

## Improvement of water and nutrient efficiencies oil palm through bio-silicic acid application

*Peningkatan efisiensi penggunaan air dan hara pada kelapa sawit melalui aplikasi bio-asam silikat*

Laksmita P. SANTI<sup>1\*)</sup>, Adhy ARDIYANTO<sup>2)</sup>, Agung KURNIAWAN<sup>2)</sup>, Lilik A. PRABOWO<sup>2)</sup>, & Ian SEBASTIAN<sup>3)</sup>

<sup>1)</sup> Indonesian Research Institute for Biotechnology and Bioindustry, Jl. Taman Kencana No.1, Bogor 16128, Indonesia

<sup>2)</sup> PT Bumitama Gunajaya Agro, Jl. Melawai Raya No.10, Melawai, Kebayoran Baru, Jakarta Selatan, DKI Jakarta 12160, Indonesia

<sup>3)</sup> PT Labodia Prima, Jl. Boulevard Barat Raya Kelapa Gading Jakarta Utara 14240, Indonesia

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### Abstrak

Efisiensi penggunaan air pada tanaman perkebunan merupakan suatu hal yang sangat penting untuk memperoleh produktivitas tinggi pada saat pasokan air dalam kondisi terbatas. Tujuan dari penelitian ini adalah menetapkan efisiensi air dan ketersediaan hara pada tanaman kelapa sawit belum menghasilkan (umur 2 tahun setelah tanam) dan tanaman menghasilkan (umur 5 tahun setelah tanam) di tanah berpasir selama periode curah hujan rendah melalui aplikasi bio-asam silikat (BioSilAc). Kegiatan penelitian dilakukan pada tanah berpasir di perkebunan kelapa sawit di Kalimantan Tengah. Penelitian disusun dalam rancangan acak blok dengan tujuh perlakuan dan tiga ulangan menggunakan kombinasi tandan kosong kelapa sawit (TKKS) yang dikomposkan dan BioSilAc. Perlakuan dosis ( $\text{pokok}^{-1} \text{ tahun}^{-1}$ ) sebagai berikut: 100% NPK dosis standar (T1); T1 + 1,5 kg pasir kuarsa (T2); 75% (T1) + 1,5 kg pasir kuarsa (T3); T1 + 4 tablet BioSilAc (T4); 75% (T1) + 4 tablet BioSilAc (T5); T1 + 50 kg kompos tkks + 2 tablet BioSilAc (T6); dan 75% (T1) + 50 kg kompos tkks + 2 tablet BioSilAc (T7). Peubah yang diamati adalah kadar hara tanah dan daun, berat dan jumlah rata-rata tandan buah segar (TBS) serta konsumsi air harian dan potensial air dengan sap flow meter dan stem psychrometer untuk menghitung efisiensi penggunaan air pada T1 (kontrol) dan T5 yang merepresentasikan aplikasi BioSilAc. Hasil penelitian menunjukkan bahwa aplikasi 75-100% NPK + 4 tablet BioSilAc  $\text{pokok}^{-1} \text{ tahun}^{-1}$  pada tanaman menghasilkan dapat meningkatkan produksi 11,95% (T5) dan 12,1% (T4) serta efisiensi konsumsi air sampai dengan 31,1% (TM) dan 50,4% (TBM) dari perlakuan kontrol.

[Kata kunci: bio-asam silikat, cekaman abiotik, kelapa sawit, mikrob pelarut silika, tanah tekstur berpasir]

<sup>\*)</sup>correspondence author: laksmita.santi@gmail.com

### Abstract

Crop water use efficiency is critical for high yields in conditions of limited water supplies. This study aims at determining the effect of bio-silicic acid (BioSilAc) application on water use efficiency and nutrient availability for immature (2 years after planting) and mature (5 years after planting) oil palms in sandy soil during a period of low rainfall. A field experiment was conducted on sandy soil at an oil palm plantation in Central Kalimantan. The experiment was arranged in a randomized block design with seven treatments and three replicates using a combination of composted empty fruit bunches of oil palm (CEFBOP) and BioSilAc applications. The treatments ( $\text{tree}^{-1} \text{ year}^{-1}$ ) were as follows ( $\text{tree}^{-1} \text{ year}^{-1}$ ): (T1) 100% NPK standard dosage; (T2) T1 + 1.5 kg quartz sand; (T3) 75% (T1) + 1.5 kg quartz sand; (T4) T1 + 4 tablets BioSilAc; (T5) 75% (T1) + 4 tablets BioSilAc; (T6) T1 + 50 kg CEFBOP + 2 tablets BioSilAc; and (T7) 75% (T1) + 50 kg CEFBOP + 2 tablets BioSilAc. The parameters observed were soil and leaf nutrient contents, average weight, and number of fresh fruit bunch (FFB), and daily water usage and water potential using a sap flow meter and stem psychrometer to calculate water use efficiency in T1 (control) and T5 which represents the application of BioSilAc. The results indicated that the application of 75-100% NPK + 4 tablets BioSilAc  $\text{tree}^{-1} \text{ year}^{-1}$  in mature oil palm was capable of improving yield of 11.9% (T5) and 12.1% (T4) and water use efficiency of 31.3% (mature) and 50.4% (immature) of the control treatment.

[Keywords: abiotic stress, bio-silicic acid, oil palm, sandy soil, silicate-solubilizing microbes]

## Introduction

Silicon (Si) has been found in significant concentrations in plants. Many studies have shown the beneficial effects of Si in increasing drought tolerance in plants by maintaining leaf water potential, photosynthetic activity, stomatal conductance, leaves erectness, and structure of xylem vessels under high transpiration rates. All these parameters have been widely used as physiological indicators for the selection of drought-tolerant plant materials (Saud *et al.*, 2014). Mono-silicic acid ( $H_4SiO_4$ ) in the form of Si used by plants is found both in liquid and adsorbed phases of Si in soils. The concentration of the  $H_4SiO_4$  in soil solution is influenced by the soil pH, clay, minerals, organic matter, and Fe/Al oxides/hydroxides, which are collectively related to the geological age of the soil (Tubana & Heckman, 2015). Bio cycling of Si in the soil also occurs through microbial activities that involve fungi, bacteria, and actinomycetes. Thus, through their intricate interplay with soil minerals, plants and microbes contribute appreciably to the ecological Si cycle (Schaller *et al.*, 2021).

