



Growth Responses of Sugarcane (*Saccharum officinarum* L.) Ratoon Cane to Vegetative Phase and Sugarcane Formula Fertilizer in Inceptisol

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Abstract

Sugar demand is rising with population growth, and although sugar production increased from 2018 to 2022, it has not met national demand. To boost national sugar production, proper fertilizer management is crucial. By calculating and applying compound fertilizer formulations tailored to the specific needs of sugarcane, fertilization efficiency, productivity, and sugar yield can be enhanced. This research aimed to evaluate the performance of morphological characteristics of ratoon sugarcane in response to NPK nutrient management using specific fertilizer formulations. The field study was conducted in Sleman, Special Region of Yogyakarta, from September 2023 to December 2024. The experiment was arranged in a randomized complete block design (RCBD) with three treatments, consisting of NPKSZn (15-15-15-9-0.2) at 400 kg ha⁻¹ + ZA (21N-24S) at 600 kg ha⁻¹ (control); NPKS (14-9-18-4) at 1000 kg ha⁻¹ (Formulation 1); and NPK (23-7-14) at 1000 kg ha⁻¹ (Formulation 2), and four blocks as replications. The collected data were analyzed using Analysis of Variance (ANOVA) at a 5% significance level, followed by the Least Significant Difference (LSD) test at $\alpha = 5\%$ to determine the most effective fertilizer formulation. The results showed that the application of these fertilizer formulations significantly affected stalk diameter, millable cane yield and brix content. These findings highlight the importance of synchronized vegetative phase fertilization to optimize ratoon cane growth and support sustainable sugarcane production in Inceptisol soils.

INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) is a key industrial crop in Indonesia, serving as the main source of White Crystal Sugar (WCS). Globally, it is among the most productive sugar-producing plants, particularly in Brazil, India, China, and Australia (FAO, 2022). Sugarcane thrives in tropical regions and has the potential for high yields (Budi and Laliyah, 2023). This plant can accumulate high amounts of sucrose because it is a C4 plant, which efficiently utilizes natural resources and yields products like sucrose (Khan et al., 2022). Despite its potential, Indonesia's sugarcane production has fluctuated in

the past five years. In 2022, WCS output reached 2.4 million tons from 488,982 ha, an increase of 2.34% from 2021 (Directorate General of Plantations, 2023), but still below national demand.

In Indonesia, ratoon cane cultivation is widely adopted due to its economic advantages. Ratoon crops regenerate from the stubble of harvested plants, reducing costs for land preparation, seed procurement, and early management while allowing faster canopy closure and earlier maturity compared to plant cane (Bonnett, 2013; Xu et al., 2021). Sugarcane is a high-yielding crop, requiring substantial nutrients as mineral elements constitute 3–5% of its dry matter (Sanches et al., 2021), making nutrient management



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critical to sustaining productivity.

Inceptisols are relatively young soils with weakly developed horizons and widely distributed in tropical regions. In Indonesia, Inceptisols cover a considerable land area and are commonly used for agricultural production, including sugarcane cultivation. Although these soils have good physical properties and are relatively easy to cultivate, their chemical fertility is generally low to moderate, with limited availability of essential nutrients, such as nitrogen (N), phosphorus (P), and potassium (K). Therefore, appropriate soil fertility management is required to optimize crop productivity in Inceptisol soils (Rahmayuni et al., 2023). Due to these limitations, fertilization becomes a key management practice to supply nutrients that are insufficiently available in the soil.

Sugarcane is a nutrient-demanding crop that requires large amounts of macronutrients, particularly nitrogen, phosphorus, and potassium, to support vegetative growth, stalk formation, and sugar accumulation. Nitrogen plays an important role in promoting vegetative growth and leaf development, phosphorus supports root development and energy transfer processes, while potassium is essential for sugar translocation, stalk strength, and overall crop productivity (Chandrakar et al., 2018). However, the availability of these nutrients in many Inceptisol soils is often insufficient to meet crop demand, making external nutrient inputs through fertilization necessary (Chairuman et al., 2023; Herawati and Syafruddin, 2024).

