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Humic acid enriched with urea and NPK factory by-products promoted the growth and yield of *Saccharum officinarum* L.

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Abstract

Nutrient uptake efficiency in sugarcane (*Saccharum officinarum* L.) must be increased using organic matter to restore soil fertility, resulting in greater productivity. The humic substance is a complex organic material that is excellent for overcoming this challenge. This study aimed to determine the effect of the humic acid enriched by liquid urea by-product (PSUC) and liquid NPK by-product (PSNC) application on the growth and productivity of sugarcane. The experiment was conducted from October 2021 to September 2022 on PT RNI plantation land, Jatitujuh, Majalengka. The research was arranged in a completely randomized design (CRD) using two different humic acid product prototypes (PSUC and PSNC) with two evaluation times, a screening and a semi-pilot scale. Solid humic at a dose of 15 Kg ha^{-1} was applied by mixing it with inorganic fertilizers, while liquid humic at a total dose of 15 L ha^{-1} was applied by foliar spray technique at 1, 2, and 3 months after planting (MAP). The results showed that applying humic acid PSUC and PSNC enhanced sugarcane shoot growth, segmented stem number, and stem diameter. In addition, it could consistently promote sugarcane yields on the semi-pilot scale up to 19.18% and 24.26% under humic acid PSUC and PSNC treatments, respectively. Therefore, both in the screening and semi-pilot evaluation, the solid and liquid humic acid PSUC and PSNC applied simultaneously are potential organic materials to enhance sugarcane growth and yield.

INTRODUCTION

According to BPS (2018), Indonesia's total sugar consumption increased from 7.05 million tons (2018/2019) to 7.15 million tons (2019/2020), with an average per capita consumption of 13 kg year^{-1}. However, the sugar production in 2019/2020 was 27.7 million tons, lower than the average production for the last five years, which was 30.2 million tons. That follows the low average productivity of Indonesian sugarcane, with less than 7 tons ha^{-1}, while the potential could reach 10−15 tons ha^{-1}. Consequently, Indonesia imports a massive amount of sugar yearly (Putra et al., 2017; Anggraeni et al., 2022). One main constraint for low sugarcane production is the wide gap between yield potential and actual sugarcane production. To date, cultivation techniques have focused on conventional fertilization. In addition, the low productivity of sugarcane occurs due to low soil fertility and insufficient water availability (Anggraeni et al., 2022).

Among the essential nutrients, nitrogen (N) fertilizer is an essential element in forming proteins and nucleic acid. The N fertilizer was applied to sugarcane as ammonium nitrate, urea, or ammonium sulfate. Sugarcane cultivation requires large quantities of N fertilizer, 45−300 Kg ha^{-1} year^{-1}, to reach an average

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plant growth, leaf expansion, root growth, and biomass production. The N deficiency can lead to the earlier transition from the growth to the development or flowering stage, stunted growth, and a decrease in the quality and quantity of sugar, which directly impacts the economic stability of farmers and the sugarcane industry (Otto et al., 2014; Witte, 2011; Saleem et al., 2012).

The recent concept of fertilization is not only to ensure the availability of nutrients in the soil but also to increase nutrient uptake efficiency. Applying organic fertilizers and soil ameliorants is favorable to improving plant growth performance and soil fertility while minimizing the environmentally hazardous impact caused by the massive application of inorganic material. Generally, organic material is used as a soil ameliorant to increase soil fertility, starting by stimulating the growth of fixing microorganisms, providing nutrients, and improving soil quality (Hardjowigeno, 2012). Organic matter consists of a complex and heterogeneous chemical structure, while its percentage in the soil is relatively small. The availability of organic matter in the soil is an essential factor that directly affects soil texture and fertility. Prakoso et al. (2020) stated that applying organic materials with a high affinity for amorphous minerals, such as humic acid, was excellent for cultivation on andisol soils.

Humic acid is an essential component in the soil that can increase nutrient availability, improving the soil's physical, chemical, and biological properties. A humic substance is a unit of several types of organic materials formed through the chemical and biological humification of plants and animals by the biological activity of soil microorganisms. Humin, humic acid, and fulvic acid are the main fractions of a complex humic substance and are biologically active organic matter in the soil (Khaled and Fawy, 2011; Leite et al., 2020). Studies have proven that humic substances and humic acid were proven to increase nutrient absorption and plant growth. Humic substances were reported to improve photosynthesis and water use efficiency, protein content, and total dissolved sugars, which align with the synergistic effects of carbon and nitrogen metabolism. Several studies demonstrated the effect of humic acid application in increasing maize growth performance, mineral uptake, and availability of phosphorus nutrients in various soil characteristics such as saline soil (Daur and Bakhashwain, 2013), acid soil (Wulandari et al., 2019), and andisol soil (Prakoso et al., 2020). Application of humic substances and humic acid in combination with urea through the foliar spray technique was reported to increase nitrogen use efficiency (NUE) up to 30 days after application (DAA) significantly, namely 23.53% and 82.35%, respectively, compared to the control. In addition, the nitrogen could be quickly absorbed and stored in protein and starch, indicating an increase in NUE (Cenellas and Oliiveras, 2014; Leite et al., 2020)

The use of humic acid to promote the growth and productivity of various crop commodities and improve soil characteristics has been widely practiced. However, a lack of studies has revealed the effect of humic acid on sugarcane, especially in nutrient uptake efficiency. Leite et al. (2020) revealed that applying inorganic fertilizers combined with humic substance and humic acid in sugarcane is an alternative strategy for increasing NUE. Efforts to improve nutrient uptake efficiency are crucial because only a 1% improvement could save costs up to 1.1 million dollars year^{-1} (Stuart et al., 2014). In humic substance production, the addition of enriching materials can be performed both with seaweed and by-products of the urea (PSUC) and NPK (PSNC) factories that still contain N, P, and K, which are beneficial for plants and soil fertility (Aziz et al., 2022). Therefore, this study aimed to determine the effect of humic acid PSUC and PSNC applications on the growth and productivity of sugarcane.