Oil palm (*Elaeis guineensis* Jacq.) is one of the most important oil crop species in the world and is widely cultivated in Southeast Asia, especially in Indonesia. According to Cha-um *et al.* (2013), fibrous root system of oil palm quickly absorbs water from the soil in areas under irrigation (0.7 m in depth), while deep roots (1.1 m) develop in palms growing in rainfed areas. In mature oil palms, the daily transpiration rate (T) depends on the season, which is approximately 3.3-6.5 mm d<sup>-1</sup> in the rainy season and 1.3-2.5 mm d<sup>-1</sup> in the dry season (Carr, 2011). Also, the level of precipitation (> 1,500 mm year<sup>-1</sup>) is one of the most important factors in oil palm cultivation. Oil palm is a commodity that is quite sensitive to drought (Putra *et al.*, 2015; Rodríguez & Romero, 2016).

Water availability plays an important role in many aspects of growth, development, and oil palm yield. Several studies indicate that drought lowered the yield of fresh fruit bunches up to 26.3% (Al-Amin *et al.*, 2011). The decline of oil palm yield is a direct effect of inhibition of the photosynthetic activity of oil palm. Drought causes stomatal conductance of oil palm leaves to decline rapidly because of stomatal closure. The stomatal conductance decreases the rate of CO<sub>2</sub> diffusion, so that the photosynthesis activity of oil palm is inhibited by drought in the middle period of the life cycle of the tree (Henson & Harun, 2007). Other factors that inhibit the rate of photosynthesis in drought conditions are the relative water content (Zain *et al.*, 2014), chlorophyll content, and the content of nitrogen and phosphorus in leaf tissue of plants which are low (Ashraf & Harris, 2013). It is pertinent to investigate optimum water supply that has been identified as a major cost of oil palm production (Fereris & Soriano, 2007). According to Safitri *et al.* (2019), the various negative issues

associated with the absorption of water by oil palm plants are inversely proportional because water uptake through the roots of the oil palm is relatively low compared to wheat, rice, maize, soybean, and barley. The maximum level of water absorbed in the upper root zone also shows that oil palm plants absorb a lot of rainwater, which is fast circulation compared to groundwater.

Many studies according to Meena *et al.* (2013), Santi *et al.* (2018), and Katz *et al.* (2021) have claimed that Si application can increase the tolerance to drought in plants. The mechanisms for this protection include physiological, biochemical, and biophysical aspects. Silica fertilizer has a double effect on the soil-plant system under abiotic stresses, i.e.: (i) improved plant-Si nutrition reinforces plant-protective properties against diseases, insect attack, and unfavorable climatic conditions, (ii) soil treatment with biogeochemically active Si substances optimizes soil fertility through improved water, physical and chemical soil properties, and maintenance of nutrients in plant-available forms. The plant absorbs Si from the soil solution in the form of mono silicic acid, also called orthosilicic acid ( $H_4SiO_4$ ) (Zargar *et al.*, 2019). Furthermore, there were no significant differences in greenhouses experiment regarding the effect of silicic acid and silicate solubilizing microbe (SSM) application on drought resistance of oil palm seedlings (Amanah *et al.*, 2019).

To improve plant-available Si in the soil, silicate solubilizing fungi (SSF) are potentially important in solubilizing insoluble forms of silicate (Santi, 2020). Silicate solubilizing microorganisms have recently attracted great interest. Maleva *et al.* (2017) reported that silicate solubilizing microbe could play an efficient role not only in solubilizing insoluble forms of silicates but also potassium and phosphates, hence increasing soil fertility and thereby enhancing plant productivity. This study aims at determining water use efficiency and nutrient uptake on immature and mature oil palm in sandy soil, Central Kalimantan, using NPK fertilizer in combination with CEFBOP and BioSilAc.

## Materials and Methods

### *Bio-Silicic acid preparation*

The silica source was quartz type (325-mesh) collected from Bangka-Belitung province, Indonesia. Silica extract was prepared using the method reported by Santi & Goenadi (2017) and Santi *et al.* (2017). The extract then was mixed with 5% (w/w) selected SSF (Santi, 2020), i.e., *Trichoderma polysporum* (10<sup>6</sup> propagules). The slow release-tablet form of silica sources is referred to as Bio Silicic Acid (BioSilAc).

*The effects of BioSilAc application in immature and mature oil palm*

The field experiment was conducted in Central Kalimantan from December 2017 to December 2019. Socfindo varieties were used as immature (2 years after planting) and mature (5 years after planting) oil palms. The experiments were arranged in a randomized block design with seven treatments and three replications. The treatments comprised a combination of CEFBOP and BioSilAc application as well as a reduction of dosages of NPK fertilizers.

Soil samples were air-dried and passed through a 2 mm sieve and analyzed for the following parameters: pH, soil texture, organic-C, nitrogen (N), phosphorus (P), potassium (K), calcium carbonate ( $\text{CaCO}_3$ ), cation exchange capacity (CEC), boron (B), and exchangeable aluminum (Al), hydrogen (H), silica ( $\text{SiO}_2$ ), and available  $\text{SiO}_2$ . The available  $\text{SiO}_2$  in the form of silicic acid ( $\text{H}_2\text{SiO}_4$ ) was measured using a Spectronic 21 spectrophotometer at 660 nm wavelength using the method reported by Rinder & Oelkers (2014). Leaf nutrient analysis was carried out to determine the content of N, P, K, Mg, and  $\text{SiO}_2$  in oil palm

leaf. Soil chemical characteristics of the immature-mature-plant plot were as follow in Table 1.