Fertilizer application should be based on both crop nutrient requirements and soil nutrient availability to ensure efficient nutrient use and optimal crop yields. Sugarcane removes substantial amounts of N, P, and K from the soil during growth and harvest, which must be replenished to maintain soil fertility and productivity (Cherubin et al., 2019). However, many sugarcane farmers still rely on conventional fertilizer practices, typically applying NPK (15-15-15) combined with ZA (21N-24S), without considering soil nutrient status. Such practices may lead to nutrient imbalances, inefficient fertilizer use, and reduced crop productivity (Weil and Brady, 2017; Bado and Bationo, 2018).

One approach to improve fertilizer efficiency and crop performance is the use of sugarcane-specific compound fertilizers formulated according to crop nutrient requirements. These fertilizers are designed to provide balanced nutrients tailored to the

physiological needs of sugarcane at different growth stages. By supplying nutrients in appropriate proportions, compound fertilizer formulations can improve nutrient uptake efficiency, reduce nutrient losses, and support better plant growth and sugar yield (Jana et al., 2024). Therefore, evaluating the performance of different NPK-based fertilizer formulations on ratoon sugarcane grown on Inceptisol soils is important to identify fertilization strategies that can enhance productivity and contribute to sustainable sugarcane production.

MATERIALS AND METHODS

The research was conducted from September 2023 to December 2024. The field experiment was conducted in Planden Hamlet, Sendangrejo Village, Minggir District, Sleman Regency, Special Region of Yogyakarta, Indonesia, located at approximately 7°42'42" S latitude and 110°16'34.7" E longitude. Laboratory analyses were conducted at the Laboratory of the Agency for the Assessment and Application of Agricultural Technology and the Crop Production Management Laboratory (Plant Science sub-laboratory) at the Faculty of Agriculture, Universitas Gadjah Mada, Yogyakarta. Laboratory activities included the analysis of soil physical and chemical properties, sugarcane morphology, and sugarcane biomass.

The field experiment investigated the impact of different NPK fertilizer formulations on sugarcane, with a specific focus on ratoon cane. The research was arranged in a Randomized Complete Block Design (RCBD) with four blocks as replications to ensure robust data. The study was conducted in an existing ratoon cane field, utilizing Bululawang (BL) sugarcane variety. The three NPK fertilizer formulations consisted of the existing/control NPKSzn (15-15-15-9-0.2) at 400 kg ha⁻¹, supplemented with ZA (21 N - 24 S) at 600 g ha⁻¹; NPKS (14-9-18-4) formulation at 1000 g ha⁻¹ (Formulation 1); and another NPK (23-7-14) formulation also at 1000 kg ha⁻¹ (Formulation 2). Fertilizer for all treatments was applied precisely at one and three months after ratooning.

Data were collected from leaf and soil samples taken from each treatment plot. Three individual sampling points for both leaves and soil were taken from each plot. These individual samples were then combined to create a single composite sample for leaves and another for soil. Soil samples were collected twice: before and after fertilizer application.

Environmental and soil conditions during sampling were measured using a thermohygrometer, a Benetech GM1010 digital lux meter, and a YY-1000 soil EC moisture meter. Leaf samples were taken after fertilizer application. Growth parameters were observed monthly from each experimental unit, including stalk length, stalk diameter, and plant population. Stalk length was measured using a measuring tape, stalk diameter was measured using a caliper, and plant population was recorded using a counter. Harvest data were collected using a 2 × 10 m sampling area within each experimental unit to determine estimated yield, brix, fresh weight, and dry weight of the plants. Measurements were carried out using a measuring tape, refractometer, digital scale, and oven. The collected data, encompassing soil properties, leaf tissue nutrient content, sugarcane growth characteristics, and harvest data, were subjected to Analysis of Variance (ANOVA) followed by the Least Significant Difference (LSD) test at $\alpha = 5\%$. All data were analyzed using R Studio.

