Esmeralda rice seeds were sown per pot. At 10 DAE, each pot was thinned to eight plants. At blooming, each pot was thinned again to two plants. The water content in each pot was adjusted daily based on the weights of control pots.

Determinations of C, N, and lignin contents

At blooming, all flag leaves of six plants were harvested and two plants remained intact until grain harvest in each pot. The flag leaves were washed with distilled water, dried in a forced air circulation oven at 65–70 °C until constant weight, ground, and stored in paper bags in a moisture-free cabinet. The C and N contents of the dried leaves were determined using an LECO CN628 elemental analyzer (LECO, USA).

To determine the lignin content, the acid detergent fiber (ADF) was first measured, followed by the "Klason" or acid detergent lignin (Silva and Queiroz, 2002). For the ADF determination, 50 mL acid detergent solution was added to 0.5 g sample of dried leaves, and then autoclaved at 1.5 atm for 40 min. The suspension was washed with 30–40 mL distilled water at 95–100 °C and filtered three times. After the third washing, the residue was filtered under vacuum until dry. Residues were oven-dried for 8 h at 100 °C, cooled in a desiccator, and then weighed (weight 1). To determine the lignin content, 30 mL 72% H_2SO_4 (15 °C) were added to each filter funnel. The acid and residue were mixed, and the mixture was allowed to cool to 20 °C. One hour later, the filter funnels were replenished, followed by two more washings. After that, the residues were filtered under vacuum until dry, and then the filter funnels and residues were washed in hot water (95–100 °C). Washing was repeated until the acid was completely removed, and the residue was filtered under vacuum until dry once again. The filter funnels and the residues were then dried at 100 °C for 8 h or overnight, and reweighed after cooling down in a desiccator (weight 2). Afterward, the filter funnels were placed in a muffle furnace at 500 °C for 3 h, cooled down in a desiccator, and then reweighed (weight 3). The ADF and lignin contents were determined from the weight losses: ADF = (weight 2 − weight 1)/sample weight; lignin = (weight 2 − weight 3)/ sample weight.

Scanning electron microscopy (SEM) analysis

The analysis process followed the protocol routinely used at the Laboratory of Electronic Microscopy of Faculdade de Ciências Agrárias e Veterinárias of UNESP de Jaboticabal in Brazil (Maia and Santos, 1997). Flag leaf blade segments of approximately 1 cm long were collected at blooming from the treatments with Si dose of 2 420 g ha^{-1}. Leaves were cut into two main parts and fixed with 3% glutaraldehyde for 48 h. The material was then dehydrated in a series of increasing ethanol concentrations (30%, 50%, 70%, 80%, 90%, and 100%), at 20 min intervals. Leaf samples were then dried in a dryer (EMS-850, Industry Road, USA) until the critical CO_2 point was reached. Samples were mounted with the adaxial side up and placed in a Denton Vacuum metallizer (Denton Vacuum, USA) for 120 min. Scanning electron micrographs were then taken at 750 × magnification using a JSM-5410 SEM (Hitachi S-570, Japan) (Han *et al.*, 2016).

Determinations of experimental parameters

The net C assimilation and transpiration rates were determined at the grain filling stage (milky grain), using two randomly selected flag leaves per plant in each pot. Gas exchange performance is better assessed when the photosynthetic photon flux density is higher and before the temperature increases to a limiting value for C3 photosynthesis (Feistler and Habermann, 2012). Therefore, the plants were evaluated between 9:00 a.m. and 11:00 a.m. using a portable infrared gas analyzer (LI-6400, LI-COR, USA). During the gas exchange measurement period, the temperature ranged from 31.4 to 37.9 °C and the average relative humidity was 60.1%. The mean photon flux density in the external environment was 503.5 µmol m^{-2} s^{-1}, while that in the chamber was 1 500 µmol m^{-2} s^{-1}.

At the grain physiological maturity stage, two plants from each pot were cut at the soil level. Leaves and stems were separated from the panicles. Whole plants, except for the panicles, were dried in a forced air circulation oven at 65 °C for 72 h and then weighed to determine the dry matter weight. Afterward, the plant material was milled to determine the contents of N, P (Bataglia *et al.*, 1983), and Si (Korndörfer *et al.*, 2004). The amounts of nutrients accumulated were calculated from the nutrient contents in the plant tissue and dry matter. Straw panicles were manually separated from the grain to determine net grain yield, which was corrected for a 130 g kg^{-1} water content.