MATERIALS AND METHODS

The research was conducted in PT RNI plant cane (PC) sugarcane fields, Jatitujuh, Majalengka, from August 2021 to September 2022. The research was arranged in a completely randomized (CRD) design to evaluate two product prototypes, humic acid PSUC and PSNC, with three replications. Humic acid PSUC and PSNC production, following Aziz et al. (2022), met the standards based on the Ministry of Agriculture regulation No. 1, 2019. In brief, the product is generated by extracting lignite as the main raw material using PSUC or PSNC as an additional solvent. The final product is solid and liquid humic acid containing additional nutrients such as N, P, and K from the by-products. The study was conducted in two area scales: the screening and the semi-pilot scale. In the screening scale, seven treatments including the control were used, consisting of solid and liquid humic acid products and applied separately or in combination (Table 1). Meanwhile, in the semi-pilot scale, three treatments were used: humic acid PSUC (HpcU), humic acid PSNC

(HpcN), and control (C) (Table 2). The spacing between plant rows was 1.35 m. The screening scale test was carried out in block 452, while the semi-pilot scale was carried out in 3 different locations, namely blocks 344, 381, and 563. A different technical culture was applied in each block, so the treatment group was compared to each control.

The screening scale testing was carried out on an area of 0.5 Ha. The experimental plot for each treatment consisted of 11 land rows with a length of 50 m or an area of 742.5 m². The varieties used was Kidang Kencana (KK), planted by planting 3−4 bud eyes seeds with 50% overlap. The total dose of fertilizer was 800 Kg ha^{-1} consisting of urea and NPK (1:2, w/w). The semi-pilot testing was carried out on an area of 3.23 hectares consisting of three blocks (Table 3). The first location was block 344, which has 32 land rows with a length of 95 m or an area of 0.41 Ha. The second location was block 381, which has 57 land rows with a length of 50 m or an area of 0.33 Ha. At the same time, the third location was in block 563, which has 27 land rows with a length of 90 m or an area of 0.33 Ha.

Solid humic acid PSUC and PSNC at a dose of 15 Kg ha^{-1} were manually mixed with NPK fertilizer 15:10:12 (Figure 1). In contrast, liquid humic acid was sprayed onto the leaf organ (foliar spray) at 1, 2, and 3 months after planting (MAP) by first diluting it at a volume of 300 L ha^{-1} (Table 1 and Table 2). A mixture of fertilizer and solid humic acid was applied according to the treatment, which was carried out manually by sowing to the soil. The fertilizer was applied without adding solid and liquid humic acid in control.

Sugarcane growth and productivity were observed five times at 1, 3, 6, 9, and 12 months after planting (MAP), with each parameter following Yusup et al. (2021). A 9 m-long plant row sample was randomly selected and divided into three points for each repetition. The number of shoots was observed at one MAP by counting the germinating bud eyes. The number of plants at three MAP was determined by

Table 1. The detail of humic acid PSUC and PSNC application in screening scale testing

Treatment	Code	Solid humic				Liquid humic			
		Dose (Kg ha^{-1})		Application		Dose (L ha^{-1})		Application	
		Total	/application	Total	Period	Total	/application	Total	Period
Control	C	-	-	-	-	-	-	-	-
Liquid humic PSUC	HcU	-	-	-	-	15	5	3	1,2, & 3 MAP
Liquid humic PSNC	HcN	-	-	-	-	15	5	3	1,2, & 3 MAP
Solid humic PSUC	HpU	15	15	1	Fertilization I	-	-	-	-
Solid humic PSNC	HpN	15	15	1	Fertilization I	-	-	-	-
Solid humic + liquid PSUC	HpcU	15	15	1	Fertilization I	15	5	3	1,2, & 3 MAP
Solid humic + liquid PSNC	HpcN	15	15	1	Fertilization I	15	5	3	1,2, & 3 MAP

Remarks: (-) = no humic acid application, MAP = months after planting.

Table 2. The detail of humic acid PSUC and PSNC application in semi-pilot scale testing

Treatment	Code	Solid humic				Liquid humic			
		Dose (Kg ha^{-1})		Application		Dose (L ha^{-1})		Application	
		Total	/application	Total	Period	Total	/application	Total	Period
Control	C	-	-	-	-	-	-	-	-
Solid humic + liquid PSUC	HpcU	15	15	1	Fertilization I	15	5	3	1,2, & 3 MAP
Solid humic + liquid PSNC	HpcN	15	15	1	Fertilization I	15	5	3	1,2, & 3 MAP

Remarks: (-) = no humic acid application, MAP = months after planting.