Applied on immature and mature plants the treatments dosages ( $\text{tree}^{-1} \text{ year}^{-1}$ ) for each immature and mature plants were as follows:

- T1 = 100% NPK standard dosage  
 T2 = T1 + 1.5 kg quartz sand (325-mesh)  
 T3 = 75% (T1) + 1.5 kg quartz sand (325-mesh) (T3)  
 T4 = T1 + 4 tablets BioSilAc (T4)  
 T5 = 75% (T1) + 4 tablets BioSilAc  
 T6 = T1 + 50 kg CEFBOP + 2 tablets BioSilAc  
 T7 = 75% (T1) + 50 kg CEFBOP + 2 tablets BioSilAc

The 325-mesh quartz was obtained from Bangka-Belitung, whereas the composting EFBOP was carried out by bio-composting for 4 weeks. Selected parameters observed included leaf nutrient content (N, P, K, Mg, and  $\text{SiO}_2$ ) sampled from leaf no. 9 (immature) and no.17 (mature), average weight, and number of fresh fruit bunches of oil palm (FFB). A one-way ANOVA was carried out to compare the means of different treatments at the 5% level using Duncan's Multiple Range Test (DMRT).

Table 1. Soil chemical characteristics of immature-mature oil palm plot

Tabel 1. Karakteristik kimia pada plot kelapa sawit belum menghasilkan (TBM) dan menghasilkan (TM)

Soil chemical characteristics <i>Karakteristik kimia tanah</i>	Immature-plant <i>tanaman belum menghasilkan</i>	Mature-plant <i>tanaman menghasilkan</i>
pH	5.0	4.8
Sand (%)	83.0	66.0
Clay (%)	14.5	20.7
Silt (%)	2.5	13.3
N (%)	0.12	0.17
P <sub>2</sub> O <sub>5</sub> (%)	0.006	0.102
K <sub>2</sub> O (%)	0.18	0.17
CaO (%)	0.10	0.34
Organic Carbon (%)	1.98	3.02
SiO <sub>2</sub> (%)	1.47	1.49
Available silica (ppm)	9.8	9.6
B (ppm)	6.4	5.5
CEC ( $\text{cmol}^{(+)} \text{kg}^{-1}$ )	3.67	6.8
Exchangeable Al ( $\text{cmol}^{(+)} \text{kg}^{-1}$ )	0.79	1.4
Exchangeable H ( $\text{cmol}^{(+)} \text{kg}^{-1}$ )	0.32	0.74

Table 2. Rainfall data based on monthly average during 11 years (2009-2019) observation weather station at Metro 4 area, 30 km from plot site

Tabel 2. Data curah hujan rata-rata setiap bulan selama 11 tahun (2009-2019) pengamatan dari stasiun cuaca dan iklim di daerah Metro, 30 km dari lokasi demoplot

Month Bulan	Years (mm) Tahun (mm)											Average Rata-rata
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	
Jan	313	284	341	195	270	-	52	285	125	172	270	231
Feb	85	259	153	291	420	120	131	190	106	301	250	210
Mar	74	197	254	207	443	288	209	103	185	502	195	242
Apr	200	376	239	243	343	128	94	150	106	280	288	222
May	83	315	256	200	310	338	378	105	98	336	310	248
June	24	374	70	120	125	373	106	222	91	256	265	184
July	52	483	110	240	293	68	56	67	206	306	130	183
August	28	222	51	214	150	70	0	37	198	65	105	104
Sept	29	579	186	83	240	0	0	68	212	140	25	142
Oct	281	372	522	408	326	65	39	97	125	460	94	254
Nov	394	509	455	275	239	119	235	132	163	465	135	284
Dec	326	361	494	402	351	100	115	53	179	458	280	284
M-wet <sup>*)</sup>	5	11	7	8	10	3	4	2	2	9	6	8
M-dry	7	0	2	1	0	4	5	5	2	1	2	0

<sup>\*)</sup>M-wet: > 200 mm; M-dry: < 100 mm

<sup>\*)</sup>Bulan basah: > 200 mm; bulan kering: < 100 mm

### Sap flow measurement

Water-saving in plants mainly refers to the effective use of water resources in the growth and development of plants, thereby increasing crop water use efficiency (WUE). The heat ratio method (Hölttä *et al.*, 2015) was used to measure the sap flow (water usage) with the SFM1 instrument from ICT International (Australia). This instrument consisted of three needles. The middle needle generates a heat pulse, and the other two are each fitted with two extremely sensitive thermocouples. Three needles were installed on oil palm fronds (9<sup>th</sup> frond for immature trees and 17<sup>th</sup> frond for mature trees) before the rudimentary leaflets. The measurements were real-time recorded at 30 minutes intervals for a cycle of 7 days for immature and mature trees, respectively; the period of time for the frond to change positions in the oil palm tree's phyllotaxy. The heat pulse used was 30 Joules (data not shown). These sap flow meters' measurements were combined with Stem Psychrometer (PSY1), Soil Moisture Meter (SMM1), and Soil Oxygen Meter (SOM1). A solar panel can be directly connected to the non-polarized charging ports to trickle charge the internal battery for continuous field operation. For this measurement, only two treatments were taken, i.e., each from T1 as a control treatment and T5 as the representative of BioSilAc application. During the months of the study (2019), the average rainfall in the site was

158 mm month<sup>-1</sup>. According to Oldeman's rainfall type classification, the site belongs to B1 agroclimatic zone with 7-9 consecutive wet months and 0-1 dry months (Table 2).