Soil samples were collected from the top 15 cm of each pot, where the Si sprays were applied at sowing. The samples were then air-dried and sieved through a 2-mm mesh sieve. The Si content was determined using 0.01 mol L^{-1} $CaCl_2$ (Korndörfer *et al.*, 2004).

Data analysis

Data were subjected to analysis of variance (ANOVA). The Si treatments were compared using the Tukey's test at $P < 0.05$. The effects of Si doses were evaluated by regression analysis, since the magnitudes of regression coefficients were significant at $P < 0.05$ as determined by the F-test. All statistical analyses were performed by the SISVAR 4.3 (Ferreira, 2008).

RESULTS AND DISCUSSION

Si in soil and plant and Si accumulation in plant shoot

Nanosilica application increased the Si content in soil to a maximum of 4.31 g kg^{-1} when a Si dose of 1 643 g ha^{-1} was used. Soluble silicate applications linearly increased the Si content in soil to a maximum of 3.75 g kg^{-1} at the highest Si dose (Fig. 2).

Regardless of the Si source, the maximum levels of Si in soil were not high as the products were applied locally and at moderate doses. Soluble silicate significantly increased the Si content in leaf when compared with nanosilica (Fig. 2), with a maximum of 8.49 g kg^{-1} at the Si dose of 1 833 g ha^{-1} (Fig. 2). Nanosilica linearly increased the Si content in leaf to a maximum of 7.90 g kg^{-1} at the highest dose (Fig. 2), which was lower than that reported by Korndörfer *et al.* (1999a) (< 17 g kg^{-1}). These differences between the Si contents in leaf can be explained by the different rice cultivars and Si doses used in the two studies.

Regardless of the Si source, spray application increased Si accumulation in plant. Soluble silicate increased Si accumulation in plant to a maximum of 282.93 g kg^{-1} at the Si dose of 1 314 g ha^{-1}. Nanosilica linearly increased Si accumulation in plant to a maximum of 282.90 g kg^{-1} at the highest Si dose (Fig. 2). The Si content in the soil corroborates these findings.

N and P accumulation

Nanosilica was the most promising Si source for promoting greater increase in Si accumulation both in the soil and rice shoot when compared with other Si