Table 3. The detail of varieties, fertilizer, and area of humic acid PSUC and PSNC in semi-pilot scale testing

Block number	Varieties	Land area per treatment (Ha)	Total area (Ha)	Inorganic fertilizer	Total fertilizer dose (Kg ha^{-1})
344	PA130	0.41	1.23	Urea & NPK	900
381	KK	0.33	1.00	Urea & NPK	700
563	BM9603	0.33	1.00	Urea & NPK	800

Figure 1. NPK fertilizer 15:10:12 (A), the mixing of NPK and solid humic (B), and the mixture of NPK and solid humic (C)

Table 4. Soil properties of the planting area

Parameters	Unit	Value	Status*
pH	-	4.14	Very acidic
Organic C	%	4.83	High
Total N	%	0.95	Very high
P_2O_5	ppm	98.78	Very high
K_2O	cmol Kg^{-1}	64	Very low
Available P	ppm	16.07	Very high
K-exch	cmol Kg^{-1}	11	-
Ca-exch	cmol Kg^{-1}	2	-
Al-exch	cmol Kg^{-1}	10	-
Na-exch	cmol Kg^{-1}	9	-
CEC	cmol Kg^{-1}	23.87	Medium
Humic content	%	0.72	-
Total Microbes	CFU gr^{-1}	37×10^1	-

Remarks: (*) status based on Balai Penelitian Tanah (2005). CFU: Colony forming unit.

counting the segmented and unsegmented tillers. Plant height was determined by measuring the height of the plant from the soil surface to the triangular joint of the top leaf in the two representative plant clumps or the plant clump in the center of the plant row sample. Stem diameter was determined by measuring the diameter at the center of the stem in two representative clumps or two plant clumps in the center using a caliper. Meanwhile, the number of plants, plant height, and stem diameter were measured at 3, 6, and 9 MAP. Stem weight was determined at 12 MAP by weighing the stems in the plant row sample and converting them into hectares to determine potential productivity. Brix value assay was performed with a refractometer. The data obtained were tested statistically using analysis of variance (ANOVA) with the Tukey HSD test ($p > 0.05$). The soil's physical, chemical, and biological properties were analyzed at the Analysis Service Laboratory, Indonesian Oil Palm Research Institute, Bogor Unit.

RESULTS AND DISCUSSION

Soil physical, chemical, and biological properties of the planting area

Based on the analysis shown in Table 4, it is known that the soil characteristics in the planting area are very acidic, with a pH of 4.14 and very high N and P levels, 0.95% and 98.78 ppm, respectively. However, the K level is low, 0.64%, while the available P is very high, 16.07 cmol Kg^{-1}. It has a medium cation exchange capacity (CEC) with a humic content of 0.72%. Soil CEC plays a vital role in nutrient uptake by plants. One of the main factors in increasing CEC is the availability of organic matter, which could be provided by humic acid applications.

Applying humic substances is expected to restore soil fertility by improving the soil's physical, chemical, and biological properties. Wulandari et al. (2019) reported that applying 5%, 10%, and 15% humic acid increased the P availability status in the soil. A 5% humic acid significantly increased P availability from very low to medium at 15 weeks after planting (WAP), while 10% and 15% doses increased the status from very low to low. According to Zhu et al. (2018), the application of humic acid increased the movement and concentration of available P in the soil around the area where humic acid was applied so that there were more P residues.

Effect of humic acid application on the growth and productivity of sugarcane on screening scale testing

Regarding the observation (Table 5), the number of control shoots was the highest and significantly different from several treatments, such as HcN, HpU, and HpcN, one month after planting (MAP). Although there was a slight difference in the number of shoots, there was no significant difference between treatments. The number of shoots in control was 7.21 per meter, while there were around 4 to 6 shoots in the treatment. That could occur due to several factors, such as soil contours and waterlogging differences. The treatment plot had a lower height than the control, so it was suspected that it caused waterlogging due to heavy rainfall, which resulted in some shoots failing to germinate. However, the plants were still in the early growth stage, so it still had the opportunity to grow and develop until it enters the generative phase.

At three MAP, growth performance was observed by counting the number of plants with segmented and unsegmented stems and measuring stem height (Table 6). There was no difference in the number of plants with segmented stems between the treatment groups and control. However, the control plants indicated the highest number of unsegmented stems, significantly different from all treatments. It indicates that the application of humic acid can accelerate the initial growth of sugarcane, especially in stem growth. Kumalawati et al. (2021) stated that applying a consortium product of humic acid, biostimulants, and bio-fertilizers with active ingredients mycorrhizae increased the number of sugarcane shoots significantly,

Table 5. The influence of humic acid PSUC and PSNC on the plant number one month after planting (MAP)

Treatment	Number of shoots per m
C	7.21 ± 0.55 a
HcU	5.29 ± 0.66 ab
HcN	4.99 ± 0.32 b
HpU	4.23 ± 0.05 b
HpN	6.03 ± 0.49 ab
HpcU	5.43 ± 0.80 ab
HpcN	4.89 ± 1.01 b

Remarks: C= Control, HcU= liquid humic PSUC, HcN= liquid humic PSNC, HpU= Solid humic PSUC, HpN= Solid humic PSNC, HpcU= Solid humic & liquid PSUC, HpcN= Solid humic & liquid PSNC. Means followed by the same letters in the same column are not significantly different based on the Tukey test at 95% of confidence level.

