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Silicate Rock-Based Fertilizers Improved the Production of Sugarcane Grown on Udipsamments Kediri, East Java, Indonesia

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Abstract: Improving the farming productivity and profitability of sugarcane in Indonesia requires appropriate fertilization method. So, three types of silicate rock-based fertilizers were developed and tested in field condition. The main objectives of this research were to identify the effects of liquid-silicate rock fertilizer (LSRF) in addition to NPK, and granules of NP_{70}-Si and NP_{100}-Si on the growth and yield components of sugarcane grown on Udipsamments. A randomized complete block design was employed with the treatment consisting of F-0 (NPK) as the reference of fertilizer package, F-1 (NPK + LSRF applied onto the leaf), F-2 (NPK + LSRF applied to the soil), F-3 (NP_{70}-Si), and F-4 (NP_{100}-Si), and those were replicated in five blocks. Results reveal that the applications of those different fertilizer packages significantly affected the germination of seed buds, cane production, and sugar yield, but did not for the other growth and yield components. The order of its agronomic and economic effectiveness of the fertilizer packages, based on the value of either cane production or sugar yield, was F-2 > F-1 > F-4 > F-0 > F-3. Therefore, the use of the fertilizer package of F-2 (NPK + LSRF) may be promoted as an appropriate fertilization method to improve the farming productivity and profitability of sugarcane in Indonesia.

Keywords: cane production, silicate rock, sugarcane, Si fertilizer, sugar yield

1. Introduction

Sugarcane (*Saccharum officinarum*) is an important cash crop in Indonesia. During the last decade, the status of Indonesia has switched from an exporting to importing country for sugar. The situation is not only caused by the increase in national demand, but also by the decline of domestic production of sugar. A substantial effort to reach sustainable self-supporting for sugar is by implementing the specific recommendation of the application of multi-nutrient and organic fertilizers [1]. However, particular attention should also be given to the use of silicate (Si) - a commonly neglected nutrient but so much beneficial for sugarcane production.

In the farming of sugarcane, the use of N, P, and K, or NPK fertilizers is essential because the plant requires a large amount of those nutrients. Nevertheless, continuous application of those nutrients at high rates in the successive-monoculture farming system can deplete the other essential nutrients [2]. Moreover, sugarcane is a silicate-accumulator plant [2], absorbing much more Si than N, P, or K [3, 4, 5]. Many researchers reported that the application of Si fertilizers improves cane production [6, 7, 8]. The use of Si fertilizers may also suppress pest and disease attacks [9, 10, 11, 12] and the harmful effects of saline soils on plant growth [13, 14, 15]. Based on those references, the use of Si-based fertilizers containing all plant-essential nutrients may be proposed as an essential part of the exertions for improving

the production of sugarcane in Indonesia. The question is, which kind of fertilizer package is suitable especially for the smallholder farmers of sugarcane.

The farming business of sugarcane in Indonesia is mostly (54 %) operated by smallholder farmers, and partly by the state (16 %) and private (30 %) companies [16]. But, not many of the smallholders invests the Si-based fertilizers in sugarcane farm. Besides the lack of their knowledge, the foremost cause of the case is the high cost of available Si fertilizers. Thus, the use of cheap but effective Si-based fertilizers could be the best solution, and the innovation of producing Si-fertilizers based on local resources should become a vital part of the development program of sugarcane in Indonesia.

During the last several decades, there has been an increasing interest of agronomists worldwide, including in Indonesia, to the utilization of Si-containing materials for use as a multi-nutrient fertilizer. Those include ground silicate rocks [17], calcium silicate slag [18, 19, 20, 21, 4], boiler ash, furnace slag, and zeolite [8], and steel slag [22] as the sources for Si-containing fertilizer. However, the solubility of Si from those materials is commonly very low. Consequently, the application of those materials requires a very high rate (> 20 $t.ha^{-}$).

A promising effective fertilizer made from basaltic-silicate rocks is liquid-silicate rock fertilizer (LSRF) [23]. The results of a field test [24] show that the foliar application of LSRF, in addition to the basal fertilizers of N, P, and K, on sugarcane doubled the cane production reaching 184 $t.ha^{-}$, and increased sugar rendement and yield respectively reaching 8.4 % and 15.4 $t.ha^{-}$. However, sugarcane is a high and dense-growing plant so that the foliar application of LSRF requires a particular tool and high cost. For this reason, we have developed the other silicate rock-based fertilizers in granule form, i.e., NP_{70}-Si and NP_{100}-Si. The effectiveness of those fertilizers for sugarcane was evaluated in this present research.

The primary objective of this research was to evaluate the agronomic and economic effectiveness of the newly developed Si fertilizers, i.e., LSRF, NP_{70}-Si, and NP_{100}-Si, to improve sugarcane production.