RESULTS AND DISCUSSION

Soil Chemical Properties

Soil chemical properties are influenced by various environmental and other factors. Inceptisol, characterized by its relatively young development, is commonly found across diverse agricultural landscapes.

This soil type exhibits a range of physical and chemical properties that can be shaped by factors, such as slope, depth, and land use (Tarigan et al., 2018). The initial soil pH at the research site was 6.65 (Table 1), classifying it as neutral to slightly acidic. After fertilizer application, the pH shifted slightly to a range of 6.22–6.48, still remaining within the neutral to slightly acidic category. This finding aligns with Damanik et al. (2011), who describe Inceptisol reactions as ranging from acidic to slightly acidic (pH 4.6–5.5) and slightly acidic to neutral (pH 5.6–6.8). Furthermore, the organic carbon (organic C) level at the research location was already relatively high, at 1.44%, prior to treatment. Following fertilizer application, the organic C levels showed a further increase, ranging from 1.56% to 1.78%. This consistently high organic C level, both before and after treatment, is significantly higher than the 1.2% threshold considered high by Hardjowigeno (2003).

Initial potential available nitrogen (N) was high at 0.62 me% (Table 1). After fertilizer application, Formulation 2 (NPK 23-7-14) resulted in significantly higher available N compared to Formulation 1 (NPKS 14-9-18-4). This difference aligns with the applied fertilizer dosages, as Formulation 2 delivered a higher nitrogen composition (230 kg N.ha⁻¹) compared to Formulation 1 (140 kg N.ha⁻¹). In the dynamics of paddy soils, specifically Inceptisols, ammonium (NH₄⁺) concentrations tend to be higher than nitrate (NO₃⁻) after fertilization. This phenomenon

Table 1. Soil chemical properties at initial condition and one month after the second fertilizer application

Variable	Early Soil Chemical Properties	Soil Chemical Properties One Month after the Second Fertilizer Application			
		Control	Formulation 1	Formulation 2	CV (%)
pH H ₂ O	6.65	6.48 a	6.45 a	6.22 a	3.06
Organic C (%)	1.44	1.56 a	1.67 a	1.78 a	9.02
Potential N (me%)	0.62 **	-	-	-	-
Available NH ₄ ⁺ (%)	-	25.18 ab	22.76 b	28.88 a	7.54
Available NO ₃ ⁻ (%)	-	17.92 b	14.20 b	23.58 a	12.15
Available P (mg.kg ⁻¹)	105.90 ****	22.98 a	28.59 a	24.21 a	11.79
Available K (cmol.kg ⁻¹)	0.76 **	0.40 b	0.46 a	0.42 ab	4.48
Available S (mg.kg ⁻¹)	28.86 **	50.86 a	37.53 ab	26.44 b	19.44
Available Zn (mg.kg ⁻¹)	3645.00 *	1.93 a	1.79 a	1.45 a	11.56

Remarks: *, **, *** indicate moderate, high, and very high rating categories, respectively, based on Soil Research Center (2023).

Means within a row followed by the same letters are not significantly different according to LSD at $\alpha = 5\%$.

Control/existing = 400 kg.ha⁻¹ NPKSZn (15-15-15-9-0,2) + 600 kg.ha⁻¹ ZA (21 N - 24 S);

Formulation 1 = 1000 kg ha⁻¹ NPKS (14-9-18-4); and Formulation 2 = 1000 kg.ha⁻¹ NPK (23-7-14).

is primarily attributed to the soil's clay texture and high cation exchange capacity (CEC), which enable greater temporary retention of NH_4^+ (Mulyani et al., 2001). Initial available phosphorus (P) was very high, at 105.9 mg kg^{-1} (Table 1). However, there was no significant difference in P levels among treatments after fertilizer application. The decrease in available P after fertilization was likely caused by intensive plant uptake during sugarcane growth and by P fixation with Fe and Al oxides in the soil, which converts soluble P into less available forms (Jayadi et al., 2023).

