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Silicon, Potassium and Nitrogen Accumulation and Biomass in Corn under Hydroponic Conditions

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Abstract

The aim of the research was to evaluate the effect of the interaction of silicon, potassium, and nitrogen on the foliar area, the accumulation of these elements in the aerial part and the dry biomass in corn plants. The research was developed under hydroponic conditions in Jaboticabal Sao Pablo, Brasil using the 30A77HX hybrid. Two silicon concentrations were evaluated (0 and 2 mmol L⁻¹); two concentrations of potassium (1 and 12 mmol L⁻¹) and four nitrogen concentrations: (1, 10, 15, and 20 mmol L⁻¹). A completely randomized design was used, with factorial arrangement 2 × 2 × 4 and three replications. The foliar area, the dry biomass and, nitrogen, potassium, and silicon content were determined. The application of silicon at a high concentration of K causes an increase in the accumulation of K, which is reflected in an increment of the total dry biomass in the plants of corn, while excess and a deficit of N diminish the accumulation of Si in the aerial part of the plant, which is more evident at a low concentration of K in the nutritious solution, affecting the accumulation of the total dry biomass.

Keywords: benefic element, dry biomass, nutritious, *Zea mays*

1. Introduction

Nitrogen (N) and potassium (K) are essential elements for plants life being part of multiple structural compounds and participating in many vital processes [1]. On the other hand, silicon (Si) is not considered an essential element for plants, however, its absorption can produce beneficial effects in some crops, such as resistance to pests and diseases [2], attenuating abiotic stress [3, 4] and hydric stress [5]. Among the main accumulative crops of Si, are gramineous as sugar cane (*Saccharum* spp.), rice (*Oriza sativa* L.), and corn (*Z. mays* L.) [6].

Some research report about the effect of the combinations of silicon and nitrogen on plants [7–10] and silicon and potassium on the development of plants and yields [11], mainly in accumulative crops of silicon. However, there are not enough results on the effects produced by the interaction of silicon, nitrogen, and potassium on the accumulation of these elements inside the vegetables and their implications on the growth of the plants.

High nitrogen concentration and low concentrations of potassium increase the susceptibility of the corn plants to the noxious agents because it diminishes the absorption of Si. This fact is important because it is well-known that silicon can induce higher resistance to the plants in front of the pests [2].

In an accumulative crop of Si like rice, Andreotti et al. [7], informed that the supply of Si had a small influence on the production of dry matter, although it increased the number of panicles per plant at the highest concentrations of Si, and on the other hand, the concentration of Si decreased with the increment of the dose of fertilization with urea [11].

However, some researchers have stated that there is a lack of information on the use of silicon in general and in particular in corn crops that justifies the need to carry out further research on this subject [12]. Castellanos et al. [13] demonstrated the positive effect of the application of Si on the damages of *Spodoptera frugiperda* Smith in corn to an intermediate dose of N, while Matías and García-Montalvo [14] pointed out that the positive role of the silicon in the resistance to the foliar insects in *Zea diploperennis* L., however in *Z. mays* this is not yet well explained.

González et al. [15] verified the increment of the green forage in one variety of corn and not in others when the application of an intermediate dose of Si was made, while any varieties had a response at the highest dose.

In front of this situation, two hypotheses arise, one that the unbalanced management of N and K, or the excessive use of N associated with the insufficient application of potassium can diminish the silicon absorption and the production of dry biomass in the plants, and other, that the use of silicon can improve the response of the plant in dry biomass production in function of the application of N and K.

To confirm one of those hypotheses the aim of the present investigation was to evaluate the effect of the interaction of silicon, potassium, and nitrogen on the foliar area and the accumulation of these elements and the dry biomass in corn plants.

2. Material and methods

The investigation was performed in a greenhouse located at the department of soils and fertilizers, FCAV/UNESP Jaboticabal Campus, SP, with geographic coordinates of 21° 15' 22" South, 48° 18' 58" West and an elevation of 600 m between March and June of 2014, in a hydroponic floating system.

Two silicon concentrations were evaluated (0 and 2 mmol L⁻¹) using as source silicate of calcium; two concentrations of potassium (1 and 12 mmol L⁻¹) corresponding to 16 and 200% of the solution of K proposed by Hoagland and Arnon [16], using as source monobasic potassium phosphate, and four nitrogen concentrations: 1, 10, 15, and 20 mmol L⁻¹ corresponding at 10, 100, 150, and 200% of the solution of Hoagland and Arnon [16], respectively. The added nitrogen corresponded the 25% to ammoniac form (from ammonium chloride) and the 75% to nitric form (from calcium nitrate).

