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SILICON SOURCES FOR STUDIES OF RICE PLANTS IN NUTRIENT SOLUTIONS

FONTES DE SILÍCIO PARA ESTUDOS COM A CULTURA DO ARROZ EM SOLUÇÃO NUTRITIVA

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ABSTRACT: The objective of this work was to evaluate the effects of various Si sources currently used in studies of Si doses in nutrient solutions on dry matter yield and the accumulation of nutrients and Si in rice plants. Treatments of rice plants with three sources of Si (monossilicic acid, sodium metasilicate, potassium metasilicate) and a treatment without Si were allocated in a randomized block design with ten replications. After 39 days in the nutrient solution, the following traits were evaluated: leaf area, leaf specific mass, dry matter yield of roots and shoots, and levels of K, Na, and Si in leaves and roots. Si increased leaf area, leaf specific mass, and dry matter yield of shoots and roots regardless of the Si source. Levels of Si in leaves and roots were significantly higher in relation to the control treatment but no significant difference among Si sources was identified. It was also observed that K and Na were adequately balanced across the treatments. Thus, a cheaper and easier to obtain Si source, such as sodium metasilicate and potassium metasilicate, may be chosen to carry out studies of Si additions to nutrient solutions.

KEYWORDS: *Oryzae sativa*. Silicate. Agricultural experimentation.

INTRODUCTION

The supply of Si to rice plants brings many benefits such as higher grain yields and enhanced resistance to biotic and abiotic stresses conditions, for instance diseases, pests, drought, salinity, and toxicity caused by Al, Mn, Fe, and other metals (ZANÃO JÚNIOR et al., 2009; KIM et al., 2015; ZHU; GONG, 2014).

In rice, Si accumulation can exceed that of all macronutrients reaching levels close to 100 g kg^{-1} in leaves (MA et al., 2002; ZANÃO JUNIOR et al., 2010). Rice is one of the most studied crops regarding Si effects on plants.

In studies of Si in nutrient solutions, various sources of this element with good solubility in water are used, such as sodium metasilicate (Na_2SiO_3), silicic acid (H_4SiO_4), and potassium metasilicate (K_2SiO_3) (ARSENAULT-LABRECQUE et al., 2012; CHEN et al., 2016; KOPITTKE et al., 2017).

Used in many studies, H_4SiO_4 is labor-intensive and costly to obtain. Its advantage, however, is that it does not require the addition of other elements that may interfere in the assessment of the effects of Si. It is obtained by passing a solution of K_2SiO_3 or Na_2SiO_3 through a cation-exchange resin (MA et al., 2002) to remove potassium or sodium. Conversely, Na_2SiO_3 and K_2SiO_3 are salts or solutions ready to be used in the preparation of nutrient solutions, which besides Si contain Na^+ and K^+, respectively. Consequently, to isolate the effects of Si, the evaluated treatments must be balanced by providing the same amount of Na or K to control treatments.

An efficient, easily obtainable, and cheap source of Si is ideal in these studies. Therefore, the objective of this work was to evaluate the effects of Si sources currently used in studies of Si in nutrient solutions on dry matter yield and the accumulation of nutrients and Si in rice plants.

CONTENT

The experiment was conducted under greenhouse conditions using a nutrient solution. Three Si sources were arranged in a randomized block design with ten replications. The following sources of Si were used: monosilicic acid, sodium metasilicate, potassium metasilicate, and the control (without Si addition). Each experimental unit was composed of a cylinder made from PVC tubes of 3 L, 40 cm high containing two rice plants of the cultivar 'Metica-1'.

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Seeds were germinated in rolls of germitest paper moistened with distilled water at a volume equivalent to 2.5 times the dry weight thereof. The rolls were kept in a germinator set at 25°C for six days. Then, the seedlings were conditioned in pots containing the nutrient base solution proposed by Zanão Júnior et al. (2009) diluted to ½ strength, without Si, and remained in these conditions for three days.

After this period, selected seedlings were transferred to tubes containing respective treatments. The nutrient solution, without aeration, was changed every three days. Constant level of the solution was maintained by adding distilled water. The level of pH was monitored daily and kept close to 6.0 by adding NaOH or HCl (1 mol L^{-1}) solutions.