Table 6. The influence of humic acid PSUC and PSNC on the number of plants and plant height at three months after planting (MAP)

Treatment	Plant number per m			Plant height (cm)
	Total	Segmented stem	Unsegmented stem	
C	15.50 ± 0.50 a	6.50 ± 0.50 a	9.00 ± 0.00 a	85.00 ± 2.50 a
HcU	14.50 ± 0.17 a	8.17 ± 0.17 a	6.33 ± 0.00 b	90.25 ± 8.08 a
HcN	14.17 ± 0.83 a	8.33 ± 0.00 a	5.83 ± 0.83 b	85.00 ± 0.00 a
HpU	14.17 ± 0.17 a	6.50 ± 1.17 a	7.67 ± 1.33 b	88.42 ± 1.75 a
HpN	14.67 ± 1.33 a	6.67 ± 1.33 a	8.00 ± 2.67 b	85.08 ± 8.42 a
HpcU	14.83 ± 0.50 a	7.67 ± 0.67 a	7.17 ± 1.17 b	86.17 ± 8.67 a
HpcN	15.33 ± 0.33 a	7.83 ± 0.50 a	7.50 ± 0.17 b	84.50 ± 3.83 a

Remarks: C= Control, HcU= liquid humic PSUC, HcN= liquid humic PSNC, HpU= Solid humic PSUC, HpN= Solid humic PSNC, HpcU= Solid humic & liquid PSUC, HpcN= Solid humic & liquid PSNC. Means followed by the same letters in the same column are not significantly different based on the Tukey test at 95% of confidence level.

both with and without segments recorded at nine weeks after planting (WAP). At three MAP, there was significant growth in the number of plants recorded in the treatments or control group. Compared to the growth performance at one MAP, each treatment generally showed a faster growth increment than the control. That was indicated by the number of plants in the treatment and control, which was not significantly different. Meanwhile, in the plant height, there was no difference between all treatments and the control, although the HcU and HpU treatments showed higher values than the control, 90.25 cm and 88.42 cm, respectively. Kumalawati et al. (2021) stated that the application of a consortium product of humic acid, biostimulants, and mycorrhizae had not shown a significant difference in the increase in shoot height at four and six weeks after planting (WAP), while at eight WAP, the increase in shoot height was significantly different from the control (17.50 cm), 39.25 cm.

The growth performance of sugarcane at six months after planting (MAP) is presented in Table 7. At six MAP, all treatments and control showed an increase in growth compared to that at three MAP, with the number of plants per meter ranging from 19 to 21. The application of humic acid significantly affected the increase in the number of plants at six MAP. That is indicated by the number of plants in each treatment, which is higher than the control. Nonetheless, the increased number of treated plants at six MAP was similar to the control.

At six MAP, the plant height of the treatment and control ranged from 224 cm to 244 cm. Even though the stem height in the HcU, HcN, and HpN treatments was higher than the control, there was no significant difference. All treatments showed a higher stem diameter than the control, which ranged from 20 mm to 26 mm, while in the control, it was only 18.60 mm. Except for the HcU treatment, other treatments showed a significantly different stem diameter than the control. That indicated that at six MAP, the application of humic acid caused an increase in the growth of sugarcane stem diameter. The previous study reported by Wahyuni et al. (2018) demonstrated an increase in the sugarcane height and stem diameter by 23% to 27% by treating a biostimulant consortium based on humic acid and seaweed enriched with mycorrhiza.

At nine MAP, the number of plants in the treatment and control showed a slight decrease compared to the performance at six MAP, which ranged from 17 to 19 plants (Table 8). As in the previous observation, there was no significant difference in the stem height parameter at nine MAP. Significant differences were observed in stem diameter; all treatment groups showed a higher stem diameter than the control. The highest stem diameter observed in the HpcN treatment was 28.19 mm, while in the control, it was 23.30 mm. These results indicated that the application of humic acid PSUC and PSNC, both individually and in combination, played a significant role in the growth of sugarcane stems, especially in stem diameter. Yusup et al. (2021) stated that sugarcane's stem height and diameter in the biostimulant treatment accompanied by the application of humic acid and mycorrhiza were higher than the control after commencing 6 to 12 MAP. Previous findings stated that the application of a biostimulant consortium based on humic acid and seaweed enriched with mycorrhizal bio-fertilizers could increase stem height, stem diameter, number of internodes, and stem weight at harvest by 32.2%, 5.5%, 24%, and 53.2% respectively (Amanah and Putra, 2018).

Table 7. The influence of humic acid PSUC and PSNC on the number of plants, plant height, and stem diameter at six months after planting (MAP)

Treatment	Number of plants per m	Plant height (cm)	Stem diameter (mm)
C	15.50 ± 0.50 a	6.50 ± 0.50 a	9.00 ± 0.00 a
HcU	14.50 ± 0.17 a	8.17 ± 0.17 a	6.33 ± 0.00 b
HcN	14.17 ± 0.83 a	8.33 ± 0.00 a	5.83 ± 0.83 b
HpU	14.17 ± 0.17 a	6.50 ± 1.17 a	7.67 ± 1.33 b
HpN	14.67 ± 1.33 a	6.67 ± 1.33 a	8.00 ± 2.67 b
HpcU	14.83 ± 0.50 a	7.67 ± 0.67 a	7.17 ± 1.17 b
HpcN	15.33 ± 0.33 a	7.83 ± 0.50 a	7.50 ± 0.17 b

Remarks: C= Control, HcU= liquid humic PSUC, HcN= liquid humic PSNC, HpU= Solid humic PSUC, HpN= Solid humic PSNC, HpcU= Solid humic & liquid PSUC, HpcN= Solid humic & liquid PSNC. Means followed by the same letters in the same column are not significantly different based on the Tukey test at 95% of confidence level.