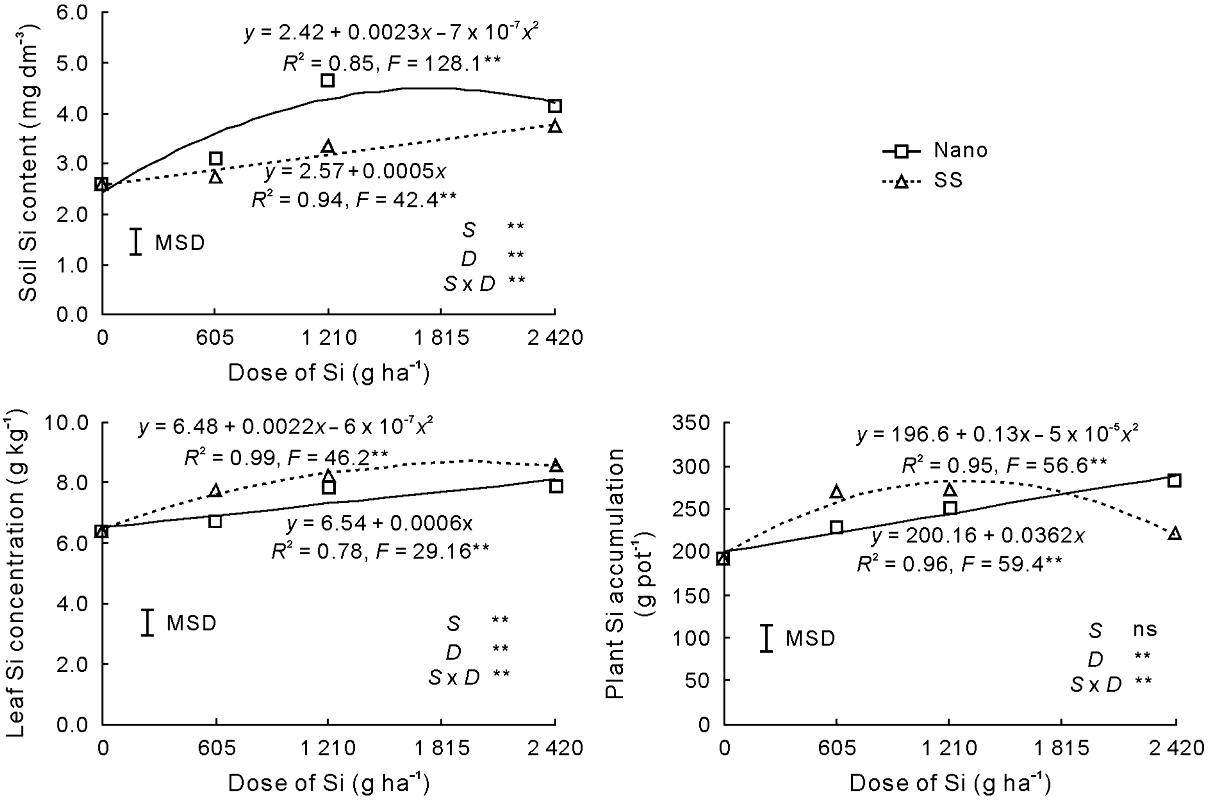

Fig. 2 Silicon (Si) content in soil, Si concentration in rice flag leaf, and Si accumulation in rice plant as functions of Si source (S), nanosilica (Nano) and soluble silicate (SS), and dose (D) applied to the seeding furrows. MSD means the minimum significant difference at $P < 0.05$ according to the Tukey's test. The asterisk (**) indicates significant difference at $P < 0.01$. ns = not significant.

sources. Regardless of the Si source, Si doses did not affect N and P accumulation in rice plant (Fig. 3).

The lack of correlation between Si dose and N accumulation in rice plant was reported by Artigiani *et al.* (2014), and the lack of correlation between Si dose and P accumulation in rice plant was reported by Alovisi *et al.* (2007).

C and lignin contents in rice leaf

The C content in the leaf blades of rice plants treated with nanosilica was lower than that of plants treated with soluble silicate (Fig. 4). The reduction in C content at high Si levels may be due to the partial substitution of Si for C in the organic compounds of plant tissues (Schaller *et al.*, 2012). According to Raven (1983), this change is advantageous to plant, since Si compounds are energetically cheaper to form, compared with C compounds, and provide structural protection such as lignified structures (Schoelynck *et al.*, 2010). Inanaga *et al.* (1995) reported that Si was associated with a lignin-carbohydrate complex in rice epidermal leaf cell walls and may increase lignification.

At all doses, nanosilica resulted in higher leaf lignin content than soluble silicate (Fig. 4). At the Si dose of 2 420 g ha^{-1}, nanosilica produced the highest leaf lignin content. Lignin contributes to plant pathogen resistance by reinforcing cell walls (Hatfield and Vermerris, 2001). Studies on rice have reported that Si increases lignin concentration in plant tissues (Rodrigues *et al.*, 2005; Cai *et al.*, 2008; Schurt *et al.*, 2013). Si may associate with the lignin-carbohydrate complex in rice leaf epidermal cell walls and increase the lignification of these structures (Inanaga *et al.*, 1995).

C:N:P stoichiometry in rice shoot

Determination of the C:N:P stoichiometry as a function of Si application may reveal the correlations between plant Si uptake, C fixation, and N and P ac-