Available potassium (K) was initially high at $0.76 \text{ cmol kg}^{-1}$ (Table 1). After fertilizer application, Formulation 1 (NPKS 14-9-18-4) resulted in significantly higher available K compared to the control, but did not differ significantly from Formulation 2 (NPK 23-7-14). This increase was closely related to the amount of K applied in each formulation. Formulation 1 supplied the highest potassium input (180 kg K ha^{-1}), which was three times higher than the control (60 kg K ha^{-1}), resulting in greater K availability. Formulation 2 also provided a relatively high potassium input (140 kg K ha^{-1}), explaining why the available K remained higher than the control. Potassium in soil is mainly present as exchangeable K on the surface of clay minerals and organic matter; therefore, higher K inputs can increase this pool. However, part of the applied K may also be absorbed by plants or temporarily retained on soil exchange sites. Due to its high solubility, K is susceptible to leaching, particularly in coarse-textured soils with low CEC (Xu et al., 2020).

Initial available sulfur (S) was high (Table 1). Following fertilizer application, the S level in the control treatment was significantly higher than in Formulation 2. This aligns with the applied dosages,

as the control treatment supplied 180 kg S ha^{-1} , whereas Formulation 2 supplied no sulfur (0 kg S ha^{-1}). After treatment, particularly in the control and Formulation 1, the available S level increased from the initial value of 28.86 mg.kg^{-1} . This increase is attributed to the addition of sulfur from the fertilizers, which may have stimulated microbial activity and accelerated the mineralization of organic sulfur into plant-available sulfate (Lisowska et al., 2023). Initial available zinc (Zn) was adequate, at 3.64 mg kg^{-1} (Table 1). Initial available zinc (Zn) was adequate, at 3.64 mg kg^{-1} (Table 1). After fertilizer application, there was no significant difference in Zn level across all treatments, and it decreased compared to initial levels. This decrease could be due to plant uptake or potentially to antagonistic effects from high phosphorus (P) application, which can lead to Zn-P precipitation and inhibit Zn availability and uptake (Recena et al., 2021).

Sugarcane Nutrient Uptake

Nutrient uptake by plant tissues reflects the plant's ability to utilize available nutrients in the soil. Nitrogen uptake is particularly active during the vegetative growth phase, specifically during shoot development and stalk elongation, approximately 2–3 months after ratooning. Nitrogen absorption in plants primarily occurs through the uptake of nitrate (NO_3^-) and ammonium (NH_4^+). Nitrogen uptake showed no significant difference among treatments, with values of $3.41 \text{ g plant}^{-1}$ for Formulation 1 (NPKS 14-9-18-4), $3.29 \text{ g plant}^{-1}$ for the control (NPKSZn 15-15-15-9-0.2 + ZA 21N-24S), and $2.92 \text{ g plant}^{-1}$ for Formulation 2 (NPK 23-7-14) (Table 2). The sufficient N uptake indicates optimal N availability in the soil and effective absorption by the plant, supporting healthy leaf and stalk formation. According to Havlin

Table 2. Sugarcane nutrient uptake

Variable	Nutrient Uptake			
	Control	Formulation 1	Formulation 2	CV (%)
N uptake (g.plant^{-1})	3.29 a	3.41 a	2.92 a	10.37
P uptake (g.plant^{-1})	1.00 b	1.26 a	0.93 b	3.75
K uptake (g.plant^{-1})	4.85 a	5.30 a	4.25 b	5.37
S uptake (g.plant^{-1})	2.63 a	3.12 a	2.26 a	9.30 *
Zn uptake (g.plant^{-1})	5.15 a	4.64 a	3.42 a	18.57

Remarks: Means within a row followed by the same letters are not significantly different according to LSD test at $\alpha = 5\%$. The (*) indicates transformed data. Control = 400 kg.ha^{-1} NPKSZn (15-15-15-9-0,2) + 600 kg.ha^{-1} ZA (21 N - 24 S); Formulation 1 = 1000 kg.ha^{-1} NPKS (14-9-18-4); and Formulation 2 = 1000 kg.ha^{-1} NPK (23-7-14).

et al. (2014), soil nitrogen availability significantly affects uptake efficiency by plants; if soil nitrogen levels are already sufficient, additional fertilizer application may not result in significant differences.