## Results and Discussion

### Chemical characteristics of BioSilAc

Chemical characteristics of BioSilAc was analyzed to determine total SiO<sub>2</sub>, available Si, heavy metals contents and other parameter based on Kepmentan No.209/Kpts/SR.320/3/2018 standardization of the product of silica an-organic fertilizer in Indonesia. The results showed a high pH and very low heavy metals content (Table 3) found in the BioSilAc. This product had highly available silica in H<sub>4</sub>SiO<sub>4</sub> form at the level of 7.2%, which is higher than that of similar commercial product of silica fertilizer. According to USPTO (2001) about "silica-based fertilizer and method for using the same", claimed that the silica gel could be used as the main component of the fertilizer of the invention contains all stages of silica gel from silica hydrogel to silica xerogel. The silica gel or silica sol to have such a property that the silicic acid (H<sub>4</sub>SiO<sub>4</sub>) concentration becomes equal to 5-15 ppm. Furthermore, BioSilAc has a specification parameter in pH and amount of SSF, i.e., 9.6 (pH) and 10,000 - 1,000,000 propagule g<sup>-1</sup> of *T. polysporum*. As a result of this study, it is obvious that silica

fertilizers in crop plantations are still uncommon and can be regarded as cutting-edge technology in combination with bio-fertilizers. Silica-based fertilizers are commonly made from rice husk, sugar cane bagasse, fly ash, and basic slag, while BioSilAc was prepared from quartz sand extract.

#### *Effects of BioSilAc application on immature oil palm*

##### *Nutrient use*

The data from this experiment showed that the application of organic matter in EFBOP had not been able to suppress the loss of nutrients due to evaporation and adsorption by clay particles. Organic carbon (C) level was measured at very low range (T1 and T2) to moderate (T3-T7). Generally, nutrient uptake of K, Ca, and Mg are reduced by the water deficit. The application of BioSilAc in this area can suppress the level of exchangeable Al in the soil of 34.5% to 69.8%, and therefore the availability of P and K can be optimized for oil palm trees. Furthermore, the total and available SiO<sub>2</sub> at T5 treatment were higher than in the other treatments, including the control (T1). Tubana & Heckman (2015) reported that despite its abundance, Si is never found in an available form inside the plant tissue but is always combined with other elements, usually in oxides or silicates. Mono silicic acid (H<sub>4</sub>SiO<sub>4</sub>) is the only form of Si used by plants, which is found both in liquid and adsorbed phases of Si in soils. BioSilAc application increased the amount of released Si in the soil solution. According to Santi *et al.* (2018), the deposition of bio-silica occurs in the endodermis part of roots of oil palm seedling. The results of a field experiment revealed that applying BioSilAc to sandy soil for two years can increase the rate of total and available SiO<sub>2</sub> in the soil up to 16.3% (SiO<sub>2</sub>) and 6.9% (H<sub>4</sub>SiO<sub>4</sub>) of the control (T1) (Table 4).

Based on the nutrients analyzed in immature oil palm (Table 5), it is observed that the application of BioSilAc in the nutrients content of N and P were not significantly different than the control treatments, but the value of K was generally higher at 4.7% to 33% with BioSilAc treatments, compared to the control treatments. The results of the analysis showed that the nutrient content of N is high-optimum, while P and K levels were optimum. BioSilAc application increased the silica nutrient in the leaves of immature oil palm by about 4.3-13.5%. Furthermore, the adequacy of micronutrients, such as Cu and B in all treatments were optimum to high level and, the action of SSF and silicic acid reactions in the soil make the silica content of oil palm leaf in T4, T5, and T6 treatments significantly different from T1 (control). However, it is necessary to further study the role of SSF and silicic acid (H<sub>4</sub>SiO<sub>4</sub>) in increasing total and available silica in the soil and oil palm leaf, respectively.

#### *Water use efficiency*

In oil palm, water deficit also affects sex differentiation, reduces the proportion of female inflorescences, promotes inflorescence abortion, and may affect bunch ripening and oil accumulation (Adam *et al.*, 2011). The potential application of BioSilAc to increase oil palm resistance to drought stress was analyzed directly through the determination of water usage on immature and mature oil palm in the field conditions by using a sap flow meter and stem psychrometer. The sap flow meter was used to monitor oil palm's daily water usage at various conditions. The stem psychrometer monitored the oil palm's water potential, which can be correlated to plant resistance to drought stress. The measurement data of the sap flow meter were analyzed using ICT International Data View software, and this showed that the daily rate and accumulation of water usage in the immature crop control treatment (T1) was greater than the T5 treatment, i.e., 18.05 L tree<sup>-1</sup> day<sup>-1</sup> compared to 8.96 L tree<sup>-1</sup> day<sup>-1</sup> (Table 6). This means that the application of BioSilAc to immature oil palm for three consecutive years can improve the water use efficiency, i.e., the amount of carbon assimilated as biomass or FFB produced per unit of water used by the oil palm tree with 50.4%.

According to stem psychrometer data, the T5's (green graph) plant water potential was more negative (-1.5 MPa) than T1 (blue graph, -0.97 MPa). By the end of every day, T5 recovered faster (returned to 0 MPa in the absence of sunlight) than T1 (Figure 1). The results of this study suggest that BioSilAc application on T5 can reduce water consumption in oil palm and increase the water potential (the tendency of water to move from one area to another due to osmosis, gravity, mechanical pressure, and matrix effects such as capillary action of the plant) thus the photosynthesis rate making more effective recovery possible during drought condition compared to the T1 (control). Furthermore, the measurement of frond 9<sup>th</sup> by using Durometer showed that BioSilAc application increased the hardness of immature oil palm frond from 50.5 Hd (T1) to 57 Hd (T5).

#### *Effects of BioSilAc application in mature oil palm*

##### *Nutrient use*

In the plot area of BiosilAc application for mature oil palm, N soil nutrient levels were low to moderate range, while P and K were very low to low, and the organic matter was low to moderate. The application of BioSilAc in T3-T6 treatments increased the total SiO<sub>2</sub> and available Si in the soil. The available Si in T4 treatment was higher than that of other treatments. Furthermore, P availability for plant in T2-T7 with quartz sand and BioSilAc treatments were higher than that of the T1 (control) while the concentration of exchangeable aluminum in T2-T7 were lower than

T1 (Table 7). In the soil system, the release of Si has more significant interaction with P and other nutrients (Meena *et al.*, 2014). Si application reduces soil sorption of P, especially at low pH, and thus increases the plant-available portion of P in the soil (Greger *et al.*, 2018).

