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RESEARCH ARTICLE

Response of Silixol Sugarcane to Growth and Physio-Biochemical Characteristics of Sugarcane

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Abstract Field experiment was conducted during spring season to study the effect of Silixol Sugarcane on growth, yield and juice quality attributes of sugarcane. Treatments comprised two sets with three doses of Silixol @ 2 ml, 4 ml and 8 ml/l of water: Set I—application was done at five critical stages of growth and Set II—Silixol was applied in every month till maturity. Application of Silixol Sugarcane improved bud germination with increasing dose, highest being @ 4 ml/l. Higher specific leaf weight was observed in treated plants as compared to control. Silixol Sugarcane application showed improvement in plant height at various growth stages, being highest at grand growth stage. Dry matter partitioning in leaf, stalk, leaf sheath and root tissues indicates that Silixol Sugarcane application has positive effect on physiological processes. At grand growth stage, maximum dry matter accumulation was recorded in stalks of all treatments. Activity of nitrate reductase, an indispensible enzyme for nitrogen metabolism, in leaves is improved by Silixol application. Silicon content determined in leaf tissues increased with an increase in the Silixol level; highest was obtained with 8 ml/l, and lowest was in control. Silixol Sugarcane application had a positive impact on cane yield attributes viz., cane length and girth, which contributed to more cane yield. Juice quality attributes viz., Brix, juice purity, sucrose, CCS% juice, were relatively better in treated canes. Monthly application of Silixol even at higher dose has no negative impact on plant growth and yield, indicating that the formulation is completely safe. Findings of the present study indicated that applications of Silixol Sugarcane @ 4 ml/l at five critical stages could lead to a yield increment up to 20%.

Keywords Silixol Sugarcane · Sucrose content · Juice quality · CCS

Abbreviations

Si Silicon
CCS Commercial cane sugar
SLW Specific leaf weight

Introduction

Silicon (Si), the second most abundant element in earth crust, is usually found as complex such as silicates or metasilicates. In spite of its abundance in the biosphere, essentiality of Si as an essential nutrient for higher plants is difficult to prove. Silicon has been documented to have potential roles in reducing incidence of lodging, pest and pathogens, water loss by evapotranspiration and heavy metal toxicities. Plants absorb silicon as monosilicic acid (H_4SiO_4), which is present in small quantities up to 2 mmol, depending upon the soil type (Jones and Handreck 1967; Fox et al. 1967). Members of the grass family, such as sugarcane (*Saccharum species hybrids*) and rice (*Oryza sativa* L.), accumulate large amounts of Si as biogenic silicon ($SiO_2{\cdot}nH_2O$), which is localized in between

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epidermis and cuticle as well as in phytoliths (Meyer and Keeping 2000). The benefits of Si for sugarcane were realized at Hawaii in 1965, where field amended with Si-rich compounds had significantly higher yields compared to untreated control. As silicic acid, it catalyzes various biochemical reactions within plants, while the polymerized silicic acid integrates firmly into the structural matter and provides mechanical strength and also acts as a physical barrier for insect pest and pathogen infestation. Silicon (Si) is effective in alleviating both abiotic and biotic stresses in most of the crops (Yoshida 1975). Si suppresses brown spot, stem rot, sheath brown rot in rice and *Fusarium* wilt and *Corynespora* leaf spot on cucumber (Datnoff et al. 2002) and also increases resistance to the fungal disease in cucumber roots (Cherif et al. 1994).

Sugarcane is a typical Si-accumulating plant, which absorbs a large amount of silicon from the soil and responds strongly to Si supply. The present investigation was aimed to study effects of Silixol Sugarcane on sugarcane growth, yield and juice quality attributes. Silixol Sugarcane is a unique propriety formulation of stabilized orthosilicic acid (OSA), obtained from Privi Life Sciences Pvt. Ltd., Navi, Mumbai, India.