2. Materials and Method

2.1. Site Description

This research was carried out in the research station of the state company of PTPN X in Kediri, East Java, Indonesia (7°5234.1"S 112°1011.1"E) for 12 months (April 2017 to May 2018). The land consisted of fairly deep (30 – 40 cm) sandy textured soil (Udipsamments), being characterized by slightly acid (pH 5.4), high N total (0.13 %) and Bray-extractable P (87 $mg.kg^{-}$), low cation exchange capacity (6.1 $cmol.kg^{-}$), and fair to slightly high exchangeable Na^{+}, K^{+}, Ca^{+2}, and Mg^{+2}, respectively, were 1.0, 0.98, 3.3, and 0.8 $cmol.kg^{-}$.

2.2. Experimental Design

This experiment was laid out in a randomized complete block design with five replications (blocks), and the treatments were five fertilizer packages described in Table 1. The planted cane seedling was PS 881 variety. The cane seeding was cut for use as the seed which each cut contained three seed buds. Each experimental plot consisted of 10 rows of 16-m length, and the distance between rows was 1.35 m. The seedling canes containing 48 buds were planted in each row; thus, there were 480 buds per plot of 216 m^2.

Table 1. The description of fertilizer packages (treatments) used in this current experiment

Treatment Code	Description	Application Method
F-0	Reference fertilizer* (NPK): 160 N + 72 P_2O_5 + 150 K_2O $kg.ha^{-}$	Applied twice at 7 and 30 days after planting (d.a.p) through the soil at 5-cm depth.
F-1	F-0 + 24-L LSRF (NPK + LSRF)	LSRF was applied onto the leaf and stem 4 times at 21, 35, 50, and 77 d.a.p.
F-2	F-0 + 24-L LSRF (NPK + LSRF)	LSRF was applied twice through the soil at 7 and 30 d.a.p.
F-4.	NP_{70}-Si (a granule fertilizer), 800 $kg.ha^{-}$.	NP_{70}-Si was applied twice through the soil, 2 x 50 % of the rate, at 7 and 30 d.a.p.
F-5.	NP_{100}-Si (a granule fertilizer) 800 $kg.ha^{-}$	NP_{100}-Si was applied twice through the soil, 2 x 50 % of the rate, at 7 and 30 d.a.p.

* NPK in this research was a combination of 160 N + 72 P_2O_5 + 150 K_2O ($kg.ha^{-}$), respectively, in forms of urea, TSP, and KCl.

2.3. Data Collection and Analysis

The main observed parameters were the growth and yield components. The growth components were (1) germination rate of seed buds observed at one month after planting (m.a.p), (2) plant height (cane length) of 3, 6, and 9 m.a.p, (3) cane diameter of 6 and 9 m.a.p., and (4) plant population of 3,6, and 9 m.a.p. The observed yield components were (1) cane production harvested at 12 m.a.p, (2) brix (the sweetness or the percentage of sugar relative to the cane juice), (3) rendement (the percentage of sucrose in the cane), and (4) sugar yield.

Data of each observed parameter were subjected to the analysis of variant (ANOVA), followed by the analysis of least significant difference (LSD) at $\alpha = 0.05$ for the parameters that were significantly affected by the treatments. The relative

effectiveness of each fertilizer package was calculated as the percentage of cane production (for agronomic effectiveness) and of farming benefit (for economic effectiveness) over that for the reference fertilizer package (F-0).

3. Results and Discussion

3.1. Growth Components

The effect of different fertilizer packages on the growth components of sugarcane is summarized in Table 2. The treatments did not significantly affect the growth components but the percentage of germinating seed buds. The germination of seed buds receiving NP_{100}-Si fertilizers was about 6 % higher than for that of the reference fertilizer (NPK).

As shown in Table 2, the percentages of germinating seed buds receiving the treatments of F-0, F-1, and F-2 were nearly the same (about 45.6 %), whereas for that of F-3 and F-4 were 47.2 – 49.6 %, or 3 – 4 % higher than for that of the reference (F-0). However, the plant population of 3, 6, and 9 months was not significantly affected by the application of the treatments. The plant population of the 3 months ranged from about 123 to 135 x 10^3 ha^-, whereas for that of 6 and 9 months were about the same (62 x 10^3 ha^-). The diameter of cane reached the maximum value (about 31 mm) after the plant was six-month-old, and that was not affected by the treatments. Similarly, the cane length (plant high) was not affected by the treatments, reaching a maximum extent of about 115 – 118 cm after 6-month old.

Based on the results of simple linear correlation analyses, there was no close correlation or cause-effect relationship between the germinating rates of seedling cane with plant population, height, or cane diameter. It seems that sufficient supply of the macronutrients of N, P, and K from all fertilizer packages for sugarcane provides no difference in growth components.

3.2. Yield Components

The effect of different fertilizer packages on the yield components of sugarcane is summarized in Table 3. The yield components significantly affected by the treatments were only the cane production and sugar yield.