Table 3. Chemical characteristics of bio-silicic acid in tablet form

Tabel 3. Karakteristik kimia bio-asam silikat dalam bentuk tablet

Parameters <i>Peubah</i>	Units <i>Satuan</i>	Results <i>Hasil</i>	Standard (Kepmentan No.209/2018) <sup>*)</sup>	Method <i>Metode</i>
Silica Total (SiO <sub>2</sub> )	%	17.7	Min.10	ICP
Available silica	%	7.2	-	Spectrophotometer
Water content	%	2.0	Max.5	Gravimetric
Arsenic (As)	ppm	<0.002	Max.100	AAS
Mercury (Hg)	ppm	<0.001	Max 10	AAS
Cadmium (Cd)	ppm	7	Max.100	ICP
Copper (Pb)	ppm	200	Max. 500	ICP
Nickel (Ni)	ppm	43	<4,000	ICP
Chromium (Cr)	ppm	20	<40,000	ICP
pH	-	9.6	-	pH meter
<i>T.polysporum</i>	Propagule g <sup>-1</sup>	10 <sup>4</sup> -10 <sup>6</sup>	-	Total Plate Count

<sup>\*)</sup> Indonesian Agriculture Ministerial Decree

<sup>\*)</sup> Keputusan Menteri Pertanian Indonesia

Table 4. Soil nutrients in immature oil palm area, two-years after BioSilAc application on a regular basis

Tabel 4. Kadar hara tanah pada area TBM dua tahun setelah aplikasi BiosilAc secara rutin

Treatments <i>Perlakuan</i>	pH <i>pH</i>	Sand (%) <i>pasir (%)</i>	Silt (%) <i>debu (%)</i>	Clay (%) <i>klei (%)</i>	N (%) <i>N (%)</i>	P (ppm) <i>P (ppm)</i>	K (ppm) <i>K (ppm)</i>
T1	4.9 <sup>*)</sup>	77.51	6.50	15.99	0.07	119	12.50
T2	4.8	78.51	5.50	15.99	0.06	139	7.50
T3	4.9	79.51	5.50	14.99	0.10	331	21.67
T4	4.9	77.52	5.50	16.98	0.13	431	10.0
T5	4.9	75.52	7.50	16.98	0.13	188	13.33
T6	4.9	77.52	6.50	15.98	0.14	188	7.50
T7	4.9	81.51	3.50	14.99	0.09	107	24.9

Treatments <i>Perlakuan</i>	Org-C (%) <i>C-org (%)</i>	Al (%) <i>Al (%)</i>	Exch-Al (Cmol <sup>(+)</sup> Kg <sup>-1</sup> ) <i>Al dapat ditukar (Cmol<sup>(+)</sup> Kg<sup>-1</sup>)</i>	Exch-H (Cmol <sup>(+)</sup> Kg <sup>-1</sup> ) <i>H dapat ditukar (Cmol<sup>(+)</sup> Kg<sup>-1</sup>)</i>	CEC (Cmol <sup>(+)</sup> Kg <sup>-1</sup> ) <i>KTK (Cmol<sup>(+)</sup> Kg<sup>-1</sup>)</i>	SiO <sub>2</sub> (%) <i>SiO<sub>2</sub> (%)</i>	Available Si (ppm) <i>Si tersedia (ppm)</i>
T1	0.80	0.06	1.16	0.18	2.27	1.47	9.82
T2	0.74	0.04	0.35	0.06	2.06	1.48	10.13
T3	1.32	0.03	0.45	0.14	3.30	1.58	10.44
T4	1.30	0.03	0.76	0.14	3.72	1.49	10.19
T5	1.93	0.03	0.60	0.08	3.63	1.71	10.50
T6	1.91	0.03	0.61	0.08	3.84	1.50	10.30
T7	1.84	0.03	0.40	0.05	2.47	1.59	10.47

<sup>\*)</sup>The soil fertility evaluation standard for oil palm according to Fairhurst and Hardter (2003): N (%) = <0.08 (very low), 0.12 (low), 0.15 (medium), 0.25 (high), > 0.25 (very high); P (ppm) = <120 (very low), 200 (low), 250 (medium), 400 (high), >400 (very high); organic-C (%) = <0.8% (very low), 1.2 (low), 1.5 (medium), 2.5 (high), and >2.5 (very high), pH=<3.5 (very low), 4.0 (low), 4.2 (moderate), 5.5 (high), >5.5 (very high)

<sup>\*)</sup>Standar evaluasi kesuburan tanah untuk kelapa sawit menurut Fairhurst dan Hardter (2003): N (%) = <0,08 (sangat rendah), 0,12 (rendah), 0,15 (sedang), 0,25 (tinggi), > 0,25 (sangat tinggi); P (ppm) = <120 (sangat rendah), 200 (rendah), 250 (sedang), 400 (tinggi), >400 (sangat tinggi); C-organik (%) = <0,8% (sangat rendah), 1,2 (rendah), 1,5 (sedang), 2,5 (tinggi), dan >2,5 (sangat tinggi), pH= pH=<3,5 (sangat rendah), 4,0 (rendah), 4,2 (sedang), 5,5 (tinggi), >5,5 (sangat tinggi)

Table 5. Leaf nutrients content in immature oil palm, two-years after BioSilAc application on a regular basis

Tabel 5. Kadar hara daun pada TBM dua tahun setelah aplikasi BioSilAc secara rutin