Plants absorb phosphorus (P) as H_2PO_4^- and HPO_4^{2-} through phosphate dissolution. Phosphorus is vital for plant growth, particularly in root formation, cell division, and energy metabolism (ATP and ADP), which support photosynthesis and sucrose biosynthesis. Tissue analysis showed a significant treatment effect on phosphorus uptake (Table 2). Formulation 1 recorded the highest value at $1.26 \text{ g plant}^{-1}$, which was significantly higher than both the control ($1.00 \text{ g plant}^{-1}$) and Formulation 2 ($0.93 \text{ g plant}^{-1}$). Formulation 1 significantly boosted phosphorus absorption efficiency, which is critical for root growth and cell division. This increased uptake directly correlates with the amount of P available in the soil. Additionally, soil organic matter enhances P availability by improving soil properties, keeping P in a more accessible form, and increasing soil pH (Soares et al., 2021).

Potassium (K) uptake in sugarcane is crucial and typically higher than that of nitrogen (N) and phosphorus (P). Plants absorb potassium as K^+ ions through diffusion from the soil solution into the roots. Potassium is vital for sugarcane growth and biomass accumulation because it regulates stomatal opening, maintains cell turgor, and enhances photosynthesis (Mualif & Kusumawati, 2021). Tissue analysis showed a significant impact on potassium uptake (Table 2). The highest values were observed in Formulation 1 ($5.30 \text{ g plant}^{-1}$) and control ($4.85 \text{ g plant}^{-1}$), both significantly different from Formulation 2 ($4.25 \text{ g plant}^{-1}$). This indicates that the plants were able to absorb sufficient amounts of K. This condition may be related to nutrient balance and interaction among nutrients in the fertilizer formulations. The control treatment contained not only NPKSZn fertilizer but also ZA fertilizer, which supplied additional nitrogen and sulfur that could enhance root growth and nutrient absorption efficiency. Adequate nitrogen availability stimulates vegetative growth and increases the plant's ability to absorb other nutrients, including potassium. In contrast, Formulation 2 contained a relatively high nitrogen concentration (23%) but lower sulfur input, which may have affected nutrient balance and uptake efficiency. Furthermore, excessive nitrogen availability can sometimes lead to nutrient imbalance and reduce the efficiency of potassium utilization by plants. The

study also confirmed that a higher concentration of K in the soil solution leads to greater K absorption by sugarcane plants. The availability of K in the soil is influenced by soil chemical properties and the potassium saturation level (Elephant et al., 2023).

Sulfur (S) plays a crucial role in chlorophyll production, protein synthesis, and overall plant metabolism. Plants primarily absorb sulfur in the form of sulfate (SO_4^{2-}). Sulfur uptake did not differ significantly across treatments, with values ranging from $2.26 \text{ g plant}^{-1}$ in Formulation 2 to $3.12 \text{ g plant}^{-1}$ in Formulation 1 (Table 2). This indicates that the plants were able to absorb sufficient amounts of sulfur, which is essential for the synthesis of amino acids and plant proteins. Sulfur is a vital component of various important biological molecules, including protein-building amino acids like methionine and cysteine, as well as other critical compounds, such as glutathione, vitamins (biotin and thiamine), phytochelators, chlorophyll, coenzyme A, and S-adenosyl-methionine (Narayan et al., 2023).

Zinc (Zn) uptake in plants is a continuous process, involving the absorption of Zn from both fertilizers and the soil. Plants primarily absorb Zn as Zn^{2+} ions from the soil solution through their roots, which are then transported to other parts of the plant. Zinc uptake did not differ significantly across treatments, with values of $5.15 \text{ mg plant}^{-1}$ for the control, $4.64 \text{ mg plant}^{-1}$ for Formulation 1, and $3.42 \text{ mg plant}^{-1}$ for Formulation 2 (Table 2). While Zn uptake did not vary significantly across treatments, its availability was sufficient. Although applying zinc fertilizer generally increases Zn concentration in plant tissues, this rise does not always directly correlate with an increase in the plant's dry biomass. This suggests that plants can accumulate more Zn than they actually need for normal vegetative growth (Juliati, 2008).