Sodium metasilicate (Sigma-Aldrich), which contained 270 g kg^{-1} SiO_2 and presented alkaline reaction (pH> 10.0), was used in a salt form, and potassium metasilicate (FertiSil®, Ineos Sílicas Ltda), which contained 265,9 g kg^{-1} SiO_2 and presented alkaline reaction (pH> 11.0), was used in a liquid form. Monosilicic acid (H_4SiO_4) was obtained by passing a solution of potassium metasilicate through a cation exchange resin column (Amberlite IR-120B, H^+ form, Sigma-Aldrich), according to MA et al. (2002). Solutions with Si were prepared at the time of changing the nutrient solutions in the tubes, while macro and micronutrients were already in the stock solution. Table 1 shows the composition of the nutrient solutions (treatments) in this experiment.

Table 1. Composition of evaluated nutrient solutions (treatments).

	Control	K_2SiO_3	Na_2SiO_3	H_4SiO_4
	---------- mmol L^{-1} ----------			
K_2SiO_3	0	2	0	0
Na_2SiO_3	0	0	2	0
H_4SiO_4	0	0	0	2
KNO_3	4	0	4	4
HNO_3	0	4	0	0
$NH_4H_2PO_4$	0.5	0.5	0.5	0.5
NaCl	4	4	0	4
HCl	0	0	2	0
$Ca(NO_3)_2$	2	2	2	2
$MgSO_4$	1	1	1	1
	---------- µmol L^{-1} ----------			
$CuSO_4.5H_2O$	0.3	0.3	0.3	0.3
$ZnSO_4.7H_2O$	0.33	0.33	0.33	0.33
H_3BO_3	11.5	11.5	11.5	11.5
$Na_2MoO_4.2H_2O$	0.1	0.1	0.1	0.1
Fe-EDTA	20	20	20	20
$MnCl_2.4H_2O$	0.5	0.5	0.5	0.5

Treatment evaluations were performed after 39 days in the nutrient solution. Specific foliar mass (SFM) was obtained by removing five leaf discs of 1 cm² in each replication and calculating their mean value. The discs were dried at 65°C until reaching constant mass and then weighed to obtain the weight of dry matter of the discs for their respective leaf areas.

The leaf area (LA) of leaf blades detached from stems was determined using a leaf area meter (LI 3100, Li-cor, USA).

Shoots and roots were washed with distilled water and dried in a forced air circulation oven at 65°C for 72 h and subsequently weighed and ground in a Wiley-type mill with a 0.84 mm mesh sieve.

The dry matter of leaf blades (without sheaths) and roots was mineralized using a nitric-perchloric mixture (3:1 v v^{-1}). Levels of K and Na were determined by flame emission photometry, and Si levels were determined according to Korndörfer et al. (2004).

Obtained results were submitted to the analysis of variance (ANOVA) and means compared by the Tukey test at 5% probability.

A dose of 2 mmol L^{-1} Si added to the nutrient solution, regardless of Si source, increased dry matter yield of shoots (DMYS), roots (DMYR), leaf area, and leaf specific mass (LSM) of rice plants (Table 2).

Table 2. Leaf area (LA); leaf specific mass (LSM); dry matter yield of roots (DMYR) and shoots (DMYS); and levels of K, Na, and Si in leaves and roots of rice plants grown in a nutrient solution with Si.