Materials and Methods

Three bud setts of sugarcane variety CoLk 94184 were planted in randomized block design in the month of February 2015 under field condition to study the effect of soil application of Silixol Sugarcane through drenching along with market product at different stages of crop growth. Silixol Sugarcane was applied in different doses @ 2, 4 and 8 ml/l of water. The number of applications was also varied. One treatment (Set I) received above concentrations five times at critical stages (at the time of planting, germination, active tillering, grand growth stage and maturity phase), while in another (Set II) these were given on monthly basis till maturity (total of ten applications). Control was without any application of silicon source, and silicon powder @ 4 g/l of water, applied at critical growth stages only, served as market product control. At the time of planting, loam soil of experimental field had pH 7.12, EC 0.08, OC 0.44%, nitrogen (N) 261.07 kg ha^{-1}, phosphorus (P) 82.04 kg ha^{-1} and potassium (K) 236.54 kg ha^{-1}. During the experimental duration, the crop was given the fertilizer in 150:60:60 kg in three splits, full phosphorous and potassium along with one-third nitrogen as basal dose and remaining nitrogen in two splits after 60 DAP and 120 DAP. Weed removal was done only through manual hoeing by labors. The experiment was conducted during spring planting season for the year 2015–2016. Chlorophyll content and NR activity were determined at tillering stage. Data on dry weight of different plant parts and growth attributes, plant height, leaf area, specific leaf weight (SLW) were recorded at grand growth stage.

Amount of chlorophyll content was determined according to Arnon (1949). A total of 50 mg fresh leaf material was homogenized in 80% acetone with pinch of $CaCO_3$ and centrifuged for 10 min. The supernatant was collected, and absorbance was read at 663, 645 and 470 nm, spectrophotometrically. Chlorophyll a and b contents were calculated using the formula given below, and the amounts were calculated as mg/g fresh weight of leaf:

(1) Chlorophyll a (mg/g fwt) = $[(12.7 \times A_{663}) - (2.69 \times A_{645})] \times 0.2$
(2) Chlorophyll b (mg/g fwt) = $[(22.9 \times A_{645}) - (4.68 \times A_{663})] \times 0.2$

SLW was calculated using the formula:

SLW = g dry weight of leaf/area of leaf

For dry matter partitioning, samples were oven-dried at 80 °C till constant weight and expressed as kg dry weight.

At harvesting, yield attributes viz., cane height, girth and weight, were determined. The number of millable canes and cane yield were recorded by counting and weighing of canes on plot basis. Juice quality attributes viz., Brix, sucrose% juice, juice purity, juice extraction%, CCS% juice, reducing sugars and *S*/*R* ratio, were determined after crushing of cane in the month of December 2015. Sucrose% juice was determined in clear juice by automatic saccharimeter (Rudolph Autopol). The amount of reducing sugars in cane juice was determined by Nelson's arsenomolybdate reagent (Nelson 1944). Ratio of sucrose to reducing sugar was calculated and expressed as *S*/*R* ratio. CCS% juice was determined using formula as reported earlier (Bakshi et al. 2001):

$$\text{CCS\% juice} = (1.022 \times \text{sucrose\% juice} - 0.292 \times \text{Brix})$$

All data were determined in three replications and analyzed statistically for standard error (SE ±) using mean data of three replications.

An attempt was also made to study the effect of Silixol on altered dose of NPK along with recommended dose. Two levels of NPK (recommended dose and 75% of recommended dose) were used with and without Silixol. Application was done at critical stages of crop.

Results and Discussion

Silixol Sugarcane has a promotory impact on vegetative growth parameters (Table 1). Silixol Sugarcane when used at 4 ml/l dose had exhibited positive effect. The increased number of applications did not have much beneficial

Table 1 Effect of Silixol Sugarcane on vegetative growth parameters of sugarcane at grand growth stage

Treatments	Plant height (cm)		Leaf area (cm^2)		SLW (g dry weight/cm^2)	
	Set I	Set II	Set I	Set II	Set I	Set II
0	197.0(c) ± 1.40		292.5(cd) ± 0.58		10.3(e) ± 0.75 × 10^{-3}	
2 ml/l	209.3(b) ± 1.60	193.6(c) ± 2.05	337.3(b) ± 1.82	295.3(cd) ± 4.85	13.5(bc) ± 0.69 × 10^{-3}	14.7(a) ± 0.32 × 10^{-3}
4 ml/l	214.5(b) ± 1.35	224.8(a) ± 2.00	348.7(ab) ± 0.44	362.8(a) ± 2.50	15.3(a) ± 0.62 × 10^{-3}	14.1(b) ± 0.21 × 10^{-3}
8 ml/l	182.5(d) ± 2.30	185.5(d) ± 1.10	300.2(c) ± 1.77	266.2(e) ± 0.59	11.3(d) ± 0.43 × 10^{-3}	12.4(c) ± 0.59 × 10^{-3}
Market product	174.9(e) ± 1.70		284.2(d) ± 2.60		12.5(c) ± 0.37 × 10^{-3}	