During harvest, sugarcane productivity was observed by weighing the stem in the plant row sample. The results of sugarcane stem weight and brix values are presented in Table 9, while the performance of sugarcane at harvest is in Figure 2. All treatment groups showed a higher stem weight than the control. In addition, humic acid treatment, either liquid, solid, or in combination, can potentially increase the brix value. A significant difference in the brix value compared to the control occurred in the HpN and HpcU treatments, 21.79% and 21.12%, respectively, while in control, it was 18.56%. In general, treatment with humic acids PSNC (HcN, HpN, and HpcN) showed a higher increase in stem weight compared to humic acids PSUC (HcU, HpU, and HPcU). The productivity estimation of both treatment and control groups is more than 100 tons ha^{-1}, with the highest yields occurring in the HpcU and HpcN treatments (Figure 3). Yusuf et al. (2021) stated that applying a consortium of biostimulants, bio-fertilizers, and humic acids increased sugarcane's growth performance and productivity by 11.08% to 20.36%. The product

Table 8. The influence of humic acid PSUC and PSNC on the number of plants, plant height, and stem diameter at nine months after planting (MAP)

Treatment	Number of plants per m	Plant height (cm)	Stem diameter (mm)
C	18.50 ± 4.00 a	258.67 ± 25.25 a	23.30 ± 1.46 b
HcU	18.75 ± 2.75 a	280.58 ± 22.38 a	26.15 ± 2.48 a
HcN	17.25 ± 0.25 a	265.33 ± 27.28 a	27.54 ± 1.94 a
HpU	19.00 ± 0.00 a	254.67 ± 26.16 a	27.72 ± 2.49 a
HpN	17.75 ± 2.25 a	258.25 ± 20.57 a	27.92 ± 2.49 a
HpcU	17.50 ± 1.00 a	257.00 ± 26.61 a	27.90 ± 1.43 a
HpcN	19.00 ± 0.50 a	269.17 ± 14.76 a	28.29 ± 2.10 a

Remarks: C= Control, HcU= liquid humic PSUC, HcN= liquid humic PSNC, HpU= Solid humic PSUC, HpN= Solid humic PSNC, HpcU= Solid humic & liquid PSUC, HpcN= Solid humic & liquid PSNC. Means followed by the same letters in the same column are not significantly different based on the Tukey test at 95% of confidence level.

Table 9. The influence of humic acid PSUC and PSNC on stem weight and brix value at 12 months after planting (MAP)

Treatment	Brix value (%)	Stem weight per m (Kg)	Increment (%)
C	18.56 ± 1.86 c	13.92 ± 1.33 a	-
HcU	20.24 ± 1.84 abc	14.30 ± 1.05 a	6.93
HcN	19.24 ± 1.87 bc	15.38 ± 1.53 a	10.60
HpU	19.31 ± 1.30 bc	14.67 ± 0.61 a	5.41
HpN	21.79 ± 0.89 a	15.08 ± 2.02 a	8.46
HpcU	21.12 ± 1.56 ab	15.91 ± 2.31 a	14.47
HpcN	19.24 ± 0.79 bc	16.23 ± 3.42 a	16.87

Remarks: C= Control, HcU= liquid humic PSUC, HcN= liquid humic PSNC, HpU= Solid humic PSUC, HpN= Solid humic PSNC, HpcU= Solid humic & liquid PSUC, HpcN= Solid humic & liquid PSNC. Means followed by the same letters in the same column are not significantly different based on the Tukey test at 95% of confidence level.

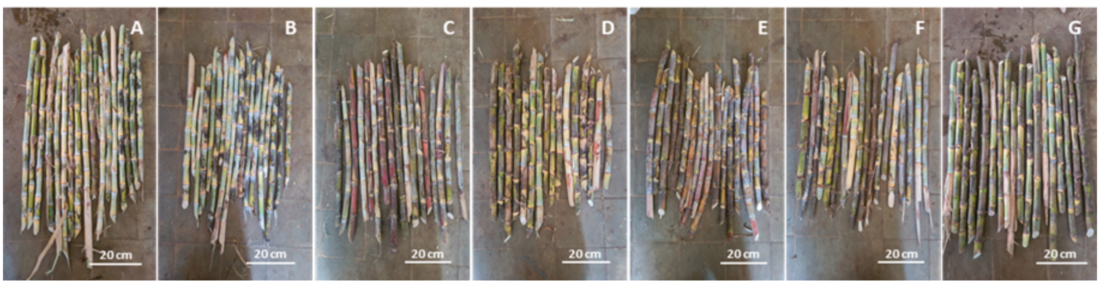

Figure 2. Sugarcane performance at harvest by humic acid PSUC and PSNC treatment

Remarks: A = Control, B = HcU, C = HcN, D= HpU, E= HpN, F= HpcU, and G= HpcN.

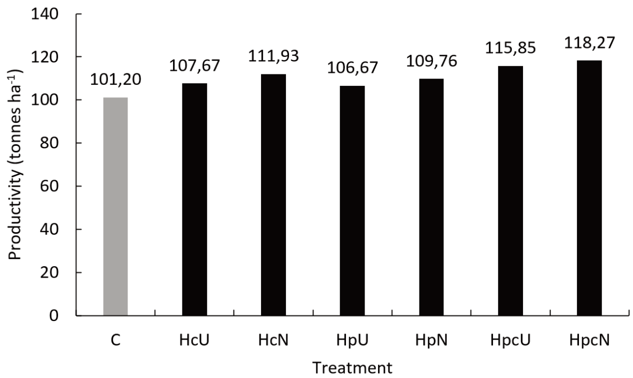

Figure 3. Sugarcane productivity potential by humic acid PSUC and PSNC treatment based on stem weight

Remarks: C= Control, HcU= liquid humic PSUC, HcN= liquid humic PSNC, HpU= Solid humic PSUC, HpN= Solid humic PSNC, HpcU= Solid humic & liquid PSUC, HpcN= Solid humic & liquid PSNC.

consortium application also increased the potential for sugar yield by 4.9% to 15.05% in three different soil typologies.