Si source	Control	K_2SiO_3	Na_2SiO_3	H_4SiO_4	CV%
Leaf area, cm^2 pot^{-1}	3465.76 b	4949.96 a	4411.76 a	4958.25 a	10.31
Leaf specific mass, mg cm^{-2}	0.93 b	1.21 a	1.18 a	1.12 a	9.36
DMYR, g $plant^{-1}$	7.68 b	9.12 a	8.87 a	8.15 a	11.95
DMYS, g $plant^{-1}$	25.16 b	34.01 a	30.08 ab	32.09 a	12.3
K levels in leaves, g kg^{-1}	23.97 a	22.70 a	22.36 a	24.06 a	6.74
Na levels in leaves, g kg^{-1}	0.38 a	0.37 a	0.40 a	0.41 a	8.38
Si levels in leaves, g kg^{-1}	4.09 b	59.65 a	59.43 a	53.71 a	9.45
K levels in roots, g kg^{-1}	11.82 a	11.73 a	10.29 a	10.67 a	27.02
Na levels in roots, mg kg^{-1}	0.14 a	0.18 a	0.17 a	0.12 a	19.11
Si levels in roots, g kg^{-1}	1.25 b	4.45 a	3.91 a	4.20 a	6.78

** Different letters, in the row, indicate a significant difference by the Tukey test at 5%.

The significant increase of LA, DMYS, and DMYR in rice in response to Si application observed in this work was also observed by several other authors (CHAGAS et al., 2016; MAUAD et al., 2011; ZANÃO JÚNIOR et al., 2010). Rice plants treated with Si accumulate significant amounts of this beneficial element in leaves resulting in a larger leaf area.

Higher DMYS may be due to an increased photosynthetic activity and a lower rate of transpiration, both enhanced by Si (ZANÃO JÚNIOR et al., 2017), although not evaluated here, which probably contributed to the increase of this variable. The presence of Si also promotes lignification and suberization of the root tissue (FLECK et al., 2011), which may explain the higher DMYR observed in plants grown with Si.

The leaf specific mass is an indirect measure of leaf blade thickness since it is the ratio of dry matter to an area of 1 cm^2 of the leaf. Thus, the higher the LSM value, the greater the leaf blade thickness. Regardless of the source used, the application of Si increased LSM and hence the thickness of the leaf blade. Cunha and Nascimento (2008) found that Si increased the thickness of the adaxial epidermis in corn leaves. According to Gong et al. (2005), the increased leaf thickness is caused by a higher deposition of Si in the form of hydrated amorphous silica ($SiO_2.nH_2O$) in the epidermal cells deposited extracellularly mainly below the cuticle.

The levels of Si in leaves and roots were significantly higher in relation to the control treatment but presented no significant difference among Si sources (Table 2). Levels of Si in leaves were considered adequate for plants, which according to Dobermann and Fairhurst (2000) should be above 50 g kg^{-1}.

The accumulation of K and Na in leaves and roots was not significantly affected by Si sources (Table 2). This fact demonstrates that K and Na were adequately balanced across the treatments (Table 1).

The lack of significant differences among the studied variables for various Si sources demonstrates the effectiveness of these sources in promoting Si absorption. Therefore, it is possible to opt for a cheaper Si source, such as K_2SiO_3 and Na_2SiO_3, to perform studies which evaluate the addition of Si to nutrient solutions.

RESUMO: O objetivo deste trabalho foi avaliar fontes de Si utilizadas atualmente nos estudos com Si em solução nutritiva, na produção de massa seca e acúmulo de nutrientes e Si em plantas de arroz. Foram avaliadas fontes de Si (ácido monossilícico, metassilicato de sódio, metassilicato de potássio) e um tratamento sem aplicação desse elemento, em delineamento em blocos casualizados, com dez repetições, utilizando a cultura do arroz. Após 39 dias em solução nutritiva com os tratamentos foram avaliadas a área foliar, massa foliar específica, produção de matéria seca das raízes e da parte aérea, teores de K, Na e Si nas folhas e nas raízes. O Si aumentou a área foliar, a massa foliar específica e produção de massa seca da parte aérea e raízes, independentemente da fonte utilizada. Os teores de Si nas folhas e nas raízes foram significativamente maiores em relação à testemunha e não houve diferença entre as fontes utilizadas. Observou-se também que o balanceamento de K e Na entre os tratamentos foi adequado. Desse modo, pode-se escolher uma fonte de menor custo e mais fácil obtenção como o metassilicato de sódio e o metassilicato de potássio para a execução de trabalhos que avaliem a adição de Si à solução nutritiva.

PALAVRAS-CHAVE: *Oryzae sativa.* Silicato. Experimentação agrícola.

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