As shown in Table 3, the application of LSRF (in addition to NPK) applied on the leaf (F-1) or through the soil (F-2) provided the cane production for about 105 t.ha- or 6 % higher than for that of the reference F-0 (NPK) for about 99 t.ha-. Meanwhile, the application of the granulated silicate rock fertilizers (NP_{70}-Si and NP_{100}-Si) produced, respectively, 93 and 103 $t.ha^-$, and those productions were the same to that of the reference F-0. The trend of sugar yield was similar to that of cane production. In contrast, the percentage of sugar brix dan rendement were not affected by the use of different fertilizer packages, which respectively were about 18 and 7.7 %.

Table 2. The effects of fertilizer packages on the growth components of sugarcane

Parameter	Unit	Fertilizer Packages					$LSD_{\alpha=0.05}$
		F-0	F-1	F-2	F-3	F-4	
Seed Germination	%	45.6 a	45.9 a	45.6 a	47.2 ab	48.6 b	1.8
Plant Population:							
3 months	$10^3.ha^-$	135.3	131.4	123.5	125.2	126.4	-
6 months	$10^3.ha^-$	64.7	62.1	62.6	61.7	62.0	-
9 months	$10^3.ha^-$	67.5	65.3	63.3	65.5	64.0	-
Cane Diameter:							
6 months	mm	30.2	31.1	30.9	31.1	31.2	-
9 months	mm	30.3	31.3	31.6	31.2	31.3	-
Plant Height:							
6 months	cm	115.4	115.5	118.0	115.6	118.0	-
9 months	cm	269.1	275.2	261.9	270.9	274.3	-

The values in the same row, labelled with the same letter, are not significantly different based on its $LSD_{\alpha=0.05}$

Table 3. The effects of fertilizer package on the yield components of sugarcane

Parameter	Unit	Fertilizer Packages					$LSD_{\alpha=0.05}$
		F-0	F-1	F-2	F-3	F-4	
Cane production	$t.ha^-$	98.9 b	104.6 c	105.2 c	92.5 a	102.5 bc	6.7
RAE-cane production	%	100.0	105.8	106.4	93.5	103.6	-
Sugar yield	$t.ha^-$	7.7 b	7.9 bc	8.1 c	7.0 a	7.9 bc	0.5
RAE-sugar yield	(%)	100.0	102.6	105.2	90.9	102.4	-
Brix	(%)	8.0	17.9	17.8	18.6	18.3	-
Rendement	(%)	7.8	7.6	7.7	7.5	7.7	-

The values in the same row, labelled with the same letter, are not significantly different based on its $LSD_{\alpha=0.05}$.

RAE = relative agronomic effectiveness

Table 4. Summary of economic analysis of sugarcane farming

Components	Fertilizer Packages				
	F-0	F-1	F-2	F-3	F-4
Materials (M_{IDR})	23.65	25.57	25.57	24.75	24.75
Operational (M_{IDR})	6.00	6.70	6.00	6.00	6.00
Total cost (M_{IDR})	29.650	32.270	31.570	30.750	30.750
Product ($t.ha^{-}$)	98.93	104.58	105.21	92.47	102.05
Rendement (%)	7.8	7.6	7.7	7.5	7.7
Prod. Price ($M_{IDR}.t^{-}$)	0.65	0.65	0.65	0.65	0.65
Prod. value (M_{IDR})	64.304	67.978	68.388	60.105	66.331
Benefit ($M_{IDR}.ha^{-}.y^{-}$)	34.654	35.708	36.818	29.355	35.581
REE – benefit (%)	100.0	103.0	106.2	84.7	102.7

M_{IDR} = millions of Indonesian dollar (Rupiah), 1 US$ ~ 14.500 IDR

3.3. Effectiveness of Silicate Rock-Based Fertilizers

The effectiveness of the silicate-rock based fertilizers relative to the reference fertilizer package, based on agronomic (RAE) and economic (REE) parameters, respectively are shown in Tables 3 and 4. The trends of RAE and REE are similar, which is F-2 > F-1 > F-4 > F-0 > F3. Based on those evaluations, the most effective fertilizer package for sugarcane is F-2 (NPK + LSRF applied through the soil). Adding LSRF to the basalt fertilizer (NPK) improved about 6 % of sugarcane production or cash benefit of the farming. Thus, the fertilizer package of NPK + LSRF may be promoted as an appropriate fertilizer package to improve productivity as well as the profitability of the farming sugarcane.

Comparing to the result of earlier research [24] producing about 184 $t.ha^{-}$ of cane, the 6-% or 6-$t.ha^{-}$ improvement of cane production in this present research is relatively small. Thus, further research is required to be able to reach higher or maximum sugar production; and it may be focused on defining the optimum fertilizer type and application, plant variety, or/and water supply.