Mean values with different letters indicate significant ($P = 0.05$) differences between treatments

Table 2 Effect of Silixol Sugarcane on chlorophyll content and NR activity in leaf at tillering stage

Treatments	Chlorophyll a (mg/g f wt)		Chlorophyll b (mg/g f wt)		NR activity (µg nitrite/100 mg f wt)	
	Set I	Set II	Set I	Set II	Set I	Set II
0	1.35(e) ± 0.04		0.34(e) ± 0.02		4.927(e) ± 0.08	
2 ml/l	1.41(de) ± 0.07	1.91(a) ± 0.17	0.41(cde) ± 0.01	0.59(a) ± 0.03	4.946(e) ± 0.06	5.823(d) ± 0.11
4 ml/l	1.55(cd) ± 0.04	1.58(bc) ± 0.13	0.42(cd) ± 0.02	0.48(bc) ± 0.04	5.804(d) ± 0.06	6.513(b) ± 0.17
8 ml/l	1.67(bc) ± 0.09	1.74(ab) ± 0.13	0.51(b) ± 0.02	0.51(b) ± 0.05	6.401(c) ± 0.13	8.174(a) ± 0.02
Market product	1.29(e) ± 0.04		0.35(de) ± 0.01		3.965(f) ± 0.06	

Mean values with different letters indicate significant ($P = 0.05$) differences between treatments

impact in improving growth parameters compared to Set I, where the applications were restricted only to critical crop stages only. Very high dose of Silixol was found to have some inhibitory impact on these parameters irrespective of the number of applications. This could be due to more condensation of plants. Increase in plant height could be due to deposition of silicon in the plant tissues causing erectness of leaves and stem (Yavarzadeh et al. 2008; Jain et al. 2016). Leaf area (ranged between 266.2 and 362.8 cm^2) increased in all the treatments as compared to control. Application of orthosilicic acid formulation showed an increase in specific leaf weight. Similar results were reported earlier in maize (Rohanipoor et al. 2013) and sugarcane (Jain et al. 2016) following Si application.

Chlorophylls a and b are vital components for the photosynthesis and work best together. Higher content of these pigments are indicative of the photosynthetic efficacy of the crop. Silixol Sugarcane application has found to increase the chlorophyll content in leaves at the tillering stage (Table 2). This is a phase when rapid plant growth occurs. The numerical values vary in different treatments, but not statistically significant. It, therefore, indicates that the dose and number of applications of Silixol Sugarcane are not very critical for this parameter. This may be due to Si application, which maintains high photosynthetic activity and efficient utilization of light and translocation of assimilated products to sink, as reported by Rani et al. (1997).

Nitrate reductase (NR) is key enzyme for assimilation of exogenous nitrate. The activity of this enzyme is indicative of the status of nitrogen assimilation in plants; therefore, it is often correlated with growth and yield of crop. Increased dose of Silixol Sugarcane had improved the NR activity. The number of applications of Silixol Sugarcane had slightly improved the NR activity though not statistically significant (Table 2).

Silicon accumulation in shoot epidermal tissues provides mechanical hardening to crop, which results in an increase in dry matter of different plant parts. Silixol Sugarcane application showed improvement in fresh and dry weight of different plant parts at grand growth phase. Dry matter partitioning is an important parameter to ascertain the plant physiological state. For proper growth and optimum yield, photosynthate has to be translocated in an efficient manner to ensure optimum yield. Grand growth stage is a critical stage of sugarcane as the cane development takes place at this phase. Any disruption in the channelization and mobilization of photosynthate would hamper the cane development and ultimately the yield. Impact of Silixol Sugarcane on the translocation of photosynthate was assessed to ascertain that its application has no deleterious impact on cane development, even when used at higher dose and more frequently. Figure 1 indicates the dry matter partitioning at grand growth stage. It indicates that at this stage, almost three-fourths of the dry matter of the crop is localized to the stalk (cane), which is agronomically important for the crop. Following Silixol Sugarcane application irrespective of the number, similar trend on the dry matter portioning has been recorded. This clearly indicates that the application of Silixol Sugarcane does not alter the normal physiological processes in the plant. Application of Si in growing medium of rice results in higher dry matter accumulation (Jawahar and Vaiyapuri 2010). Similar results have been reported earlier using silica granules by Jain et al. (2016).