Effect of NPK fertilizer formulation on sugarcane growth

The morphology, or external physical appearance, of a sugarcane plant is a result of the intricate interplay between its genetic factors and environmental conditions. Optimal morphological growth heavily relies on the availability of essential macro-nutrients like nitrogen (N), phosphorus (P), and potassium (K), as well as micro-nutrients such as zinc (Zn) and sulfur (S). In sugarcane, growth represents the accumulated

Table 3. Effect of NPK fertilizer formulation on sugarcane growth

Variable	Sugarcane growth			CV (%)
	Control	Formulation 1	Formulation 2	
Stalk length (cm)	213.17 a	217.33 a	207.03 a	3.72
Stalk diameter (cm)	2.60 ab	2.72 a	2.53 b	2.62
Plant population	137.41 a	142.08 a	131.83 a	3.70

Remarks: Means within a row followed by the same letters are not significantly different according to LSD test at $\alpha = 5\%$.

Control/existing = 400 kg.ha⁻¹ NPKSZn (15-15-15-9-0,2) + 600 kg.ha⁻¹ ZA (21 N - 24 S);

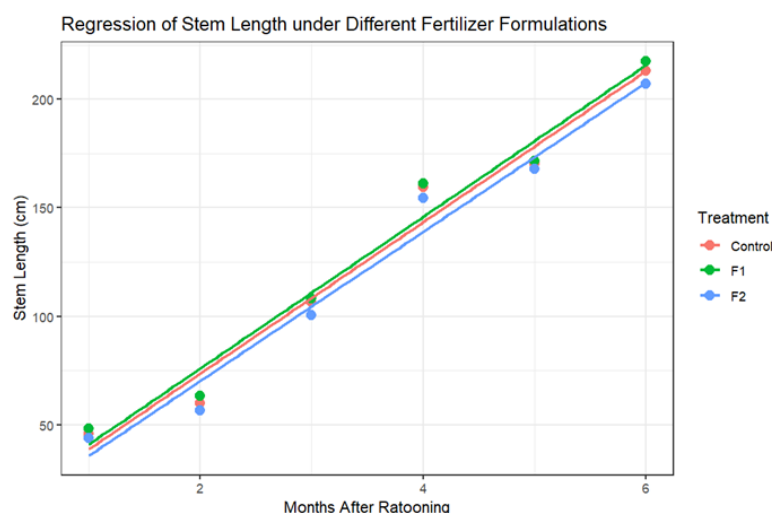
Formulation 1 = 1000 kg.ha⁻¹ NPKS (14-9-18-4); and Formulation 2 = 1000 kg.ha⁻¹ NPK (23-7-14).

outcome of various integrated physiological processes, including photosynthesis, respiration, cell division, and nutrient uptake. These processes are highly dependent on both the environment and agronomic management, especially fertilization. Proper and balanced fertilization can stimulate cell division and elongation, increase tissue volume, and enhance photosynthetic efficiency. This directly promotes the overall morphological development of the plant.

Observations over a six-month period revealed an increasing trend in stalk length across all treatments (Figure 1). While there was no statistically significant difference in stalk length across the treatments, Formulation 1 consistently showed a tendency toward longer stalks compared to both the control and Formulation 2. This suggests that Formulation 1 is more effective in supporting optimal stalk growth. The distinct composition of nutrients in Formulation 1, particularly its higher potassium content, is a key factor driving this increased stalk length. Potassium plays a vital role in water transport, protein synthesis, and cell division by regulating cell turgor pressure, which promotes cell enlargement and stalk internode elongation (Sustr et al., 2019).