4. Conclusion

The application of 5 different fertilizer packages, which were (NPK), (NPK+ LSRF applied on plant leaf), (NPK + LSRF applied through the soil), NP_{75}-Si, and NP_{100}-Si, significantly affected cane production, and sugar yield, but did not for the other observed growth and yield components of sugarcane grown on Udipsamments. Based on either its agronomic or economic effectiveness, the application of NPK + LSRF is the best fertilization method in this research. Therefore, the use of the fertilizer package (160-kg N + 72-kg P_2O_5 + 150-kg K_2O + 25-L LSRF per ha) may be proposed as an appropriate method. Indeed, further researches associating to the identification of optimum rate of fertilizer application for different plant varieties and watering strategy are required to obtain higher production of sugarcane.

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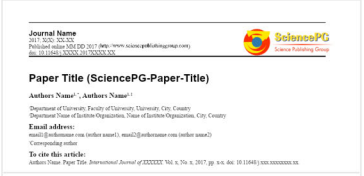
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Silicate Rock-Based Fertilizers Improved the Production of Sugarcane Grown on Udipsamments Kediri, East Java, Indonesia

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Keywords: Cane Production, Silicate Rock, Sugarcane, Si Fertilizer, Sugar Yield

1. Introduction

Sugarcane (*Saccharum officinarum*) is an important cash crop in Indonesia. During the last decade, the status of Indonesia has switched from an exporting to importing country for sugar. The situation is not only caused by the increase in national demand, but also by the decline of domestic production of sugar. A substantial effort to reach sustainable self-supporting for sugar is by implementing the specific recommendation of the application of multi-nutrient and organic fertilizers [1]. However, particular attention should also be given to the use of silicate (Si) - a commonly neglected nutrient but so much beneficial for sugarcane production.

In the farming of sugarcane, the use of N, P, and K, or NPK fertilizers is essential because the plant requires a large amount of those nutrients. Nevertheless, continuous application of those nutrients at high rates in the successive-monoculture farming system can deplete the other essential nutrients [2]. Moreover, sugarcane is a silicate-accumulator plant [2], absorbing much more Si than N, P, or K [3, 4, 5]. Many researchers reported that the application of Si fertilizers improves cane production [6, 7, 8]. The use of Si fertilizers may also suppress pest and disease attacks [9, 10, 11, 12] and the harmful effects

of saline soils on plant growth [13, 14, 15]. Based on those references, the use of Si-based fertilizers containing all plant-essential nutrients may be proposed as an essential part of the exertions for improving the production of sugarcane in Indonesia. The question is, which kind of fertilizer package is suitable especially for the smallholder farmers of sugarcane.

The farming business of sugarcane in Indonesia is mostly (54%) operated by smallholder farmers, and partly by the state (16%) and private (30%) companies [16]. But, not many of the smallholders invests the Si-based fertilizers in sugarcane farm. Besides the lack of their knowledge, the foremost cause of the case is the high cost of available Si fertilizers. Thus, the use of cheap but effective Si-based fertilizers could be the best solution, and the innovation of producing Si-fertilizers based on local resources should become a vital part of the development program of sugarcane in Indonesia.

During the last several decades, there has been an increasing interest of agronomists worldwide, including in Indonesia, to the utilization of Si-containing materials for use as a multi-nutrient fertilizer. Those include ground silicate rocks [17], calcium silicate slag [18, 19, 20, 21, 4], boiler ash, furnace slag, and zeolite [8], and steel slag [22] as the sources for Si-containing fertilizer. However, the solubility of Si from those materials is commonly very low. Consequently, the application of those materials requires a very high rate (> 20 $t.ha^{-}$).

A promising effective fertilizer made from basaltic-silicate rocks is liquid-silicate rock fertilizer (LSRF) [23]. The results of a field test [24] show that the foliar application of LSRF, in addition to the basal fertilizers of N, P, and K, on sugarcane doubled the cane production reaching 184 $t.ha^{-}$, and increased sugar rendement and yield respectively reaching 8.4% and 15.4 $t.ha^{-}$. However, sugarcane is a high and dense-growing plant so that the foliar application of LSRF requires a particular tool and high cost. For this reason, we have developed the other silicate rock-based fertilizers in granule form, i.e., NP_{70}-Si and NP_{100}-Si. The effectiveness of those fertilizers for sugarcane was evaluated in this present research.

The primary objective of this research was to evaluate the agronomic and economic effectiveness of the newly developed Si fertilizers, i.e., LSRF, NP_{70}-Si, and NP_{100}-Si, to improve sugarcane production.

2. Materials and Method

2.1. Site Description

This research was carried out in the research station of the state company of PTPN X in Kediri, East Java, Indonesia (7°5234.1"S 112°1011.1"E) for 12 months (April 2017 to May 2018). The land consisted of fairly deep (30 – 40 cm) sandy textured soil (Udipsamments), being characterized by slightly acid (pH 5.4), high N total (0.13%) and Bray-extractable P (87 $mg.kg^{-}$), low cation exchange capacity (6.1 $cmol.kg^{-}$), and fair to slightly high exchangeable Na^{+}, K^{+}, Ca^{+2}, and Mg^{+2}, respectively, were 1.0, 0.98, 3.3, and 0.8 $cmol.kg^{-}$.