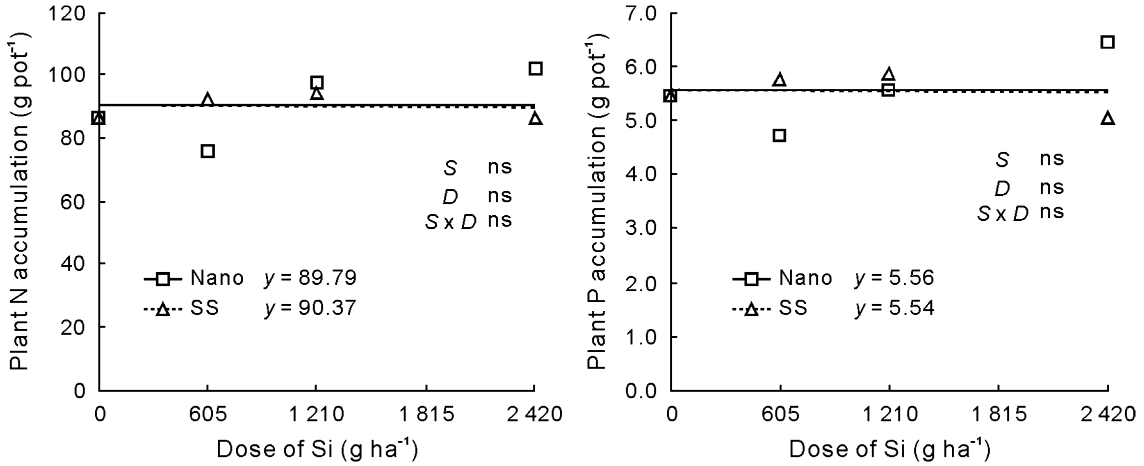

Fig. 3 Accumulation of N and P in rice plant as functions of silicon source (S), nanosilica (Nano) and soluble silicate (SS), and dose (D) applied to the seeding furrows. ns = not significant.

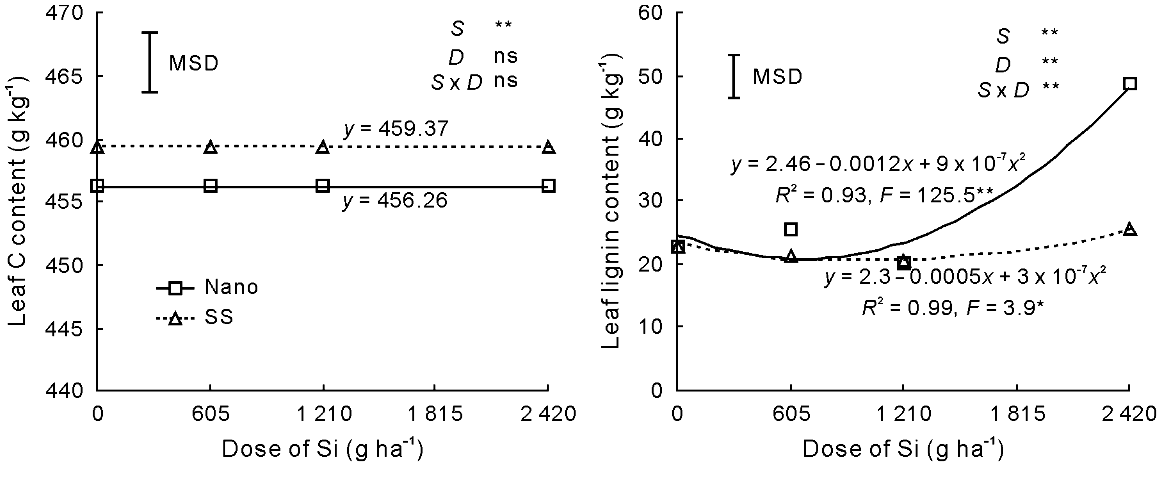

Fig. 4 C and lignin contents in rice leaf as functions of silicon source (S), nanosilica (Nano) and soluble silicate (SS), and dose (D) applied to the seeding furrows. MSD means the minimum significant difference at $P < 0.05$ according to the Tukey's test. The asterisk (**) indicates significant difference at $P < 0.01$. ns = not significant.

cumulation. Silicon forms phytoliths, which are energetically cheaper than the C compounds derived from enzymatic syntheses (Raven, 1983). In the soil, phytoliths can promote the desorption of P from retention sites and increase its availability (Alovisi *et al.*, 2007); they can also promote great accumulation of nitrate in the roots (Ávila *et al.*, 2010). Nevertheless, in the present study, soluble silicate at the Si doses of 1 210 and 2 420 g ha^{-1} did not change the C:N:P stoichiometric ratio in the rice shoot (Table I). Eneji *et al.* (2008) reported strong associations between Si, N, and P uptake in a study with several Si sources and four grass species. The authors indicated that mineral uptake varied according to the Si source used.