Leite et al. (2020) stated that applying humic substance, humic acid, and fulvic acid along with inorganic fertilizers had been proven to increase the growth and assimilation of essential nutrients such as N, P, and K in various plant commodities. Wulandari et al. (2019) reported that applying 15% humic acid to the total NPK fertilizer 16:16:16 (350 Kg ha^{-1}) on acidic soils significantly increased the total dry plant biomass and kernel dry weight of corn up to 13.14% and 21.81%, respectively. Applying humic acid to acidic soils can directly or indirectly support plant growth and yields due to the functional groups -COOH, -OH phenolate, and -OH alcoholate, which bind to metal ions, such as Al, and reduce hydrogen bonds, resulting in pH increments. That is followed by the availability of P, N, and other macronutrients due to increased CEC, buffering capacity, and soil microorganisms. Daur and Bakhashwain (2013) stated that applying 25 Kg ha^{-1} humic acid on saline soils could improve leaf area, dry weight, mineral content, and protein of maize 60 days after planting (DAP). That is due to the occurrence of root development, resulting in the improvement of water efficiency and nutrient uptake. However, Prakoso et al. (2020) reported that on andisol soils, the application of 5%−15% humic acid to NPK fertilizer 16:16:16 (350 Kg ha^{-1}) had the same effect as the NPK treatment without humic acid on increasing the productivity of maize, including weight of 100 seed, dry seed weight, harvest index, and length of cobs.

Effect of humic acid application on the growth and productivity of sugarcane on semi-pilot testing

Evaluation on a broader scale was carried out to validate the effect of humic acid PSUC and PSNC applications on screening scale tests. In addition, the tests carried out in three different locations (differences in technical culture) are also intended to strengthen the previous results. At one MAP, growth performance was observed through the number of shoots. Based on Table 10, it is indicated that there are variations in the number of shoots in each block. In blocks 381 and 563, an increase in the number of shoots was known in the humic acid treatment compared to the control, whereas in block 344, there was no increase compared to the control. The significantly different number of shoots compared to the control was in the humic acid PSUC treatment observed in block 381, which was 24.00 shoots, while in control, it was 18.33. Although not significantly different, an increase in the number of shoots was observed in block 563 in the humic acid PSUC and PSNC treatment groups, which were 19.67 and 17.67 shoots, respectively, while in control, it was 17.00.

Compared to one MAP, at nine MAP, a decrease in the number of plants was observed in both treatments and control, ranging from 10 to 13 plants per meter (Table 11). In blocks 344 and 563, the number of plants in the HpcU and HpcN treatments was higher than the control, although not significantly different. Regarding stem height, the humic acid application group in the three experimental blocks generally showed higher values than the control group. At the

Table 10. The influence of humic acid PSUC and PSNC on the number of plants one month after planting (MAP)

Treatment	Shoot number per m		
	Block 344	Block 381	Block 563
C	24.00 ± 1.63 a	18.33 ± 0.94 b	17.00 ± 1.41 a
HpcU	22.33 ± 0.82 a	24.00 ± 1.41 a	19.67 ± 2.05 a
HpcN	21.00 ± 3.30 a	20.33 ± 1.25 ab	17.67 ± 3.09 a

Remarks: C= Control, HpcU= Solid humic & liquid PSUC, HpcN= Solid humic & liquid PSNC. Means followed by the same letters in the same column are not significantly different based on the Tukey test at 95% of confidence level.

Table 11. The influence of humic acid PSUC and PSNC on the number of plants, plant height, and stem diameter at nine months after planting (MAP)

Block	Treatment	Number of plants per m	Plant height (cm)	Stem diameter (mm)
344	C	10.67 ± 0.42 a	295.00 ± 9.24 b	22.72 ± 0.53 b
	HpcU	13.67 ± 0.79 a	313.75 ± 3.36 a	24.26 ± 2.28 a
	HpcN	12.83 ± 0.16 a	289.38 ± 4.89 b	25.91 ± 2.29 a
381	C	11.50 ± 0.96 a	278.56 ± 18.9 a	28.02 ± 0.42 b
	HpcU	11.00 ± 1.25 a	288.39 ± 17.7 a	30.57 ± 1.35 a
	HpcN	11.00 ± 1.37 a	293.67 ± 21.4 a	30.54 ± 0.96 a
563	C	11.00 ± 0.82 a	236.94 ± 11.3 b	26.88 ± 1.01 b
	HpcU	13.33 ± 1.63 a	250.00 ± 1.78 a	28.75 ± 0.95 a
	HpcN	13.33 ± 1.78 a	238.39 ± 6.13 ab	29.92 ± 0.42 a

Remarks: C= Control, HpcU= Solid humic & liquid PSUC, HpcN= Solid humic & liquid PSNC. Means followed by the same letters in the same column are not significantly different based on the Tukey test at 95% of confidence level.

same time, HpcU treatment showed significantly different result compared to the control group (Blocks 344 and 563). Meanwhile, the stem diameter of the three experimental blocks consistently showed a significant difference compared to the control. Higher stem diameters were observed in blocks 381 and 563 for the HpcU and HpcN treatments, ranging from 28.75 mm to 30.57 mm. That was supported by a previous study, reporting that applying a biostimulant consortium based on humic acid and seaweed enriched with mycorrhiza could significantly increase the diameter of sugarcane stem compared to treatment without mycorrhiza and control (Putra et al., 2017). The application of humic acid to sugarcane plays a significant role in root growth, starting from the length, surface area, volume, and root diameter, compared to the application of L-glutamic acid and control (Civiero et al., 2013). It is suggested that humic acid alters the absorption of nutrients, water, and minerals, altering sugarcane's physiology.