2.2. Experimental Design

This experiment was laid out in a randomized complete block design with five replications (blocks), and the treatments were five fertilizer packages described in Table 1. The planted cane seedling was PS 881 variety. The cane seeding was cut for use as the seed which each cut contained three seed buds. Each experimental plot consisted of 10 rows of 16-m length, and the distance between rows was 1.35 m. The seedling canes containing 48 buds were planted in each row; thus, there were 480 buds per plot of 216 m^2.

Table 1. *The description of fertilizer packages (treatments) used in this current experiment.*

Treatment Code	Description	Application Method
F-0	Reference fertilizer* (NPK): 160 N + 72 P_2O_5 + 150 K_2O $kg.ha^{-}$	Applied twice at 7 and 30 days after planting (d.a.p) through the soil at 5-cm depth.
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F-2	F-0 + 24-L LSRF (NPK + LSRF)	LSRF was applied twice through the soil at 7 and 30 d.a.p.
F-4.	NP_{70}-Si (a granule fertilizer), 800 $kg.ha^{-}$.	NP_{70}-Si was applied twice through the soil, 2 x 50% of the rate, at 7 and 30 d.a.p.
F-5.	NP_{100}-Si (a granule fertilizer) 800 $kg.ha^{-}$	NP_{100}-Si was applied twice through the soil, 2 x 50% of the rate, at 7 and 30 d.a.p.

* NPK in this research was a combination of 160 N + 72 P_2O_5 + 150 K_2O ($kg.ha^{-}$), respectively, in forms of urea, TSP, and KCl.

2.3. Data Collection and Analysis

The main observed parameters were the growth and yield components. The growth components were (1) germination rate of seed buds observed at one month after planting (m.a.p), (2) plant height (cane length) of 3, 6, and 9 m.a.p, (3) cane diameter of 6 and 9 m.a.p., and (4) plant population of 3, 6, and 9 m.a.p. The observed yield components were (1) cane production harvested at 12 m.a.p, (2) brix (the sweetness or the percentage of sugar relative to the cane juice), (3) rendement (the percentage of sucrose in the cane), and (4) sugar yield.

Data of each observed parameter were subjected to the analysis of variant (ANOVA), followed by the analysis of least significant difference (LSD) at $\alpha = 0.05$ for the parameters that were significantly affected by the treatments. The relative effectiveness of each fertilizer package was calculated as the percentage of cane production (for agronomic effectiveness) and of farming benefit (for economic effectiveness) over that for the reference fertilizer package (F-0).

3. Results and Discussion

3.1. Growth Components

The effect of different fertilizer packages on the growth components of sugarcane is summarized in Table 2. The treatments did not significantly affect the growth components but the percentage of germinating seed buds. The germination of seed buds receiving NP_{100}-Si fertilizers was about 6% higher than for that of the reference fertilizer (NPK).

As shown in Table 2, the percentages of germinating seed buds receiving the treatments of F-0, F-1, and F-2 were nearly the same (about 45.6%), whereas for that of F-3 and F-4 were 47.2 – 49.6%, or 3 – 4% higher than for that of the reference (F-0). However, the plant population of 3, 6, and 9 months was not significantly affected by the application of the treatments. The plant population of the 3 months ranged from about 123 to 135 x 10^3 ha^-, whereas for that of 6 and 9 months were about the same (62 x 10^3 ha^-). The diameter of cane reached the maximum value (about 31 mm) after the plant was six-month-old, and that was not affected by the treatments. Similarly, the cane length (plant high) was not affected by the treatments, reaching a maximum extent of about 115 – 118 cm after 6-month old.

Based on the results of simple linear correlation analyses, there was no close correlation or cause-effect relationship between the germinating rates of seedling cane with plant population, height, or cane diameter. It seems that sufficient supply of the macronutrients of N, P, and K from all fertilizer packages for sugarcane provides no difference in growth components.

3.2. Yield Components

The effect of different fertilizer packages on the yield components of sugarcane is summarized in Table 3. The yield components significantly affected by the treatments were only the cane production and sugar yield.

As shown in Table 3, the application of LSRF (in addition to NPK) applied on the leaf (F-1) or through the soil (F-2) provided the cane production for about 105 t.ha- or 6% higher than for that of the reference F-0 (NPK) for about 99 t.ha-. Meanwhile, the application of the granulated silicate rock fertilizers (NP_{70}-Si and NP_{100}-Si) produced, respectively, 93 and 103 $t.ha^-$, and those productions were the same to that of the reference F-0. The trend of sugar yield was similar to that of cane production. In contrast, the percentage of sugar brix dan rendement were not affected by the use of different fertilizer packages, which respectively were about 18 and 7.7%.