Fertilizer formulations significantly impacted sugarcane stalk diameter, which showed an increasing trend over the six-month observation period (Figure 2). Sugarcane plants treated with Formulation 1 developed significantly wider stalk diameters compared to both the control and Formulation 2. The superior performance of Formulation 1 can be attributed to its balanced nutrient composition, particularly its high potassium and substantial phosphorus content. These nutrients are crucial for the formation of vascular tissues and the strengthening of cell walls. A high potassium status, as noted by Adjie et al. (2024), can increase cell wall thickness and stalk diameter, leading to a more robust stalk. Furthermore, Rianditya and Hartatik (2020) highlight the vital role of phosphorus in cell growth and the division of meristematic tissues in the stalk.

Plant population density at six months was not significantly affected by the fertilizer treatments. Populations were uniform across all treatments in September, but increased significantly from October to November, peaking in November before gradually declining from December to February (Figure 3).

**Figure 1.** Stalk length of sugarcane plants under control, Formulation 1, and Formulation 2 treatments

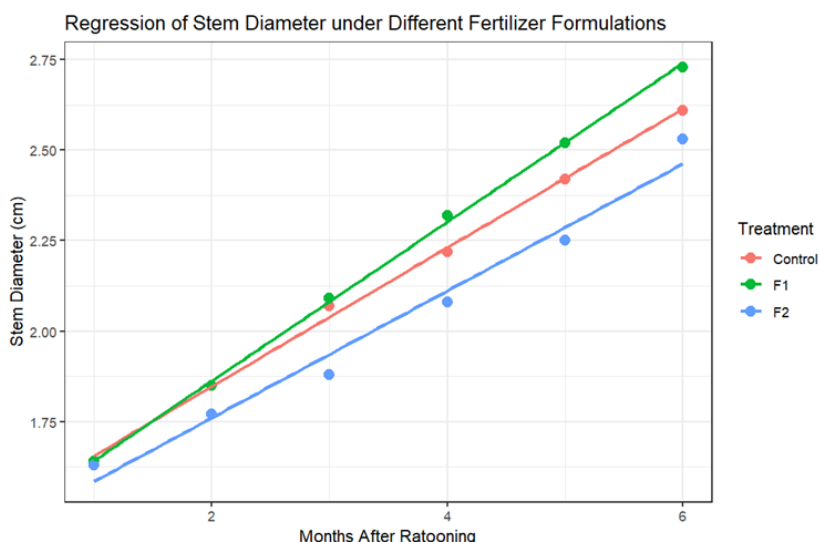


Figure 2. Stalk length of sugarcane plants under control, Formulation 1, and Formulation 2 treatments

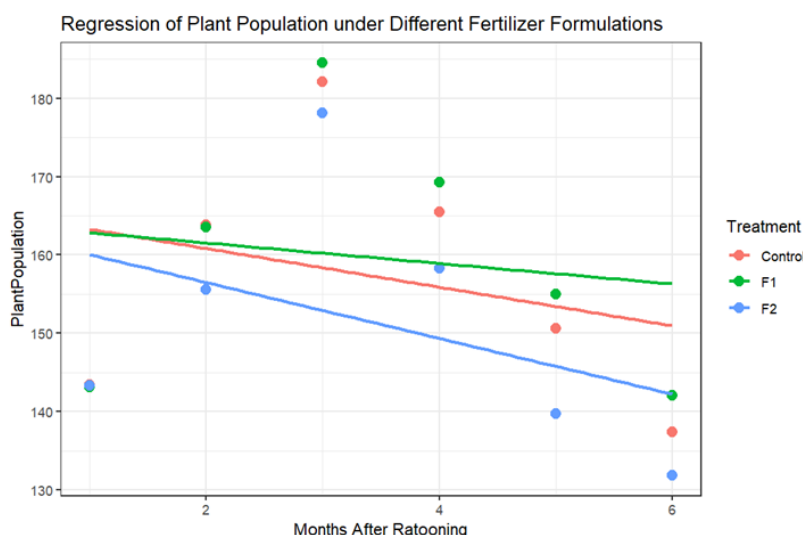


Figure 3. Plant population of sugarcane under control, Formulation 1, and Formulation 2 treatments

Overall, sugarcane plants treated with Formulation 1 tended to have a higher population count compared to those treated with control treatment and Formulation 2, although this difference was not statistically significant. This suggests that the more balanced and effective nutrient composition of Formulation 1 played a role. According to Diana et al. (2016), sugarcane plant populations per meter typically increase up to three months after planting. However, a subsequent decline in population and tiller mortality can be attributed to several factors. These include nutrient competition among plants, mechanical damage, pest infestations, and reduced light penetration due to increasingly dense plant canopies.