Treatments	N (%)	P (%)	K (%)	Cu (%)	B (ppm)	Si (ppm)
Perlakuan	N (%)	P (%)	K (%)	Cu (%)	B (ppm)	Si (ppm)
T1	3.22 a <sup>*)</sup>	0.16 a	1.06 c	0.34 c	21.8 ab	538.2 d
T2	3.27 a	0.17 a	1.41 a	0.21 c	22.3 ab	566.6 bcd
T3	3.09 ab	0.19 a	1.31 ab	0.95 a	17.1 b	597.7 abc
T4	2.75 bc	0.17 a	1.35 a	0.73 b	20.5 ab	610.6 a
T5	3.00 ab	0.17 a	1.13 bc	0.77 b	16.6 b	602.8 ab
T6	2.81 bc	0.18 a	1.11 bc	0.67 b	19.3 ab	605.4 ab
T7	3.09 ab	0.19 a	0.92 c	0.82 ab	25.0 a	561.4 cd
Coefficient of variation (%)	4.7	10.5	7.1	10.3	10.9	2.6

<sup>\*)</sup> Figures in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test (P<0.05)

<sup>\*)</sup> Angka dalam kolom yang sama yang diikuti oleh huruf yang sama tidak berbeda nyata menurut uji jarak berganda Duncan (P<0,05)

<sup>\*\*)</sup> Critical nutrient concentration in young oil palm (≤6 years) according to Fairhurst dan Hardter (2003): N (%) = <2.50 (deficient), 2.6-2.9 (optimum), >3.1 (high); P (%) = <0.15 (deficient), 0.16-0.19 (optimum), >0.25 (high); K (%) = <1.00 (deficient), 1.1-1.3 (optimum), > 1.8 (high)

<sup>\*\*)</sup> Kadar hara daun kelapa sawit muda (≤6 tahun) menurut Fairhurst dan Hardter (2003): N (%) <2,50 (defisien), 2,6-2,9 (optimum), >3,1 (tinggi); P (%) = <0,15 (defisien), 0,16-0,19 (optimum), >0,25 (tinggi); K (%) = <1,00 (defisien), 1,1-1,3 (optimum), > 1,8 (tinggi)

Table 6. Daily water consumption in immature oil palm T1 and T5 treatments

Tabel 6. Konsumsi air harian pada tanaman belum menghasilkan (TBM) perlakuan T1 dan T5

Treatments-replication	Total of frond Total Pelepah (a)	Daily water consumption (L frond <sup>-1</sup> day <sup>-1</sup> ) Konsumsi air harian (L pelepah <sup>-1</sup> hari <sup>-1</sup> ) (b)	Total water consumption (L tree <sup>-1</sup> day <sup>-1</sup> ) Konsumsi air total (L pohon <sup>-1</sup> hari <sup>-1</sup> ) C = (a) x (b)	Average daily water consumption (L tree <sup>-1</sup> day <sup>-1</sup> ) Rata-rata konsumsi air harian (L pohon <sup>-1</sup> hari <sup>-1</sup> )
T1.1	33	0.64	21.05	18.05
T1.2	32	0.47	15.04	
T5.1	28	0.30	8.34	8.96
T5.2	29	0.33	9.57	

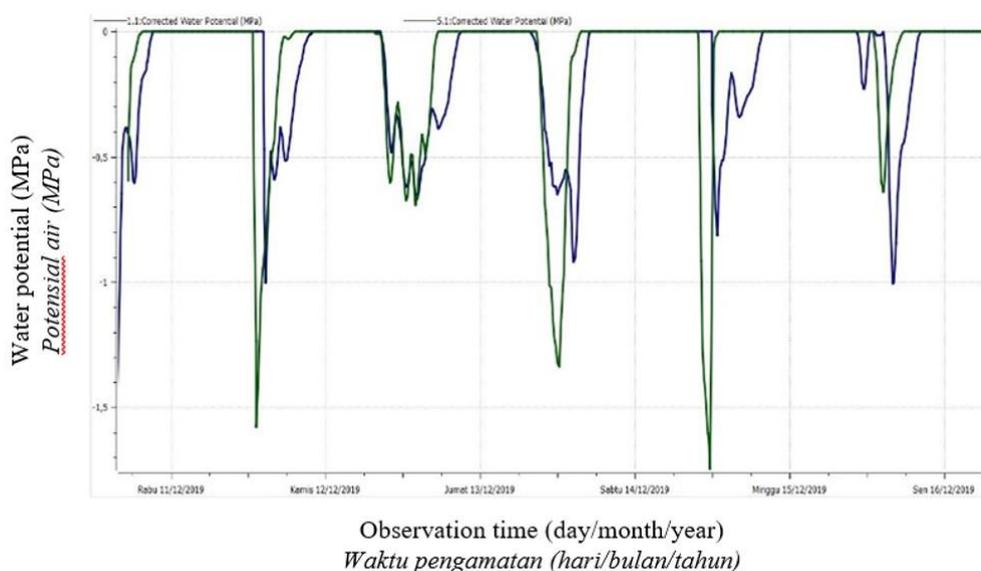


Figure 1. Stem psychrometer graphic of immature oil palm sample T1 (blue) and T5 (green) treatments

Gambar 1. Grafik psikrometer batang sampel tanaman kelapa sawit belum menghasilkan perlakuan T1 (biru) dan T5 (hijau)

Table 7. Soil nutrients in mature oil palm area, two-years after BioSilAc application on a regular basis

Tabel 7. Kadar hara tanah pada area tanaman menghasilkan (TM) setelah dua tahun aplikasi BioSilAc secara rutin

Treatments <i>Perlakuan</i>	pH H <sub>2</sub> O <i>pH H<sub>2</sub>O</i>	Sand (%) <i>pasir (%)</i>	Silt (%) <i>debu (%)</i>	Clay (%) <i>klei (%)</i>	N (%) <i>N (%)</i>	P (ppm) <i>P (ppm)</i>	K (ppm) <i>K (ppm)</i>
T1	5.25	69.25	12.40	18.35	0.12	41.6	16.7
T2	5.06	67.26	14.40	18.34	0.13	121.0	14.2
T3	4.57	66.24	14.40	19.36	0.12	45.4	12.5
T4	4.70	61.28	13.40	25.32	0.12	48.7	21.7
T5	4.39	65.28	11.40	23.72	0.28	64.79	22.5
T6	4.64	64.25	13.40	22.35	0.12	69,4	15.0
T7	4.66	63.27	15.40	21.33	0.15	79,5	18.3