In an experiment with *P. australis*, Schaller *et al.* (2012) reported that Si availability might significantly affect C:N:P stoichiometric ratios in different tissues (leaf blades, sheaths, and culms). These findings corroborate those reported for wheat by Neu *et al.* (2017). In the present work, the C:N:P stoichiometric ratio refers to the mean shoot values excluding the panicle, which is possibly the reason why the Si treatments showed no pronounced effects. In addition, the Si doses (up to 2 420 g ha^{-1}) and sources may have influenced the results. Eneji *et al.* (2008) reported different results according to the Si sources used.

TABLE I

C:N:P stoichiometry in rice shoot affected by the sources and doses of silicon (Si) applied to the rice seeding furrows

Si source	Si dose	C:N:P
	g ha^{-1}	
Nanosilica	0	188:15:1
	605	191:16:1
	1 210	183:15:1
	2 420	197:16:1
Soluble silicate	0	188:15:1
	605	183:15:1
	1 210	199:17:1
	2 420	199:17:1

Scanning electron microscopy analysis

The SEM analysis showed large amounts of amorphous silica in the flag leaf blades of rice plants treated with soluble silicate and nanosilica at a Si dose of 2 420 g ha^{-1} (Fig. 5). Amorphous silica densities were similar for both Si sources; however, they still differed significantly from the control (0 g ha^{-1} Si) (Fig. 5). Relatively low amounts were observed for amorphous silica on the leaf surfaces of rice plants in the control. Therefore, little Si was available to the plants under these conditions (Fig. 2). The amorphous silica observed in this study had the same shape as those found in wheat by Andrade *et al.* (2012).

The results from this study and that reported by Schaller *et al.* (2012) for *P. australis* suggest that rice plants can absorb Si. Mali and Aery (2008) indicated that transpiration promoted mineral transport to the shoot of wheat. Other correlations between Si doses, plant tissue content, and substrate concentration were reported for bamboo (Ding *et al.*, 2008) and several

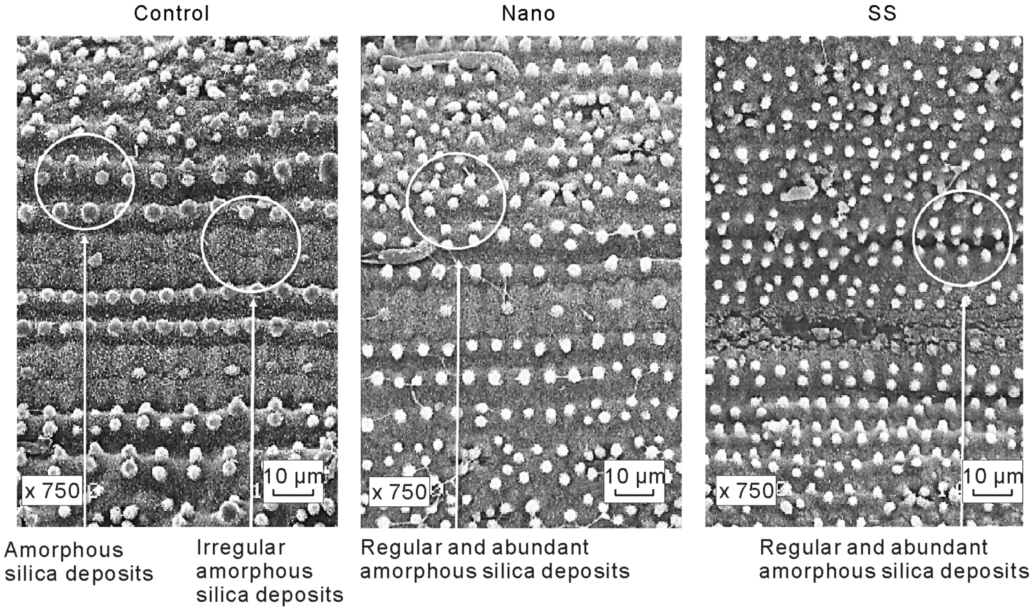

Fig. 5 Distributions of amorphous silica in flag leaf (analyzed using scanning electron microscopy) of rice plants treated with 0 g ha^{-1} silicon (control) and with nanosilica (Nano) and soluble silicate (SS) at a silicon dose of 2 420 g ha^{-1}, applied to the seeding furrows.

crop species (Liang *et al.*, 2006). Schaller *et al.* (2012) observed that Si uptake and deposition may vary according to the location and may depend on Si availability and transpiration.