The rest of the macronutrients and micronutrients were incorporated into de nutrient solutions as were proposed by Hoagland and Arnon [16], balancing the concentrations of calcium and phosphorous. The nutrient solution was maintained under continuous oxygenation by means of an air compression system.

Treatments were arranged in one 2 × 2 × 4 factorial scheme with three repetitions. Each experimental unit consisted of a polypropylene pot with a lid, measuring 48 cm long, 11 cm wide at the lower base, 16 cm wide at the upper base, and 17 cm tall, containing 8 L of nutrient solution and six corn plants (Hybrid 30A77HX). The plants were developed in a greenhouse. Initially, the sowing of the

corn was carried out in vermiculite on isopory trays, irrigated for 15 days, time in that plants reached five leaves.

Water used in the hydroponic system was distilled and deionized, where solu- tion levels were completed daily in each pot with stock solutions corresponding to each treatment. Values of pH were adjusted to between 6.0 ± 0.2 using solutions of $\text{HCl } 1.0 \text{ mol L}^{-1}$ or $\text{NaOH } 1.0 \text{ mol L}^{-1}$.

At 45 days after transplanted, the foliar area of the plants was evaluated. For that, all the leaves of the six plants of each pot were collected, being used an inte- grative apparatus of scanning the foliar area (LI-COR®modelo LI-3000C).

Later on, the dry biomass was determined from the collection of the roots and the aerial part of each pot. For this, the picked-up material was placed in paper bags and dried off in an oven with forced air circulation (65°C) until they reached a constant weight to determine the dry biomass content by pot (aerial part, roots, and the total).

The dry material was ground for chemical analysis of N and K content accord- ing to the methodology described by Battaglia et al. [8] and silicon according to Kraska and Breitenbech [17]. Using data of concentration of N, K, and Si in the dry biomass from the aerial part, from the root, and from the total, for each pot, the accumulation of each element per pot was calculated and expressed in mg per plant.

The data of the active foliar area, dry biomass, nitrogen, potassium, and silicon accumulation in the aerial part of the plants were submitted to variance analysis. The media was compared by means of the Tukey test ($P < 0.05$). The statistical package SPSS version 21 was used [18].

3. Results

The application of silicon in the nutritious solution increased the biomass of the plants of corn and the accumulation of N, Si, and K in this, however, the foliar area did not increase, while a high-dose of K caused an increment of all evaluated vari- ables. The foliar area, the biomass of the plants, and the accumulation of the three elements in the plants were influenced in some way by nitrogen dose (**Table 1**). Foliar and total dry matter and the accumulation of K in the plants were influenced by the interaction of the treatments of Si and K, but not the other variables, while

Source of de variation	Accumulation in the aerial part of			Foliar area	Roots	Biomass	
	N	Si	K			Aerial	Total
	Signification of F values						
Si	**	**	**	ns	**	**	**
K	*	**	**	**	**	**	**
N	**	**	**	**	**	**	**
Si × K	ns	ns	**	ns	ns	**	**
Si × N	ns	ns	**	ns	**	ns	ns
K × N	ns	**	**	ns	ns	**	**
CV (%)	14.12	11.51	15.6	14.42	12.51	9.50	8.85
*, **, and ns: Significant (<i>P</i> < 0.05), (<i>P</i> < 0.01), and nonsignificant by the F-test, respectively.							

Table 1.
Effect of nitrogen (N) and potassium (K) concentrations in the presence or not of silicon (Si), on the nitrogen, potassium, and silicon accumulation in the aerial part of corn plants, the foliar area to and biomass, under hydroponic conditions.

dry biomass of the root and accumulation of K were influenced by the interaction Si × N. The interaction of N and K had influenced on the accumulation of Si and K in the plants and on the increment of the dry biomass of the aerial part of the plants and the total.

The nitrogen accumulation was increased at the highest concentrations of this nutrient with a relationship at the lowest dose while this did not happen at the lowest dose (1 mmol L⁻¹). The silicon accumulation was higher at the concentration at 10 mmol L⁻¹ of N, with a statistical difference with the treatments at 15 and 20 mmol L⁻¹ of N in the nutrient solution being lower at 1 mmol L⁻¹. A similar situation was observed in relation to the influence of N doses for the foliar area (**Table 2**).