Application of Silixol had improved the cane yield attributes as well as the juice quality parameters. Monthly application of Silixol had improved both the sugarcane yield (t/ha) and sugar recovery (CCS%). At 2 ml/l dose of Silixol, a significant improvement in the CCS% was recorded when monthly applications were done compared to that of applications at critical stages. This indicates that the silicon requirement for sugarcane is more for better yield and recovery. Further, at higher dose of Silixol, the difference between numbers of applications is up to 0.5% increment. The better CCS recovery following the application of Silixol has been due to improved juice quality traits viz., Brix°, sucrose% juice and *S*/*R* ratio (Table 3).

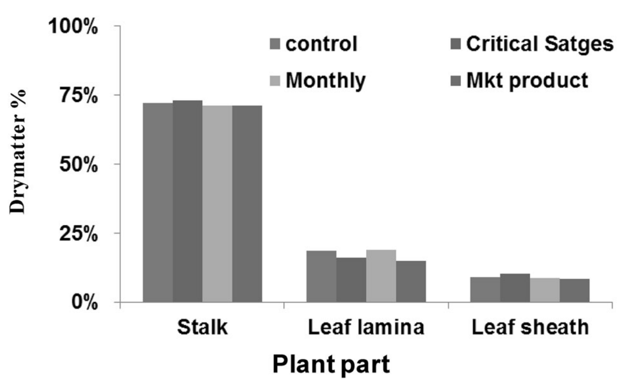

Fig. 1 Dry matter portioning in different growth stages in different treatments at grand growth stage

Nutrient contents in leaf were determined after acid digestion. Clear solution of digested samples was taken for nutrient analysis. Nitrogen (N), potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg) and silicon (Si) contents increased due to Silixol treatment irrespective of dose as compared to control and market product (Table 4). N content ranged from 1.76 to 2.23%, P from 1.32 to 1.78%, K from 0.32 to 0.47%, Ca from 1.9 to 2.5%, Mg from 0.43 to 0.67% and Si from 1.98 to 3.42%, respectively. Silicon content increased with an increase in dose of Silixol; highest was observed with 8 ml/l, and lowest was found in control.

The application of Silixol has contributed to a yield increment up to 25%. There has been a slight yield increment of about 5% in between the number of applications for the same dose of Silixol (Fig. 2). The yield of market product plot had 8% yield increment over the untreated control. Commercial cane sugar (CCS%) had increased up to 13% following application of Silixol though not much change was recorded in between the number of applications, except for the lowest dose (Fig. 2). Beneficial effect of Si in improving the growth and yield has been reported earlier on several crops viz., sugarcane (Jain et al. 2016; Elawad et al. 1982), rice (Jawahar et al. 2015) and several dicot plants (Jones and Handreck 1967). Better juice quality attributes following Silixol Sugarcane application might be due to role of silicon in cane ripening, as reported earlier by Jain et al. (2016).

A study was also conducted where the effect of Silixol Sugarcane on altered dose of NPK. Application of Silixol @ 4 ml/l at 75% NPK has improved sugarcane yield (t/ha) as well as CCS (%) and the numerical values were at par with 100% NPK (Table 5). This clearly indicates that the use of Silixol can play a vital role in reducing the fertilizer requirement without compromising on the yield.

Table 3 Effect of Silixol Sugarcane on juice quality parameters at harvest

Treatments	°Brix		Sucrose% juice		*S*/*R* ratio	
	Set I	Set II	Set I	Set II	Set I	Set II
0	17.99 ± 0.58		14.13 ± 0.16		36.14 ± 1.34	
2 ml/l	17.71 ± 0.57	19.04 ± 0.37	15.25 ± 0.29	16.59 ± 0.14	51.52 ± 1.26	58.42 ± 1.09
4 ml/l	18.18 ± 0.49	18.87 ± 0.15	15.37 ± 0.22	16.72 ± 0.44	60.73 ± 1.19	65.31 ± 0.98
8 ml/l	18.27 ± 0.45	19.31 ± 0.08	16.01 ± 0.12	16.84 ± 0.04	51.98 ± 1.23	54.13 ± 1.74
Market product	18.24 ± 0.44		16.13 ± 0.49		43.13 ± 2.04	