Table 2. *The effects of fertilizer packages on the growth components of sugarcane.*

Parameter	Unit	Fertilizer Packages					$LSD_{\alpha=0.05}$
		F-0	F-1	F-2	F-3	F-4	
Seed Germination	**%**	**45.6 a**	**45.9 a**	**45.6 a**	**47.2 ab**	**48.6 b**	**1.8**
Plant Population:							
3 months	$10^3.ha^-$	135.3	131.4	123.5	125.2	126.4	-
6 months	$10^3.ha^-$	64.7	62.1	62.6	61.7	62.0	-
9 months	$10^3.ha^-$	67.5	65.3	63.3	65.5	64.0	-
Cane Diameter:				30.9 31.6	31.1 31.2		
6 months	mm	30.2	31.1			31.2	-
9 months	mm	30.3	31.3			31.3	-
Plant Height:							
6 months	cm	115.4	115.5	118.0	115.6	118.0	-
9 months	cm	269.1	275.2	261.9	270.9	274.3	-

The values in the same row, labelled with the same letter, are not significantly different based on its $LSD_{\alpha=0.05}$

Table 3. *The effects of fertilizer package on the yield components of sugarcane.*

Parameter	Unit	Fertilizer Packages					$LSD_{\alpha=0.05}$
		F-0	F-1	F-2	F-3	F-4	
Cane production	$t.ha^-$	98.9 b	104.6 c	105.2 c	92.5 a	102.5 bc	6.7
RAE-cane production	%	100.0	105.8	106.4	93.5	103.6	-
Sugar yield	$t.ha^-$	7.7 b	7.9 bc	8.1 c	7.0 a	7.9 bc	0.5
RAE-sugar yield	(%)	100.0	102.6	105.2	90.9	102.4	-
Brix	(%)	8.0	17.9	17.8	18.6	18.3	-
Rendement	(%)	7.8	7.6	7.7	7.5	7.7	-

The values in the same row, labelled with the same letter, are not significantly different based on its $LSD_{\alpha=0.05}$.
RAE = relative agronomic effectiveness

Table 4. *Summary of economic analysis of sugarcane farming.*

Components	Fertilizer Packages				
	F-0	F-1	F-2	F-3	F-4
Materials (M_{IDR})	23.65	25.57	25.57	24.75	24.75
Operational (M_{IDR})	6.00	6.70	6.00	6.00	6.00
Total cost (M_{IDR})	29.650	32.270	31.570	30.750	30.750
Product ($t.ha^-$)	98.93	104.58	105.21	92.47	102.05

Components	Fertilizer Packages				
	F-0	F-1	F-2	F-3	F-4
Rendement (%)	7.8	7.6	7.7	7.5	7.7
Prod. Price ($M_{IDR}.t^{-}$)	0.65	0.65	0.65	0.65	0.65
Prod. value (M_{IDR})	64.304	67.978	68.388	60.105	66.331
Benefit ($M_{IDR}.ha^{-}.y^{-}$)	34.654	35.708	36.818	29.355	35.581
REE – benefit (%)	100.0	103.0	106.2	84.7	102.7

M_{IDR} = millions of Indonesian dollar (Rupiah), 1 US$ ~ 14.500 IDR

3.3. Effectiveness of Silicate Rock-Based Fertilizers

The effectiveness of the silicate-rock based fertilizers relative to the reference fertilizer package, based on agronomic (RAE) and economic (REE) parameters, respectively are shown in Tables 3 and 4. The trends of RAE and REE are similar, which is F-2 > F-1 > F-4 > F-0 > F3. Based on those evaluations, the most effective fertilizer package for sugarcane is F-2 (NPK + LSRF applied through the soil). Adding LSRF to the basalt fertilizer (NPK) improved about 6% of sugarcane production or cash benefit of the farming. Thus, the fertilizer package of NPK + LSRF may be promoted as an appropriate fertilizer package to improve productivity as well as the profitability of the farming sugarcane.

Comparing to the result of earlier research [24] producing about 184 $t.ha^{-}$ of cane, the 6-% or 6-$t.ha^{-}$ improvement of cane production in this present research is relatively small. Thus, further research is required to be able to reach higher or maximum sugar production; and it may be focused on defining the optimum fertilizer type and application, plant variety, or/and water supply.

4. Conclusion

The application of 5 different fertilizer packages, which were (NPK), (NPK+ LSRF applied on plant leaf), (NPK + LSRF applied through the soil), NP_{75}-Si, and NP_{100}-Si, significantly affected cane production, and sugar yield, but did not for the other observed growth and yield components of sugarcane grown on Udipsamments. Based on either its agronomic or economic effectiveness, the application of NPK + LSRF is the best fertilization method in this research. Therefore, the use of the fertilizer package (160-kg N + 72-kg P_2O_5 + 150-kg K_2O + 25-L LSRF per ha) may be proposed as an appropriate method. Indeed, further researches associating to the identification of optimum rate of fertilizer application for different plant varieties and watering strategy are required to obtain higher production of sugarcane.

