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The impact of bio-silicic acid (BioSilAc) to increase productivity and water use efficiency in sugarcane

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Abstract

Sugarcane (*Saccharum officinarum* L.) is a vital plantation crop, serving as a raw material for various industries, including sugar, bioethanol, amino acids, and food ingredients. Therefore, the advancement of technologies aimed at increasing productivity and fertilization efficiency in sugarcane cultivation has become a priority. Bio-silicic acid (BioSilAc) is a technology that can optimize the cultivation process. This study evaluated the effectiveness of water and fertilizer usage in plant cane (PC) and ratoon cane (RC) during low rainfall by applying BioSilAc and its impact on sugarcane productivity. This research utilized a randomized block design with three treatments (P1: 100% NPK; P2: 100% NPK + BioSilAc; and P3: 75% NPK + BioSilAc) replicated three times. Observed variables included soil and leaf nutrient levels, sugarcane growth, and productivity. Daily and potential water consumption was measured in real-time using a sap flow meter to calculate water use efficiency for P1 (control) and P2, representing the BioSilAc application. The P3 treatment (75% NPK + BioSilAc) demonstrated the highest effectiveness in terms of fertilization efficiency and productivity, resulting in notable increases in crop yield and crystal sugar. The PC category saw increases of 13.5% and 12.4%, while the RC category experienced gains of 22.82% and 25.81%, respectively. Furthermore, water use efficiency was recorded at 22.55% for the PC category and 13.72% for the RC category. Our findings suggest that the application of BioSilAc not only increase the productivity of sugarcane but also improves both fertilizer and water use efficiency.

[keywords*:* Biosilac, plant cane, ratoon cane, sap flow, water consumption]

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Introduction

Sugarcane (*Saccharum officinarum* L.) is a crucial plantation commodity that significantly affects food security in Indonesia. It serves as a primary industrial raw material for products such as sugar, acetic acid, amino acids, and various food ingredients. Additionally, bagasse, a by-product of sugarcane processing, is utilized for energy cogeneration, bioethanol production, animal feed, and organic mulch (Santos-Cividanes Terezinha *et al*., 2022). Through Presidential Regulation No. 40 of 2023, the Indonesian government aims to achieve sugar self-sufficiency by 2030 to meet consumption, industry, and bioethanol demands. However, this goal poses significant challenges, particularly since nearly 90% of sugarcane plantations are located in Java and Lampung, which also focus on other seasonal crops. Rapid land use changes occur, especially in Java, where conversion to residential and industrial areas is prevalent. To meet the self-sufficiency target, efforts must focus on optimizing land cultivation and improving productivity.

Sugarcane yield and productivity are substantially influenced by climate conditions (Zhao & Li, 2015; Toharisman & Triantarti, 2016). The critical climate factors include rainfall and evaporation rates. Changes in the length of the dry season due to climate change can affect sugarcane growth and limit both biomass production and sugar yield (Jaiphong *et al*., 2016; Liu *et al*., 2016; Marchiori *et al*., 2017; Khonghintaisong *et al*., 2018). Water scarcity can induce oxidative stress in plants, damaging physiological processes (Teixeira *et al*., 2022) and reducing nutrient-use efficiency (Hoang *et al*., 2019). Declines in sugarcane productivity in various regions due to drought can impede the advancement of sugarcane cultivation, particularly in tropical areas. Consequently, there is a pressing need for technological innovations to optimize land resources, support high sugarcane productivity, and mitigate the impacts of climate change

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One effective strategy for reducing the harmful effects of water deficiency on sugarcane is the application of silica. Silica has been widely reported to be beneficial as an element for plants, especially its ability to induce various stress mitigation mechanisms (Luyckx *et al.*, 2017; Etasama & Jeong, 2018; Verma *et al*., 2020; Ali *et al*., 2020; Verma *et al*., 2021). Sugarcane is known to absorb more silicon (Si) than any other nutrient, requiring an average of 200-500 kg of Si per hectare over a 12-month planting period, which is higher than its absorption of nitrogen (N) and potassium (K) (Camargo *et al*., 2010). Under drought stress conditions, the uptake of Si by sugarcane plants can increase the relative water content in their tissues (Camargo *et al*., 2019; Bezerra *et al*., 2019; Verma *et al*., 2019; Teixeira *et al*., 2020) and reduce oxidative stress by minimizing electrolyte leakage in cells (Bezerra *et al*., 2019). This improvement leads to greater photosystem II quantum efficiency, resulting in increased dry biomass production (Camargo *et al*., 2017; Verma *et al*., 2019; Teixeira *et al*., 2020). Plants primarily absorb Si as mono-silicic acid (H4SiO4) (Sahebi *et al*., 2015). BioSilAc is a bio-silicic acid fertilizer developed by Indonesian Oil Palm Research Institute (IOPRI) researchers. It combines Si-solubilizing microorganisms and nanotechnology (Santi & Goenadi, 2017). Applying BioSilAc to oil palm and soybeans has yielded positive results (Amanah *et al*., 2019; Santi *et al*., 2019). However, the impact of BioSilAc on sugarcane plants in the plant cane (PC) and ratoon cane (RC) categories has not been extensively studied. Therefore, this study aims to evaluate the effects of BioSilAc application in enhancing the productivity and efficiency of water and nutrient use in both PC and RC sugarcane.