The higher values in accumulation of K were observed at the concentrations of 15 and 20 mmol L⁻¹ of N, and the lower at 1 mmol L⁻¹. A similar situation to that it was observed for the total dry biomass, however, the roots dry biomass showed lower values at 1 mmol L⁻¹ of N in relation to the highest concentrations. The interaction of the application of Si with the highest concentration of K promoted an increase in the accumulation of K and the foliar and total biomass. However, there was no difference for the foliar biomass between the treatment of Si at 2 mmol L⁻¹ combined with the treatment with K at 12 mmol L⁻¹ compared with K at 12 mmol L⁻¹ without the application of Si (**Table 3**).

The accumulation of K was increased in the treatments that received 2 mmol L⁻¹ of Si and 10 and 15 mmol L⁻¹ of N, without statistic difference with the treatment that received N at 10 mmol L⁻¹ without the application of Si. The dry biomass of the root was increased in the interaction of Si at 2 mmol L⁻¹ and N at 10 mmol L⁻¹ in relation to the treatment that received 1 mmol L⁻¹ of N in the nutrient solution

Nitrogen mmolL ⁻¹	Accumulation in the aerial part of			FA	Biomass		
	N	Si	K		Roots	Aerial	Total
	mg kg ⁻¹				g per pot		
1	70.50b	36.79c	394.14c	0.67c	19.51b	36.50c	56.01c
10	269.32a	71.55a	731.96a	1.20a	29.95a	69.11a	99.06a
15	239.65a	59.62b	665.38ab	1.12b	24.39ab	60.91b	85.30ab
20	252.51a	55.85b	612.37b	1.06b	22.93ab	56.90b	79.83b

Different letters in the columns indicate significant differences according to the Tukey test for P < 0.05.

Table 2.
Effect of the nitrogen (N) concentrations on the N, K, and Si accumulation in the aerial part of corn plants, the foliar area (FA), and biomass under hydroponic conditions.

Concentrations		Accumulation of K mg kg ⁻¹	Dry biomass	
Si mmol L ⁻¹	K		Aerial	Total
0	1	47.98c	69.63b	246.01c
0	12	57.96b	80.29ab	822.52b
2	1	54.47b	77.02ab	265.48c
2	12	62.22a	88.57a	1069.82a

Different letters in the columns indicate significant differences according to the Tukey test for P < 0.05.

Table 3.
Effect of the interaction of nitrogen (N) and potassium (K) concentrations on the N, K and Si accumulation in the aerial part of corn plants, the foliar area and biomass under hydroponic conditions.

without the application of Si, but not in the relation of the rest of the treatments. The role of silicon in the absorption of the K was verified, and at the same time that the beneficial effect of silicon was not evidenced in front of low and high concentrations of N (**Table 4**).

The accumulation of Si and the dry biomass in the air part of the plant manifested an increment at the higher concentration of K (12 mmol L⁻¹) combined with 1, 10, and 15 mmol L⁻¹ of N, while the accumulation of K and the biomass of the air part showed increments at 1 mmol L⁻¹ of K and 10 mmol L⁻¹ of N and at 12 mmol L⁻¹ of K and at 10, 15 and 20 mmol L⁻¹ of N (**Table 5**).

The influence of the concentration of K in the nutritious solution on the absorption of Si was verified. The application of low and high N concentrations caused the less accumulation of Si in the plant. In the same way, the results demonstrated that the treatments that stood out for a bigger absorption of Si also stood out for higher total biomass, while those treatments that had shown higher accumulation levels of potassium also manifested higher levels of dry biomass in the air part of the plant.

Si	N	Accumulation of K	Roots biomass
Mmol L ⁻¹		mg kg ⁻¹	g per pot
0	1	318.69f	18.73b
0	10	735.97ab	23.45ab
0	15	513.11de	22.40ab
0	20	569.32cde	23.38ab
2	1	469.58ef	23.30ab
2	10	727.95abc	28.45a
2	15	817.67a	26.38ab
2	20	655.42bcd	22.48ab

Different letters in the columns indicate significant differences according to the Tukey test for P < 0.05.

Table 4.
Effect of the interaction of silicon (Si) and nitrogen (N) concentrations on K accumulation and root biomass under hydroponic conditions.

Concentrations		Accumulation		Biomass	
K	N	Si	K	Aerial	Total
Mmol L ⁻¹			mg kg ⁻¹		g per pot
1	1	40.54ef	59.65 cd	44.10c	245.21d
1	10	59.18bcd	83.23ab	65.63ab	246.96d
1	15	51.40 cd	72.73bcd	46.73bc	264.80d
1	20	50.36de	70.83bcd	44.43c	285.05d
12	1	32.48f	52.40d	29.48c	522.26c
12	10	69.05a	96.90a	77.76a	1199.11a
12	15	67.00ab	94.55a	72.52a	1083.79ab
12	20	61.85bc	83.91ab	67.27a	699.53b

Different letters in the columns indicate significant differences according to the Tukey test for P < 0.05.