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Silicate Rock-Based Fertilizers Improved the Production of Sugarcane Grown on Udipsamments Kediri, East Java, Indonesia

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Abstract: Improving the farming productivity and profitability of sugarcane in Indonesia requires appropriate fertilization method. So, three types of silicate rock-based fertilizers were developed and tested in field condition. The main objectives of this research were to identify the effects of liquid-silicate rock fertilizer (LSRF) in addition to NPK, and granules of NP_{70}-Si and NP_{100}-Si on the growth and yield components of sugarcane grown on Udipsamments. A randomized complete block design was employed with the treatment consisting of F-0 (NPK) as the reference of fertilizer package, F-1 (NPK + LSRF applied onto the leaf), F-2 (NPK + LSRF applied to the soil), F-3 (NP_{70}-Si), and F-4 (NP_{100}-Si), and those were replicated in five blocks. Results reveal that the applications of those different fertilizer packages significantly affected the germination of seed buds, cane production, and sugar yield, but did not for the other growth and yield components. The order of its agronomic and economic effectiveness of the fertilizer packages, based on the value of either cane production or sugar yield, was F-2 > F-1 > F-4 > F-0 > F-3. Therefore, the use of the fertilizer package of F-2 (NPK + LSRF) may be promoted as an appropriate fertilization method to improve the farming productivity and profitability of sugarcane in Indonesia.

Keywords: Cane Production, Silicate Rock, Sugarcane, Si Fertilizer, Sugar Yield

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* NPK in this research was a combination of 160 N + 72 P_2O_5 + 150 K_2O ($kg.ha^{-}$), respectively, in forms of urea, TSP, and KCl.

2.3. Data Collection and Analysis

The main observed parameters were the growth and yield components. The growth components were (1) germination rate of seed buds observed at one month after planting (m.a.p), (2) plant height (cane length) of 3, 6, and 9 m.a.p, (3) cane diameter of 6 and 9 m.a.p., and (4) plant population of 3, 6, and 9 m.a.p. The observed yield components were (1) cane production harvested at 12 m.a.p, (2) brix (the sweetness or the percentage of sugar relative to the cane juice), (3) rendement (the percentage of sucrose in the cane), and (4) sugar yield.

Data of each observed parameter were subjected to the analysis of variant (ANOVA), followed by the analysis of least significant difference (LSD) at $\alpha = 0.05$ for the parameters that were significantly affected by the treatments. The relative effectiveness of each fertilizer package was calculated as the percentage of cane production (for agronomic effectiveness) and of farming benefit (for economic effectiveness) over that for the reference fertilizer package (F-0).

3. Results and Discussion

3.1. Growth Components

The effect of different fertilizer packages on the growth components of sugarcane is summarized in Table 2. The treatments did not significantly affect the growth components but the percentage of germinating seed buds. The germination of seed buds receiving NP_{100}-Si fertilizers was about 6% higher than for that of the reference fertilizer (NPK).

As shown in Table 2, the percentages of germinating seed buds receiving the treatments of F-0, F-1, and F-2 were nearly the same (about 45.6%), whereas for that of F-3 and F-4 were 47.2 – 49.6%, or 3 – 4% higher than for that of the reference (F-0). However, the plant population of 3, 6, and 9 months was not significantly affected by the application of the treatments. The plant population of the 3 months ranged from about 123 to 135 x 10^3 ha^-, whereas for that of 6 and 9 months were about the same (62 x 10^3 ha^-). The diameter of cane reached the maximum value (about 31 mm) after the plant was six-month-old, and that was not affected by the treatments. Similarly, the cane length (plant high) was not affected by the treatments, reaching a maximum extent of about 115 – 118 cm after 6-month old.

Based on the results of simple linear correlation analyses, there was no close correlation or cause-effect relationship between the germinating rates of seedling cane with plant population, height, or cane diameter. It seems that sufficient supply of the macronutrients of N, P, and K from all fertilizer packages for sugarcane provides no difference in growth components.

3.2. Yield Components

The effect of different fertilizer packages on the yield components of sugarcane is summarized in Table 3. The yield components significantly affected by the treatments were only the cane production and sugar yield.

As shown in Table 3, the application of LSRF (in addition to NPK) applied on the leaf (F-1) or through the soil (F-2) provided the cane production for about 105 t.ha- or 6% higher than for that of the reference F-0 (NPK) for about 99 t.ha-. Meanwhile, the application of the granulated silicate rock fertilizers (NP_{70}-Si and NP_{100}-Si) produced, respectively, 93 and 103 $t.ha^-$, and those productions were the same to that of the reference F-0. The trend of sugar yield was similar to that of cane production. In contrast, the percentage of sugar brix dan rendement were not affected by the use of different fertilizer packages, which respectively were about 18 and 7.7%.