Material and Methods

Location and experimental design

The research on the application of BioSilAc was conducted at the Jengkol Sugar Research Center in Kediri, East Java (PTPN I Regional IV Sub-Holding Supporting Co), on sugarcane varieties PS 881 in the plant cane (PC) and ratoon cane (RC) categories. The planting process took place on dry land regosol soil types from June 2023 to June 2024. The initial chemical characteristics for the experimental plots were as follows: pH 6.76; organic carbon (C) 1.27%; cation exchange capacity (CEC) 3.17 cmol$^+$/kg; total silicon (SiO_2) 28.69%; available Si 133 ppm; nitrogen (N) 0.19%; phosphorus pentoxide (P2O5) 0.08%; and potassium oxide (K2O) 0.023%.

A randomized block design (RBD) was used to test three fertilization treatments with three replications in a plot area of 1,000 m^2 for each treatment plot. Treatment parameters consist of: (P1) recommended dose of 100% NPK as a control; (P2) 100% NPK + 250 BioSilAc tablets / Ha; and (P3) 75% NPK + 250 BioSilAc tablets / Ha, 250 BioSilAc tablets weigh a total of 1000 grams. They contain 17-20% silica (SiO_2) and 5% of available silica in the form of mono silicic acid. The recommended dosage per hectare for 100% NPK is as follows: ZA 500 kg; NPK 400 kg; SP 36 100 kg; and KCl 100 kg. The BioSilAc application is conducted twice in each planting season, specifically at 1 and 3 months after planting/ratoon (MAP/MAR). Each application process involves diluting 125 BioSilAc tablets in 250 liters of water and then spraying them onto the plants and root areas. The maintenance of the sugarcane follows standard agricultural practices, which include controlling weeds, pests, and diseases throughout the trial period.

Observation and data analysis

Plant growth was monitored through measurements of plant height, number of stems, and stem diameter. Harvest data were also collected for each treatment. The analysis of soil nutrient parameters, including silicon content in both the soil and plant tissue, was measured using the standard 4500-SiO2 D Heteropoly blue method (Eaton *et al*., 2017). A standard solution of Si 1000 ppm (Merck 132244) was used for comparison. Silica forms a blue complex with molybdate, while oxalic acid eliminates unwanted molybdate bonds, such as phosphate.

Water use efficiency refers to the optimal utilization of water resources for the growth and development of plants. To measure sap flow in the xylem, the heat ratio method (Hölttä *et al*., 2015) was utilized with a sap flow meter (SFM1) from ICT International. This instrument features three needles that generate heat pulses (the middle needle) and is equipped with a sensitive thermocouple. For the measurement, sap flow was introduced into the stem approximately 10 cm above the ground surface. Real-time measurements were taken at 30-minute intervals over a period of seven days at 9 MAP/MAR. Silica is a beneficial element that supports plants under stress, making dry conditions particularly suitable for SAP Flow meter observations, especially during the critical period when sugar cane requires substantial water (4–9 months).