At 12 MAP, the evaluation of sugarcane productivity was carried out by observing the stem weight. The performance of sugarcane at harvest in each block is presented in Figure 4. Based on Table 12, the weight of sugarcane stem either for control or treatment in block 344 was higher than in blocks 381 and 563. The stem weight of sugarcane treated by HpcU and HpcN in 3 different block experiments consistently showed higher values than controls. The increase in sugarcane productivity for the HpcU and HpcN treatments in block 344 was 19.18% and 24.26%, respectively, while in block 381, it was lower, 5.52% and 10.01%, respectively. Meanwhile, block 563 showed a higher increment than block 381, 12.53% and 21.34%, respectively. The HpcN treatment consistently showed a higher increase in productivity than HpcU. That is presumably because PSNC still contains higher micro and macronutrient residues than PSUC, thereby enriching the humic acid product. In addition, the brix values of the control and treated sugarcane in the three experimental blocks varied, ranging from 15.93% to 19.83%. In blocks 344 and 563, the brix values of the control and treated plant were not significantly different, while in blocks 381, the HpcU treated plant was significantly different from the control. This shows that applying humic acid can potentially increase sugarcane's brix value. Humic and fulvic acids are mainly produced from compounds containing N groups (nitrogenous compounds), decomposed amino acids, and complex aromatic

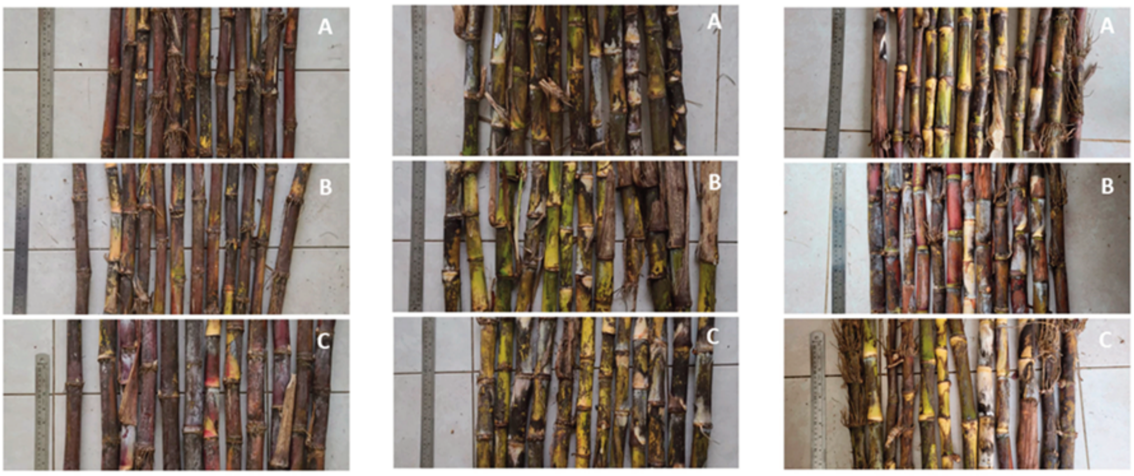

Figure 4. Sugarcane performance at harvest by humic acid PSUC and PSNC treatment at Control (A), HpcU (B), HpcN(C) in Block 344 (left), 381 (middle), and 563 (right)

Table 12. The influence of humic acid PSUC and PSNC on stem weight and brix value at 12 months after planting (MAP)

Block	Treatment	Brix value (%)	Stem weight per m (Kg)	Increment (%)
	C	17.17 ± 0.88 a	15.08 ± 1.54 a	-
344	HpcU	15.93 ± 0.87 a	17.97 ± 3.07 a	19.18
	HpcN	17.47 ± 0.25 a	18.74 ± 0.73 a	24.26
	C	17.97 ± 0.59 b	13.33 ± 0.54 a	-
381	HpcU	19.83 ± 0.34 a	14.07 ± 0.55 a	5.52
	HpcN	18.00 ± 0.44 b	14.67 ± 0.11 a	10.01
	C	18.77 ± 0.52 a	11.77 ± 1.86 a	-
563	HpcU	18.88 ± 1.46 a	13.25 ± 2.41 a	12.53
	HpcN	19.87 ± 1.07 a	14.29 ± 2.94 a	21.34

Remarks: C= Control, HpcU= Solid humic & liquid PSUC, HpcN= Solid humic & liquid PSNC. Means followed by the same letters in the same column are not significantly different based on the Tukey test at 95% of confidence level.