Table 2. *The effects of fertilizer packages on the growth components of sugarcane.*

Parameter	Unit	Fertilizer Packages					$LSD_{\alpha=0.05}$
		F-0	F-1	F-2	F-3	F-4	
Seed Germination	**%**	**45.6 a**	**45.9 a**	**45.6 a**	**47.2 ab**	**48.6 b**	**1.8**
Plant Population:							
3 months	$10^3.ha^-$	135.3	131.4	123.5	125.2	126.4	-
6 months	$10^3.ha^-$	64.7	62.1	62.6	61.7	62.0	-
9 months	$10^3.ha^-$	67.5	65.3	63.3	65.5	64.0	-
Cane Diameter:				30.9 31.6	31.1 31.2		
6 months	mm	30.2	31.1			31.2	-
9 months	mm	30.3	31.3			31.3	-
Plant Height:							
6 months	cm	115.4	115.5	118.0	115.6	118.0	-
9 months	cm	269.1	275.2	261.9	270.9	274.3	-

The values in the same row, labelled with the same letter, are not significantly different based on its $LSD_{\alpha=0.05}$

Table 3. *The effects of fertilizer package on the yield components of sugarcane.*

Parameter	Unit	Fertilizer Packages					$LSD_{\alpha=0.05}$
		F-0	F-1	F-2	F-3	F-4	
Cane production	$t.ha^-$	98.9 b	104.6 c	105.2 c	92.5 a	102.5 bc	6.7
RAE-cane production	%	100.0	105.8	106.4	93.5	103.6	-
Sugar yield	$t.ha^-$	7.7 b	7.9 bc	8.1 c	7.0 a	7.9 bc	0.5
RAE-sugar yield	(%)	100.0	102.6	105.2	90.9	102.4	-
Brix	(%)	8.0	17.9	17.8	18.6	18.3	-
Rendement	(%)	7.8	7.6	7.7	7.5	7.7	-

The values in the same row, labelled with the same letter, are not significantly different based on its $LSD_{\alpha=0.05}$.
RAE = relative agronomic effectiveness

Table 4. *Summary of economic analysis of sugarcane farming.*

Components	Fertilizer Packages				
	F-0	F-1	F-2	F-3	F-4
Materials (M_{IDR})	23.65	25.57	25.57	24.75	24.75
Operational (M_{IDR})	6.00	6.70	6.00	6.00	6.00
Total cost (M_{IDR})	29.650	32.270	31.570	30.750	30.750
Product ($t.ha^-$)	98.93	104.58	105.21	92.47	102.05

Components	Fertilizer Packages				
	F-0	F-1	F-2	F-3	F-4
Rendement (%)	7.8	7.6	7.7	7.5	7.7
Prod. Price ($M_{IDR}.t^{-}$)	0.65	0.65	0.65	0.65	0.65
Prod. value (M_{IDR})	64.304	67.978	68.388	60.105	66.331
Benefit ($M_{IDR}.ha^{-}.y^{-}$)	34.654	35.708	36.818	29.355	35.581
REE – benefit (%)	100.0	103.0	106.2	84.7	102.7

M_{IDR} = millions of Indonesian dollar (Rupiah), 1 US$ ~ 14.500 IDR

3.3. Effectiveness of Silicate Rock-Based Fertilizers

The effectiveness of the silicate-rock based fertilizers relative to the reference fertilizer package, based on agronomic (RAE) and economic (REE) parameters, respectively are shown in Tables 3 and 4. The trends of RAE and REE are similar, which is F-2 > F-1 > F-4 > F-0 > F3. Based on those evaluations, the most effective fertilizer package for sugarcane is F-2 (NPK + LSRF applied through the soil). Adding LSRF to the basalt fertilizer (NPK) improved about 6% of sugarcane production or cash benefit of the farming. Thus, the fertilizer package of NPK + LSRF may be promoted as an appropriate fertilizer package to improve productivity as well as the profitability of the farming sugarcane.

Comparing to the result of earlier research [24] producing about 184 $t.ha^{-}$ of cane, the 6-% or 6-$t.ha^{-}$ improvement of cane production in this present research is relatively small. Thus, further research is required to be able to reach higher or maximum sugar production; and it may be focused on defining the optimum fertilizer type and application, plant variety, or/and water supply.

4. Conclusion

The application of 5 different fertilizer packages, which were (NPK), (NPK+ LSRF applied on plant leaf), (NPK + LSRF applied through the soil), NP_{75}-Si, and NP_{100}-Si, significantly affected cane production, and sugar yield, but did not for the other observed growth and yield components of sugarcane grown on Udipsamments. Based on either its agronomic or economic effectiveness, the application of NPK + LSRF is the best fertilization method in this research. Therefore, the use of the fertilizer package (160-kg N + 72-kg P_2O_5 + 150-kg K_2O + 25-L LSRF per ha) may be proposed as an appropriate method. Indeed, further researches associating to the identification of optimum rate of fertilizer application for different plant varieties and watering strategy are required to obtain higher production of sugarcane.

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