Result and Discussion

Effect of biosilac application on sugarcane growth and productivity

Sugarcane requires a high level of mineral nutrients for optimal crop production (Verma *et al*., 2020; Zeng *et al*., 2015). As a C4 plant, sugarcane depends on carbon metabolism, but its various growth stages are vulnerable to drought stress. Such water deficit conditions significantly affect nutrient uptake, leading to disturbances in the plant's morphological and physiological characteristics (Verma *et al*., 2021; Bodner *et al*., 2015; Boaretto *et al*., 2014). The biomass extraction process during sugarcane harvest tends to deplete available silica in the soil, despite its critical role in mitigating drought stress and enhancing nutrient uptake in sugarcane, particularly under stressed conditions (Pascual *et al*., 2016; Xu *et al*., 2015). Soil analysis following the application of BioSilAc indicated an increase in available silicon, reaching levels between 2.91 to 3.40% for PC and 2.98 to 3.08% for RC. Available silica in the soil before treatment is 133 ppm (0.013%). There was a slight increase in organic matter and cation exchange capacity (CEC) compared to pre-application conditions, which suggests improved soil fertility and greater stability in soil structure (Table 1).

The vegetative growth of sugarcane 9 months after planting for primary cultivation (PC) and 9 months after ratooning for ratoon cultivation (RC) is depicted in Figure 1. The data shows that the provision of BioSilAc (P2-P3) tends to increase the vegetative growth of plants compared to P1 (100 % NPK recommendation), especially in the number of stems and plant height. The P3 treatment increased the number of stems and plant height in the PC category. While in the RC category, P2 gave better results. Meanwhile, there was no difference between the control and treatment in terms of stem diameter. These findings suggest that using NPK fertilizer at a dose 25% lower than the standard, in conjunction with BioSilAc, can achieve plant physical conditions comparable to the control group receiving the full 100% NPK dosage (refer to Figure 1). This aligns with research by Makarim *et al*. (2007) and Kristanto (2018), which demonstrated that applying silica to plants can strengthen and enhance the stability of root membranes, thereby optimizing nutrient absorption. Additional studies indicate that silica promotes denser root development and increases cell wall extensibility in the growth zone (Frew *et al.*, 2018; Coskun *et al*., 2019; Hattori *et al*., 2003;

Table 1. Soil characteristics 9 months after BioSilAc application

Analysis Parameters	Block E15 (PC)			Block E14 (RC)			Unit
	P1	P2	P3	P1	P2	P3	
pH	7.53	6.53	6.97	6.75	6.88	6.46	-
Organic carbon	2.13	1.72	2.25	1.87	1.96	2.67	%
N	0.1	0.08	0.08	0.09	0.12	0.08	%
P_2O_5	0.14	0.17	0.14	0.16	0.17	0.14	%
K_2O	0.019	0.018	0.014	0.047	0.065	0.032	%
total SiO_2	21.35	36.63	24.56	30.42	35.50	31.45	%
Available SiO_2	0.89	3.40	2.91	1.92	3.08	2.98	%
CEC	4.29	3.70	4.80	5.81	6.31	5.77	$cmol^+/kg$
MgO	0.039	0.021	0.021	0.092	0.087	0.09	ppm
CaO	0.028	0.029	0.016	0.043	0.051	0.044	ppm

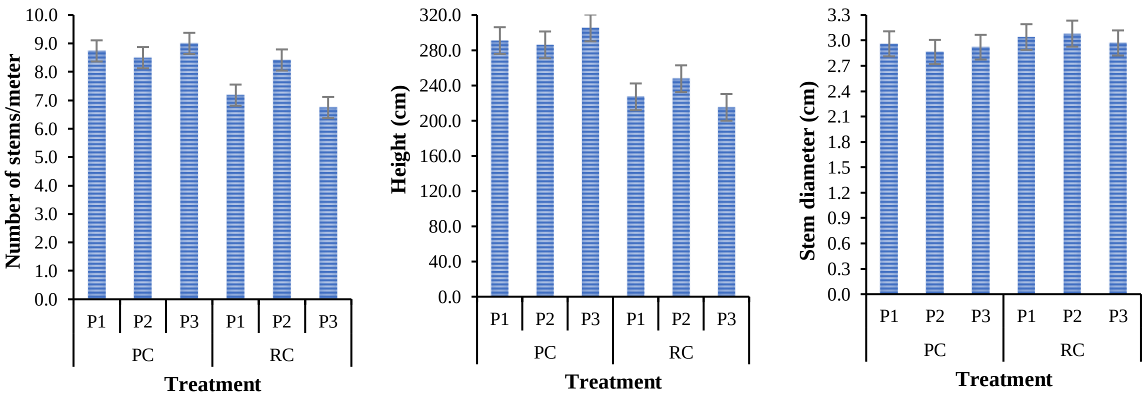

Figure 1. Number of stem (left), plant height (middle), and stem diameter (right) of sugar cane at 9 (nine) MAP/MAR

Verma *et al*., 2021). Consequently, sugarcane treated with BioSilAc as a source of mono-silicic acid (H_4SiO_4) exhibited superior growth compared to the control, due to optimized water and nutrient absorption capabilities. Silica also significantly increases plant height and sugarcane biomass (Puspitasari & Yuliatun, 2023).