The plants passively absorb Si as monosilicic acid (H_4SiO_4) together with water (Jones and Handreck, 1967). The movement of H_4SiO_4 to the roots depends on its concentration in the soil solution and on the plant species. At low concentrations, the transport by mass flow is reduced. This effect is significant for Si-accumulating plants cultivated in soils with high Si levels (Marschner, 1995). Silicon, in the form of H_4SiO_4, is transported in plants *via* the xylem. Its distribution to other parts of the plant is affected by their transpiration rates and varies according to plant species. The distribution of Si is uniform in plants that accumulate little Si. In the Si-accumulating plants, such as rice, 90% of the Si accumulates in the shoot (Korndörfer and Datnoff, 1999). The element is immobile in the plant and is deposited in the leaves, leaf sheaths, stems, bark, and roots. The amount of Si accumulated in the leaf blade is greater than that accumulated in the leaf sheath. Nevertheless, the bark accumulates the most Si content, followed by the leaves and the panicles (Mendes *et al.*, 2011). Silicon confers pathogen resistance to plants by forming a mechanical barrier (Schurt *et al.*, 2013). Silicate fertilization may also increase crop yield.

Net C assimilation rate and transpiration in rice leaf

A significant interaction was observed between the net C assimilation rate and the transpiration rate in rice leaf (Fig. 6). Soluble silicate application increased the net C assimilation rate to a maximum of 26.45 μmol CO_2 m^{-1} s^{-1} at the Si dose of 925 g ha^{-1}. Nanosilica application decreased the net C assimilation at the Si doses of 605 and 1 210 g ha^{-1}; however, it slightly increased at higher doses (Fig. 6). Soluble silicate moderately increased the net C assimilation, which was confirmed by the lack of apparent influence of Si on N accumulation in rice plant (Fig. 3). The Si sources used in this study did not affect leaf transpiration rates (Fig. 6). Nanosilica application increased leaf transpiration to a maximum of 23.19 mmol H_2O m^{-2} s^{-1} at the Si dose of 1 533 g ha^{-1}. The maximum leaf transpiration rate obtained with soluble silicate was of 24.27 mmol H_2O m^{-2} s^{-1} at the Si dose of 2 075 g ha^{-1} (Fig. 6).

Previous studies reported a positive effect of Si on net C assimilation and leaf transpiration rates. Rios *et al.* (2014) observed improvements in C assimilation and transpiration rates in wheat plants supplied with Si. Moro *et al.* (2015) stated that the net C assimilation rate in rice increased with Si supplementation.

Plant dry matter and grain yield

The shoot dry matter weight of rice was not affected by the Si source (Fig. 7). The same result was reported by Liang *et al.* (1994), Alovisi *et al.* (2007), and Ávila *et al.* (2010). The result, however, contradicts the findings reported by other authors (Deren *et al.*, 1994; Liang, 1994; Korndörfer and Datnoff, 1995; Korndörfer *et al.*, 1999a, b; Gerami and Rameeh, 2012; Moro *et al.*, 2015).

The changes in rice physiology were not significant (Fig. 6), because they did not influence the plant dry matter weight. In addition, grain yield was not significantly influenced by Si source and dose (Fig. 7). These