Mean value with ± SE ($n = 3$)

Table 4 Leaf nutrient profiling was done at harvest following the application of Silixol Sugarcane

Treatments	% content					
	Nitrogen	Potassium	Phosphorus	Calcium	Magnesium	Silicon
0	1.76 ± 0.08(d)	1.32 ± 0.04(c)	0.32 ± 0.02(c)	1.9 ± 0.12(d)	0.43 ± 0.08(b)	1.98 ± 0.17(e)
2 ml/l	2.01 ± 0.03(c)	1.78 ± 0.12(a)	0.42 ± 0.04(ab)	2.5 ± 0.09(a)	0.67 ± 0.06(a)	2.71 ± 0.13(c
4 ml/l	2.23 ± 0.10(a)	1.74 ± 0.07(a)	0.47 ± 0.05(a)	2.4 ± 0.11(b)	0.63 ± 0.02(a)	3.21 ± 0.14(b)
8 ml/l	2.12 ± 0.04(b)	1.56 ± 0.10(b)	0.41 ± 0.03(ab)	2.1 ± 0.13(c)	0.66 ± 0.06(a)	3.42 ± 0.17(a)
Market product	1.98 ± 0.07©	1.34 ± 0.11(c)	0.37 ± 0.06(bc)	2.1 ± 0.08(c)	0.39 ± 0.03(b)	2.25 ± 0.11(d)

Mean values with different letters indicate significant ($P = 0.05$) differences between treatments

Fig. 2 Impact of different doses of Silixol Sugarcane on yield and commercial cane sugar (CCS%)

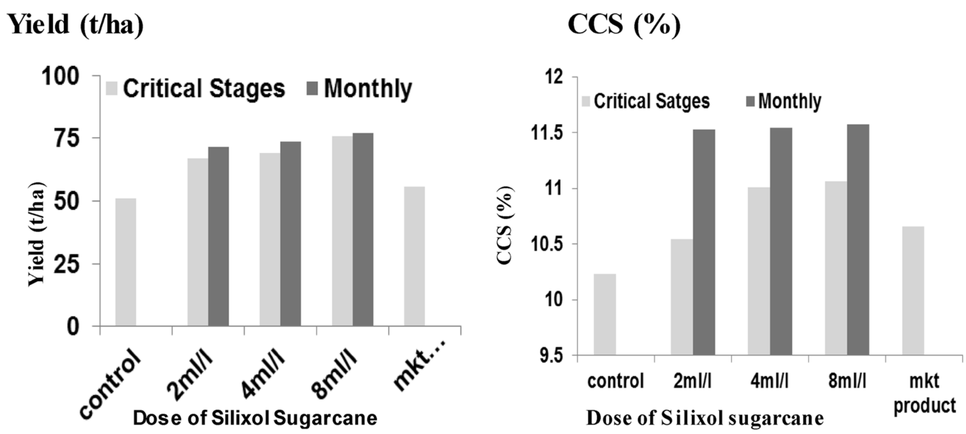

Table 5 Effect of Silixol Sugarcane on cane yield and sugar recovery at altered NPK levels

	Cane yield (t/ha)		CCS (%)	
	75% NPK	100% NPK	75% NPK	100% NPK
Without Silixol Sugarcane	51.24	60.90	10.25	10.99
Silixol Sugarcane @ 4 ml/l*	59.77	74.29	11.19	11.31

* Critical stages

Conclusions

Results of the present study indicate that application of Silixol @ 4 ml/l when used at critical stages of sugarcane (planting, germination, tillering, grand growth and maturity) has improved both the sugarcane yield and sugar recovery. Silixol applications have no negative impact on the physiological processes as indicated by dry matter partitioning. This ensures that its use will not cause any harmful impact on subsequent ratoon crops. Silixol has a role in improving the fertilizer use efficiency as the yield of the sugarcane at 75% NPK (of recommended dose) was at par with 100% NPK (recommended dose). The reduction in the fertilizer requirement of the sugarcane would be highly beneficial for farmers. Sugarcane being a long-duration crop with large biomass requires very large quantities of fertilizer. Repeated cultivation of sugarcane on same land with such high fertilizer dose would lead to soil deterioration to a very large extent. The use of Silixol Sugarcane thus plays a role in reducing the loss of soil quality.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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