The application of BioSilAc resulted in increased silica content in sugarcane leaves, with notable enhancements in both the PC and RC categories compared to the control (Figure 2). In the PC category, the silica content in sugarcane leaves increases from 1.82 to 2.41% SiO_2 for P2 and 2.22% SiO_2 for P3 (about 22-32%) due to the BioSilAc application. Similarly, in the RC category, the silica content increased from 1.76 to 2.17% SiO_2 for P2, while for P3, the silica content increased to 2.27% SiO_2 (about 23- 29%). Sugarcane actively absorbs available silicon from the soil through its roots. This process begins in the root cortex and continues to the stele, where silicon is then transported through the xylem to the stem and leaves. As plants mature, silicon concentrations increase due to water evaporation during transpiration, leading to the accumulation of amorphous silicon (SiO2-nH2O), commonly referred to as phytoliths (Ma & Yamaji, 2006; Chandler-Ezell *et al.*, 2006). This silicon accumulation contributes to plant rigidity, strengthening their tissues against pathogen infection (Ali *et al*., 2020; Chen *et al*., 2018). Higher leaf water status correlates with physical changes due to the deposition of amorphous silica, which binds cellulose in the leaf epidermis and beneath the cuticle (Mitani-Ueno & Ma, 2021) and is influenced by water uptake, transport, and loss through transpiration (Shi *et al*., 2016; Wang *et al*., 2015). Complexation of silica with cell wall macromolecules occurs through sugar stabilization, resembling the borate-mediated Formosan reaction (Guerriero *et al.*, 2016). The silica layer on leaves also plays an important role in maintaining the photosynthetic capacity of plants (Verma *et al.*, 2021; Verma *et al*., 2019; Frew *et al*., 2018). Silica can increase stomatal density and development through differential expression of proteins related to hormones, oxidation-reduction processes, and defense responses (Soundararajan *et al.*, 2017; Rios *et al.*, 2017). Optimum photosynthesis activity and nutrient absorption correlate with sugar cane productivity and the concentration of dissolved sugar produced.

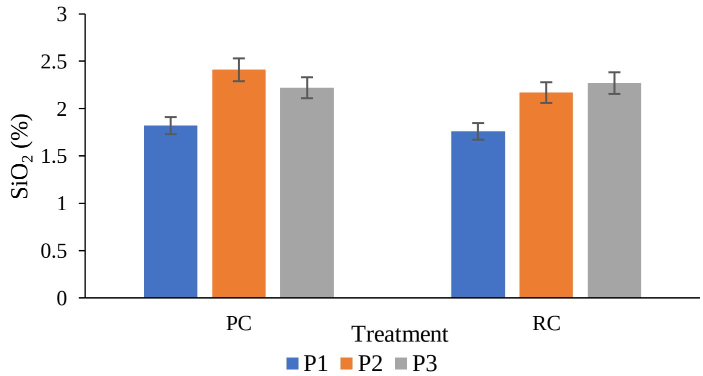

Figure 2. Silica content in sugarcane leaf from BioSilAc experiment

Table 2. Productivity and sugar crystal after harvest

Treatment	Productivity (Ton/Ha)		Sugar crystal (Ton/ha)	
PC				
100% NPK (P1)	117.70	b*)	8.32	a
100% NPK + 250 BioSilac tablet/ha	119.13	b	8.75	a
75% NPK + 250 BioSilac tablet/ha	133.59	a	9.35	a
CV (%)	2.8		5.8	
RC				
100% fertilizer dosage	56.846	a	3.956	b
100% fertilizer dosage + 250 BioSilac tablet/ha	69.710	a	5.465	a
75% fertilizer dosage + 250 BioSilac tablet /ha	69.818	a	4.977	ab
CV (%)	6.5		6.9	

*) Means in the same column followed by the same letter(s) are not significantly different according to Duncan'smultiple range test at α = 0.05