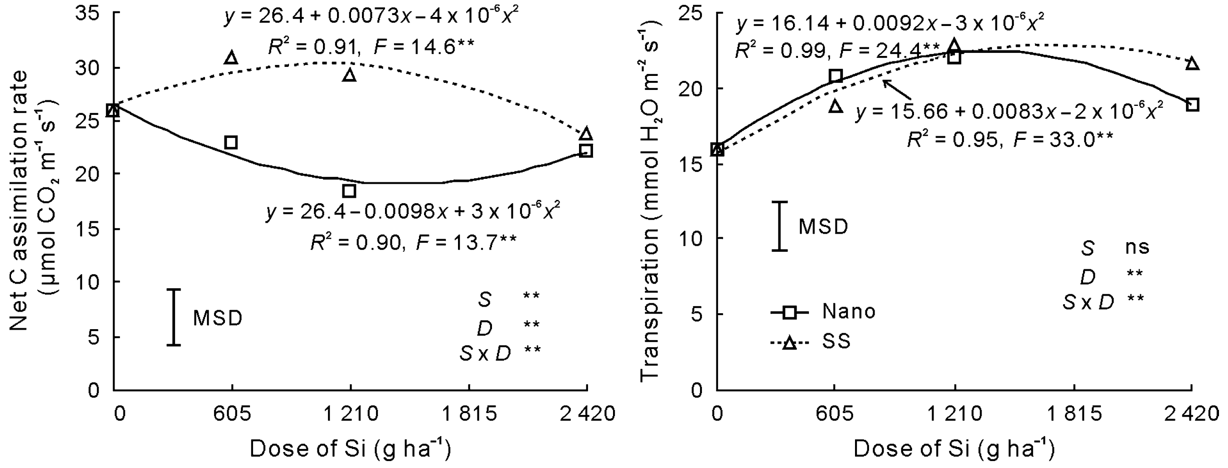

Fig. 6 Net C assimilation and transpiration rates in rice leaf as functions of Si source (S), nanosilica (Nano) and soluble silicate (SS), and dose (D) applied to the seeding furrows. MSD means the minimum significant difference at $P < 0.05$ according to the Tukey's test. The asterisk (**) indicates significant difference at $P < 0.01$. ns = not significant.

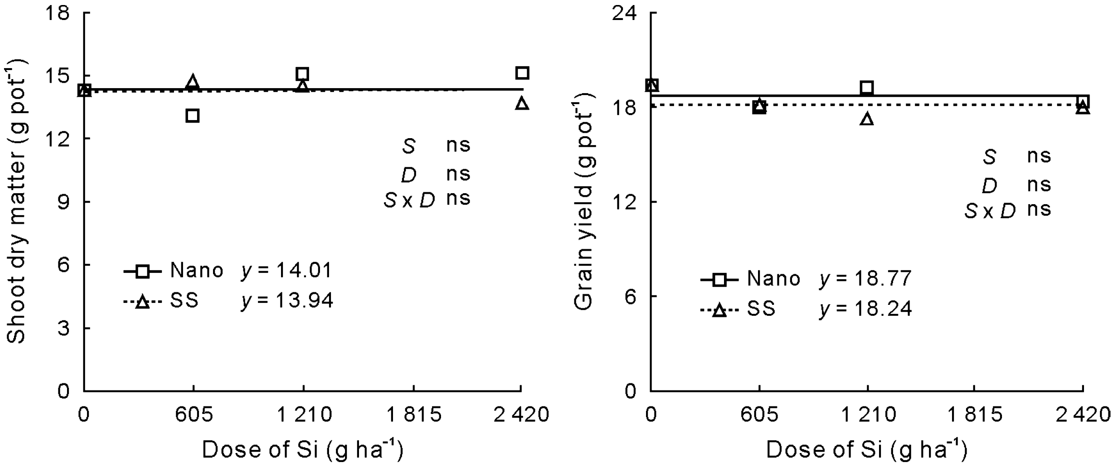

Fig. 7 Shoot dry matter weight and grain yield of rice plants as functions of silicon source (*S*), nanosilica (Nano) and soluble silicon (SS), and dose (*D*) applied to the seeding furrows. "ns" means not significant.

results are in accordance with those reported by Ramos *et al.* (2012) and Artigiani *et al.* (2014). The fact that Si did not affect rice growth or grain yield may be attributed to the relative lack of biotic or abiotic stress in rice plants during the experiment. The benefits of Si to crops subjected to several stresses, such as drought (Souza *et al.*, 2013; Moro *et al.*, 2015), hypersalinity (Alves *et al.*, 2014), and others, have been widely reported in literature.

CONCLUSIONS

Little information is available on the physiological and agronomic changes that occur in plants exposed to nanoparticles. This is the first report on the effect of nanosilica applied to the soil on rice plant mineral nutrition in Brazilian agriculture. Silicon application increased Si accumulation in rice plants, but affected neither the accumulation of N and P, nor the C:N:P stoichiometry. Nanosilica increased the lignin content in rice leaf. No significant influence was observed on rice plant dry matter weight or grain yield with Si application, owing to the lack of biotic and abiotic stresses. This study provides evidence that rice plants absorb and accumulate Si derived from nanoparticles applied to the soil. Similar studies should be performed to determine the potential of nanoparticles to enhance nutrition in other plant species.

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