Table 5.
Effect of the interaction of potassium (K) and nitrogen (N) concentrations on the Si and K accumulation in the aerial part of corn plants and biomass under hydroponic conditions.

4. Discussion

The present results agree with those of Lima et al. [19] who observed increases in dry biomass of leaves, stems, and roots in maize seedlings with the application of 1 mmol L⁻¹ of Si via nutrient solution.

Many authors have pointed out the increase of silicon accumulation in different crops as a response to the application of this beneficial element in corn [12, 20] and in rice under hydroponic conditions [11].

The increase of K accumulation in the aerial part of the plant with the application of high concentrations of this nutrient agrees with the results of Andreotti et al. [7] who obtained an increment of the concentration of K with an increase of the doses of K.

Increments in N accumulation as a function of N doses were also obtained in the aerial part of the maize plants (leaves, stems, cob, straw, and grains) by Gava et al. [21]. There are other results that also show that increases in N doses caused higher development and yield of corn plants [21, 22].

The total dry biomass in the aerial part of the plant was increased with the presence of Si, which agrees with the results of Rohanipoor et al. [23], who reported increases in the leaf area of the corn crop under different doses of Si. Also, González et al. [15] observed increases in plant height and green forage of the Morocho Blanco corn variety under hydroponic conditions when they applied an intermediate dose of Si, in relation to nonapplication. They attributed this to a synergism between Si and K.

No results were found in the literature on the influence of the interaction of the presence of Si with a high concentration of potassium on the gain of the dry biomass, however, Miaoo et al. [24] reported that in the soybean plants there was a positive effect of silicon on the increase of root length and its density subjected at low concentration of K (1 mmol L⁻¹). They attributed this to the action of Si on the affectation of the peroxidase enzyme, but this effect was not demonstrated for the case of maize in an experiment in which the plants were subjected to a low concentration of K [10].

The increase in the accumulation of dry matter observed with the application of Si can be associated with its protective effects of the photosynthetic apparatus of the plants, in the improvement of the efficiency of water use and the balance of mineral nutrients as indicated by Mateos-Naranjo et al. [25]. Other researchers have attributed this increment of biomass to the beneficial effects of Si against the oxidative damage of plant membranes and the increase of the cell wall extension capacity [9].

Other investigations have shown that Si increases stomatal conductance by promoting better water use efficiency [26], inducing increased transpiration, which may lead to increased absorption of K, an element that participates actively in the closure and opening of the stomata [25].

The role of Si in the uptake of K was verified in the present research, but this effect does not occur at low and high concentrations of N. The increase of K at 10 mmol L⁻¹ of N without application of Si can be explained by the small amounts of Si which remains in the water as indicated by Raya and Aguirre [6], despite being deionized in the experiment.

Parveen and Ashraf [27] also observed increases in dry biomass of the roots in corn plants with the application of 2 mmol L⁻¹ of Si in relation to the nonapplication of this element combined with N at 10 mmol L⁻¹ under hydroponic conditions.

The results obtained have relation to those of Mauad et al. [11] in rice, who observed a higher concentration of Si in the plant at the lowest dose of N combined with a normal dose of K, independently of the presence or absence of silicon, which show the role of the beneficial element in the presence of plant stress by N.

Castellanos et al. [13] also stated that the interaction of N and K influenced the accumulated silicon in corn with an optimum at 11.4 mmol L^{-1} of N. Similar results were obtained by Mauad et al. [11] who observed a decrease in the deposition of silica in leaves of rice plants at high doses of N.

Increments of dry biomass and productivity of corn as increase the concentration of N have also been obtained by other authors as Queiroz et al. [1].

The nitrogen effects on dry biomass gain was confirmed since this element is a constituent of all molecules, proteins, enzymes, coenzymes, nucleic acids, and cytochromes, as well as its important function as a member of the molecule of chlorophyll, as have been pointed out by Pina et al. [28].

5. Conclusions

The absorption of silicon in corn plants is influenced by the interaction of nitrogen and potassium. Application of Si combined with a high concentration of K causes an increase in K accumulation which is reflected in higher total dry biomass in corn plants. An excess and a deficit of N decrease the accumulation of Si in the aerial part of the plant, which is more evident at a low concentration of K in the nutrient solution, diminishing the accumulation of total dry biomass.

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