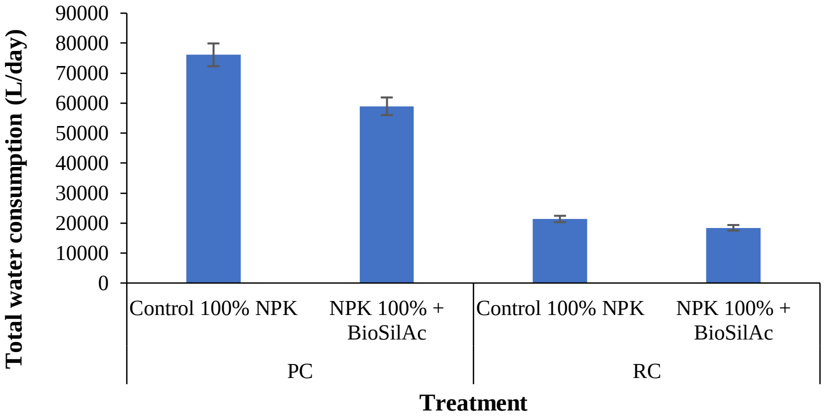

Figure 3. Sugarcane total water requirement in one hectare per day

Productivity and sugar cane crystal production in the PC category exhibited the most significant increase in the P3 treatment (NPK dose of 75% combined with 250 BioSilAc tablets/Ha). This treatment was statistically higher than the control, with an increase in productivity and sugar crystal (Hablur) of 13.50% and 12.38%, respectively, compared to the control (see Table 2). There were also increases in harvest productivity plots P2 and P3 in the RC category relative to the control (P1), although these differences were not statistically significant. However, the sugar crystals produced in the RC category were statistically higher than in the control. The most notable improvements in the RC category also occurred in the P3 treatment, resulting in increases in both productivity and sugar crystals of 22.82% and 25.81%. These findings suggest that applying BioSilAc enables a 25% reduction in fertilizer usage while boosting productivity and sugar crystal content. In PTPN I Regional IV plantation, the sugarcane variety PS 881 exhibits an average productivity of 88.8 tons per hectare, with a sugar crystal productivity averaging 7.40 tons per hectare. The results derived from recent experimental studies indicate that the application of BioSilAc has the potential to significantly optimize these productivity metrics, thereby enhancing both the productivity and quality of this particular sugarcane variety. These findings underscore the importance of innovative agricultural practices in improving sugarcane cultivation outcomes.

The impact of biosilac application on water consumption in sugarcane

Water use efficiency (WUE) can be defined as the ratio of biomass accumulation to water supplied through irrigation and rainfall conditions (Natarajan *et al.*, 2020). In addition, WUE can also be expressed in terms of intrinsic transpiration efficiency and the relationship between photosynthesis and stomatal conductance (Condon *et al.*, 2002; Natarajan *et al.*, 2020). Peak water use occurs between 10:00 AM and 1:00 PM, and Sap Flow meters allow for real-time monitoring of sap flow movements. Sap flow patterns reflect transpiration patterns (Uddin *et al.*, 2014), making these readings valuable for analyzing plant transpiration trends. Transpiration is closely related to plant water status, which is regulated by stomatal opening and driven by leaf transpiration. Notably, sugarcane treated with BioSilAc showed lower water consumption than the control group in both the PC and RC categories. Generally, the PC category requires more water than the RC category because sugarcane plants have higher water requirements during shoot initiation (tilling phase) and stem elongation phase (Ferreira *et al.*, 2017; Reyes *et al.*, 2021). Water use efficiency was recorded at 22.55% for PC and 14% for RC compared to the control (Figure 3). The WUE value in PC, which is greater than RC, is positively correlated with the productivity obtained, and this is in line with studies reporting that WUE can increase photosynthetic activity and productivity in sugarcane plants (De Silva *et al.*, 2013; Khonghintaisong *et al.*, 2024)

Conclusion

The application of bio-silicic acid through the BioSilAc product effectively enhances the dissolved silica content in both soil and sugarcane plant tissues (leaves). The most effective treatment identified in this experiment was P3, which consisted of 75% NPK combined with 250 BioSilAc tablets per hectare for both the PC and RC categories. This combination resulted in productivity and sugar crystal increases of 13.50% and 12.38%, respectively for PC, while RC showed increases of 22.82% and 25.81%, respectively. Additionally, the use of BioSilAc significantly improved water use efficiency in sugarcane plants, achieving increases of 22.55% for PC and 14% for RC. This experiment demonstrates that BioSilAc not only boosts the productivity of PS 881 variety sugarcane plants and enhances water use efficiency but also allows for a reduction in NPK fertilizer usage by 25% compared to the standard dosage.

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