Treatments <i>Perlakuan</i>	Org-C (%) <i>C-org (%)</i>	Al (%) <i>Al (%)</i>	Exch-Al (Cmol <sup>(+)</sup> Kg <sup>-1</sup> ) <i>Al dapat ditukar (Cmol<sup>(+)</sup> Kg<sup>-1</sup>)</i>	Exch-H (Cmol <sup>(+)</sup> Kg <sup>-1</sup> ) <i>H dapat ditukar (Cmol<sup>(+)</sup> Kg<sup>-1</sup>)</i>	CEC (Cmol <sup>(+)</sup> Kg <sup>-1</sup> ) <i>KTK (Cmol<sup>(+)</sup> Kg<sup>-1</sup>)</i>	SiO <sub>2</sub> (%) <i>SiO<sub>2</sub> (%)</i>	Available Si (ppm) <i>Si tersedia (ppm)</i>
T1	1.73	0.06	1.62	1.25	4.78	1.49	10.49
T2	2.08	0.06	0.92	1.53	5.45	1.46	9.60
T3	1.24	0.04	0.91	1.18	5.58	1.60	11.10
T4	1.53	0.09	1.0	1.68	6.13	1.90	16.70
T5	2.29	0.11	1.06	2.05	14.93	1.74	12.27
T6	1.90	0.10	0.76	1.56	5.62	1.63	11.30
T7	2.65	0.06	1.07	2.00	6.30	1.48	9.91

<sup>\*)</sup>The soil fertility evaluation standard for oil palm according to Fairhurst and Hardter (2003): N (%) = <0.08 (very low), 0.12 (low), 0.15 (medium), 0.25 (high), > 0.25 (very high); P (ppm) = <120 (very low), 200 (low), 250 (medium), 400 (high), >400 (very high); organic-C (%) = <0.8% (very low), 1.2 (low), 1.5 (medium), 2.5 (high), and >2.5 (very high), pH=<3.5 (very low), 4.0 (low), 4.2 (moderate), 5.5 (high), >5.5 (very high)

<sup>\*)</sup>Standar evaluasi kesuburan tanah untuk kelapa sawit menurut Fairhurst dan Hardter (2003): N (%) = <0,08 (sangat rendah), 0,12 (rendah), 0,15 (sedang), 0,25 (tinggi), > 0,25 (sangat tinggi); P (ppm) = <120 (sangat rendah), 200 (rendah), 250 (sedang), 400 (tinggi), >400 (sangat tinggi); C-organik (%) = <0,8% (sangat rendah), 1,2 (rendah), 1,5 (sedang), 2,5 (tinggi), dan >2,5 (sangat tinggi), pH= pH=<3,5 (sangat rendah), 4,0 (rendah), 4,2 (sedang), 5,5 (tinggi), >5,5 (sangat tinggi)

Silica content in the leaves of mature oil palm was not significantly different in all treatments (Table 8). It is suggested that the accumulation of silica in the mature oil palm not takes not only place in the leaves but is also distributed on other tissues. The role of BioSilAc was significant in increasing oil palm production. Application of BioSilAc in T4 and T5 treatments resulted in fresh bunch production of young mature up to 22.42 tons and 22.38 tons ha<sup>-1</sup> year<sup>-1</sup>, respectively (Table 9). The production of both treatments was higher at 12.1% and 11.9% than that of T1 (control). BioSilAc application may improve the ability of water absorption in mature oil palm and thus indirectly the productivity.

#### Water use efficiency

Sap flow meter and stem psychrometer were installed on the 17<sup>th</sup> frond of T1 and T5 treatments. Based on the measurements using the sap flow meter, the water usage for T5's frond was 0.26 L day<sup>-1</sup> and was lower than T1's (0.38 L day<sup>-1</sup>). This data showed that the daily water usage of T5 (0.75 L day<sup>-1</sup>) was lower compared to T1 (1.01 L day<sup>-1</sup>). The total daily water use of T1 was 30.38 L tree<sup>-1</sup> day<sup>-1</sup>, while T5 was 20.86 L tree<sup>-1</sup> day<sup>-1</sup> (Table 10). BioSilAc application can improve water use

efficiency by 31.3%. In plants, water deficiency can result from a deficit of water from the soil, an obstacle to the uptake of water, or excess water loss; in these cases, a similar consequence is the limitation of plant growth and crop yield. According to Deshmukh & Belanger (2015) and Chen *et al.* (2018), silicon (Si) has been widely reported to alleviate the plant water status and water balance under various stress conditions. Si application was found to be involved in the adjustment of root hydraulic conductance by up-regulating aquaporin gene expression and concentrating K in the xylem sap. The potential key mechanisms involved in Si-mediated enhancement of plant root water uptake under water deficiency include (1) enhancement of the osmotic driving force via active osmotic adjustment, (2) improvement of aquaporin transport activity at both transcriptional and post-transcriptional levels, and (3) modification of root growth and increasing root/shoot ratio.

Based on the stem psychrometer observation data, the plant water potential in T5 (green graph) was more negative (-2.2 MPa) than T1 (blue graph, -1.6 MPa) and also recovered faster by the end of every day (Figure 2).

Our study suggested that the BioSilAc application (T5) can reduce water consumption in oil palm. Plant water potential and photosynthesis rate were higher than T1. Furthermore, T5 treatment also showed a more effective recovery rate during drought conditions than control (T1). In brief, the more negative potential will improve

turgor pressure so that the plant still has higher stomatal conductance and photosynthesis. The  $H_4SiO_4$  absorbed (T5) is assumed to be transported through the xylem and is deposited in the frond leaves epidermal surfaces of oil palm, increasing the hardness of frond leaves 58.5 Hd compared to control (T1) 55 Hd.