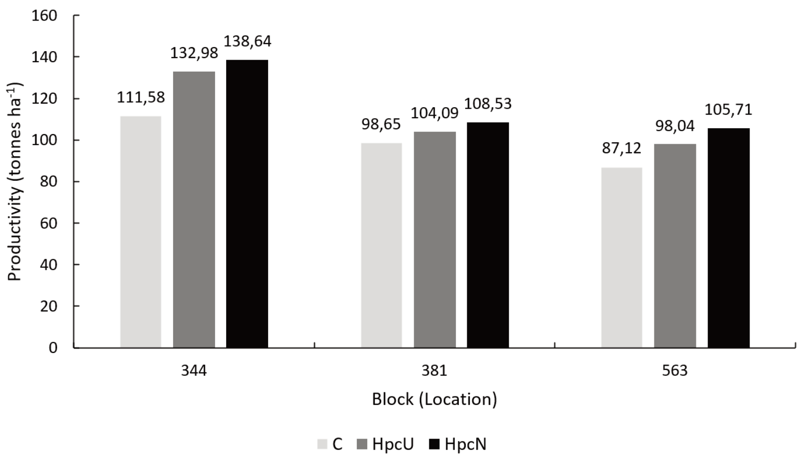

Figure 5. Comparison of potential sugarcane productivity in each block by humic acid PSUC and PSNC treatment based on stem weight

Remarks: C= Control, HpcU= Solid humic & liquid PSUC, HpcN= Solid humic & liquid PSNC.

groups. The carboxyl (-COOH) and phenolic (-OH) groups in these compounds affect soil properties and aspects of plant physiology (Khaled and Fawy, 2011).

Sugarcane stem weight was then converted to productivity on a hectare scale by multiplying the sugarcane population at plant row 1.35 m. Based on Figure 5, sugarcane productivity in the three blocks quite varied, with block 344 showing higher productivity than the other two blocks. In block 344, the productivity of sugarcane treated with HpcU and HpcN was 132.98 tons ha^{-1} and 138.64 tons ha^{-1}, while in control, it was 111.58 tons ha^{-1}. In block 381, the productivity of sugarcane treated with HpcU and HpcN was 104.09 tons ha^{-1} and 108 tons ha^{-1}, respectively. Meanwhile, in block 563, it was 98.04 tons ha^{-1} and 105.71 tons ha^{-1}, respectively. The differences in productivity of the treated sugarcane and control in each experimental block are likely due to different technical cultures, such as fertilizer doses, planting, plowing, and pest control. On the other hand, both in the screening and semi-pilot testing, the solid and liquid humic acid applied simultaneously (HpcU and HpcN treatments) showed higher productivity than individual treatments and control. Thus, it is confirmed that humic acid PSUC and PSNC can increase the growth and yield of sugarcane both in screening and semi-pilot testing.

Studies on applying biostimulants to increase sugarcane productivity have been carried out recently. Humic acid applied to leaf organs might play as a plant biostimulant, leading to increasing nutrient uptake and yield. Karthikeyan et al. (2017) used a biostimulant from Kappaphycus alvarezii seaweed extract enriched with K element to increase sugarcane productivity from PC, RC1, RC2, and RC3 each by 24.90%, 28.79%, 20.47%, and 26.16% compared to control. These results are supported by Gomathi et al. (2017), who stated that applying 1 mL L^{-1} biostimulant from seaweed extract could increase yields of sugarcane var. Co 86032 by 22.2% compared to the control, with a B/C ratio of 2.08. Another study was conducted by Silva et al. (2017) using biostimulants from PGPR (plant growth promoting rhizobacteria) formulated with humic substance to increase sugarcane productivity from PC, RC1, and RC2. The best results were obtained at 60 days after planting (DAP) per cycle, with a 37% increase in stem weight compared to the control. In RC1 and RC2, there was an increase in yields of 19% and 18%, or 11 tons ha^{-1} and 13 tons ha^{-1}, respectively. This is in line with the results of Aguiar et al. (2018), stating that the activity of plant growth-promoting bacteria (PGPB) and humic acids as biostimulants in sugarcane increases the levels of several compounds related to cell growth, such as adenine and adenosine derivatives, ribose, ribonic acid and citric acid and several compounds that correlate with stress. Yusuf et al. (2021) added that applying seaweed-based biostimulants enriched with humic acid and mycorrhizal biofertilizers in three different land typologies showed increased stem weight of 13.72%−28.57%.

Improving soil properties is vital in agricultural development, which leads to increased crop productivity. In contrast, soil conditions unsuitable for plant development generally result from a lack of organic matter. On the other hand, changes in environmental conditions, such as soil pH, sandy soil, low organic matter, drought, and rain intensity, have impacted nutrient deficiencies in sugar production to become more extreme (Saleem et al., 2012; Dawar et al., 2011). The application of humus to the soil increases N uptake in corn plants, while the application of humic acid increases the uptake of P, K, Mg, Na, Cu, and Zn (Khaled and Fawy, 2011). Alternative methods by utilizing humic substances are up-and-coming for improving nutrient use efficiency in sugarcane, reducing fertilizer costs, optimizing assimilation, faster physiological response in plants, and ultimately resulting in increasing the economic sustainability of farmers and reducing the use of inorganic fertilizers and environmental pollution (Leite et al., 2020). Aziz et al. (2022) reported that NPK by-product (PSNC) contained higher macronutrients than urea by-product (PSUC), including N, P, and K, 3.66%, 356.80 ppm, and 1.76%, respectively. Based on the study, the humic acid PSNC application indicated a better effect. It becomes an excellent product to increase nutrient use efficiency, improve soil character, and increase crop yields in sugarcane.

CONCLUSIONS

Application of humic acid PSUC and PSNC was shown to increase shoot growth, number of segmented stems, and diameter of sugarcane stems. In addition, increases in sugarcane productivity by 19.18% and 24.26% were observed in humic acid PSUC and PSNC treatments, respectively, using the combination of solid and liquid product prototypes in semi-pilot testing. However, humic acid PSNC showed a better effect, potentially increasing the growth and productivity of sugarcane. In future studies, it is necessary to evaluate the effect of humic acid PSNC on improving soil fertility and nutrient uptake efficiency in sugarcane.

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