Table 8. Leaf nutrients content of mature oil palm, two-years after BioSilAc application on a regular basis

Tabel 8. Kadar hara daun pada TM setelah dua tahun aplikasi BioSilAc secara rutin

Treatments	N (%)	P (%)	K (%)	Cu (%)	B (ppm)	Si (ppm)
Perlakuan	N (%)	P (%)	K (%)	Cu (%)	B (ppm)	Si (ppm)
T1	2.98 a	0.19 b	1.2 a	0.47 d	16.4 b	542.5 a
T2	3.10 a	0.20 ab	1.48 a	0.46 d	17.8 b	554.9 a
T3	3.05 a	0.20 ab	1.36 a	0.27 e	23.6 ab	512.9 a
T4	2.97 a	0.22 ab	1.45 a	0.89 b	22.6 ab	554.9 a
T5	2.82 a	0.24 a	1.26 a	0.98 a	25.9 a	586.9 a
T6	2.97 a	0.19 b	1.11 a	0.41 d	20.0 ab	584.4 a
T7	2.99 a	0.19 b	1.18 a	0.55 c	16.1 b	525.3 a
Coefficient of variation (%)	5.3	8.4	12.7	5.5	1.0	5.4

<sup>a)</sup> Figures in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test ( $P < 0.05$ )

<sup>a)</sup> Angka dalam kolom yang sama yang diikuti oleh huruf yang sama tidak berbeda nyata menurut uji jarak berganda Duncan ( $P < 0,05$ )

Table 9. Average productivity of mature oil palm, two-years after BioSilAc application on a regular basis

Tabel 9. Produksi rata-rata pada TM setelah dua tahun aplikasi BioSilAc secara rutin

Treatments	Yield FFB (ton ha <sup>-1</sup> yr <sup>-1</sup> )	Increase in production to control
Perlakuan	Produksi TBS (ton ha <sup>-1</sup> thn <sup>-1</sup> )	Peningkatan produksi terhadap kontrol
T1	19.99 c	-
T2	21.01 b	5.1
T3	19.92 c	-0.35
T4	22.41 a	12.1
T5	22.38 ab	11.9
T6	20.09 b	0.5
T7	19.95 c	-0.20
Coefficient of variation (%)	5.9	

<sup>a)</sup> Figures in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test ( $P < 0.05$ )

<sup>a)</sup> Angka dalam kolom yang sama yang diikuti oleh huruf yang sama tidak berbeda nyata menurut uji jarak berganda Duncan ( $P < 0,05$ )

Table 10. Daily water consumption in mature oil palm T1 and T5 treatments

Tabel 10. Konsumsi air harian pada tanaman kelapa sawit menghasilkan (TM) perlakuan T1 dan T5

Treatments- replication	Total of frond Total Pelepah (a)	Daily water consumption (L frond <sup>-1</sup> day <sup>-1</sup> ) Konsumsi air harian (L pelepah <sup>-1</sup> hari <sup>-1</sup> ) (b)	Total water consumption (L tree <sup>-1</sup> day <sup>-1</sup> ) Konsumsi air total (L pohon <sup>-1</sup> hari <sup>-1</sup> ) [C] = (a) x (b)	Average daily water consumption (L tree <sup>-1</sup> day <sup>-1</sup> ) Rata-rata konsumsi air harian (L pohon <sup>-1</sup> hari <sup>-1</sup> )
T1.1	26	0.808	21.00	
T1.2	33	1.205	39.77	30.38
T5.1	28	0.71	19.88	
T5.2	28	0.78	21.84	20.86

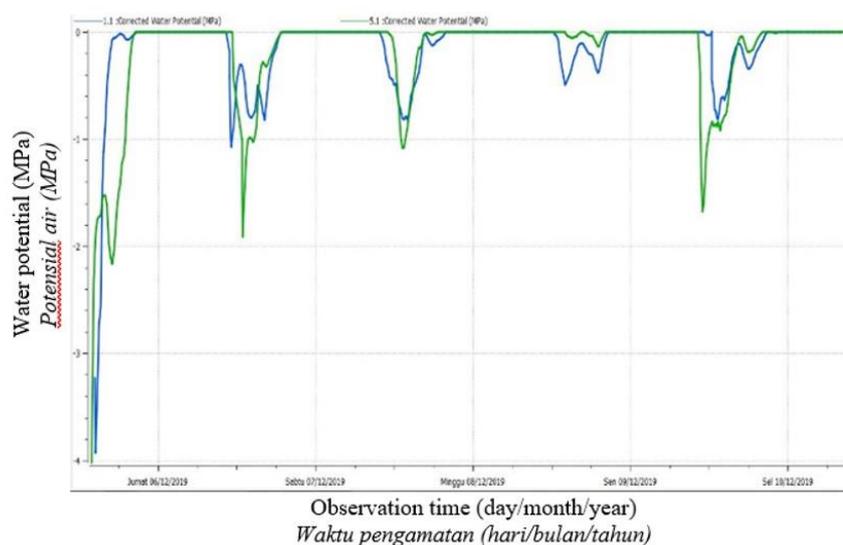


Figure 2. Stem psychrometer graphic of mature oil palm sample T1 (blue) and T5 (green) treatments

Gambar 2. Grafik psikrometer batang sampel tanaman kelapa sawit menghasilkan perlakuan T1 (biru) dan T5 (hijau)

### Conclusion

The effect of BioSilAc application on fertilizer use and water consumption efficiencies of oil palm grown on zone B climate-field sandy soil were shown to be effective in this study. The application of 4 tablets BiosilAc tree<sup>-1</sup> year<sup>-1</sup> could save NPK fertilizers dosage up to 25%, improve WUE up to 31.3% (mature) and 50.4% (immature). The highest yield of FFB was 22.38 tons to 22.4 tons ha<sup>-1</sup> year<sup>-1</sup> obtained from the combination of 75-100%NPK + 4 tablets BioSilAc tree<sup>-1</sup> year<sup>-1</sup>. BioSilAc fertilization reduced the need for mineral P and N fertilizers for FFB production and increased the hardness of immature and mature oil palm fronds. However, further study is necessary to confirm the results, particularly under a different agroclimatic area.

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