Sugarcane yield

Sugarcane productivity is highly dependent on effective fertilization during its growth phases, which is a crucial factor in yield estimation. Low sugarcane productivity is often linked to nutrient deficiencies, as sugarcane is a crop that absorbs a large quantity of nutrients from the soil (Benett et al., 2013). Two primary parameters used to evaluate yield are estimated fresh biomass yield (t ha^{-1}) and brix content, which indicates the concentration of total dissolved solids, primarily sugar, in the juice. Furthermore, stalk weight has a strong positive correlation in determining sugarcane productivity (Tyagi et al., 2013).

Table 4. Projected milled sugarcane yield and brix of sugarcane under control, Formulation 1, and Formulation 2 treatments

Variable	Sugarcane yield			CV (%)
	Control	Formulation 1	Formulation 2	
Harvest estimation (t ha ⁻¹)	74.07 ab	78.50 a	67.38 b	6.29
Brix	8.04 b	10.16 a	7.37 b	11.15

Remarks: Means within a row followed by the same letters are not significantly different according to the LSD test at $\alpha = 5\%$.

Control = 400 kg ha⁻¹ NPKSZn (15-15-15-9-0.2) + 600 kg ha⁻¹ ZA (21N-24S);

Formulation 1 = 1000 kg ha⁻¹ NPKS (14-9-18-4); and Formulation 2 = 1000 kg ha⁻¹ NPK (23-7-14).

Analysis of variance showed that fertilizer treatments significantly affected estimated yield (Table 4). Although Formulation 1 produced the highest projected millable cane yield (78.5 t ha⁻¹), it was not significantly different from that in the control (74.07 t ha⁻¹) based on the LSD test. This indicates that both treatments performed similarly in terms of yield, and both significantly outperformed Formulation 2 (67.38 t ha⁻¹). Therefore, further consideration regarding fertilizer cost and farmer profitability is necessary to determine the most practical fertilization strategy. The higher yield tendency in Formulation 1 can be attributed to its balanced nutrient supply, particularly its high potassium and phosphorus content. Potassium is known to play a role in transporting photosynthates to the stem, increasing stem diameter, and enhancing cell turgor, which supports stem growth (Yang et al., 2003). Meanwhile, phosphorus is crucial for ATP formation, which supports stem tissue growth and differentiation. The lower yield observed in Formulation 2, despite its high nitrogen dose (230 kg ha⁻¹), might be due to nutrient imbalance, specifically the absence of sulfur and zinc, which are vital for plant metabolism. Excessive nitrogen application without balancing other essential elements can lead to overly vigorous vegetative growth that is not efficient in forming economic yields (Alloway, 2008).

Analysis of variance also showed that fertilizer treatment significantly affected brix values (Table 4). The higher brix content observed in Formulation 1 reflects successful sucrose accumulation, largely attributed to its higher potassium dosage (180 kg ha⁻¹). Potassium plays a vital role in the transport and accumulation of sugars from leaves to stems, as well as maintaining osmotic balance crucial for sucrose filling in the stalks (Bharathi et al., 2022). Conversely, the lower brix content in Formulation 2 is linked to its high nitrogen dosage, which may have

an antagonistic effect on sugar accumulation. Excess nitrogen can promote vegetative growth at the expense of carbohydrate accumulation, and the resulting nutrient surplus may also limit the availability of micronutrients like zinc, which is essential for photosynthetic enzyme activity and sucrose synthesis (Alloway, 2008).

CONCLUSIONS

The compound fertilizer with nutrient composition of NPKS 14-9-18-4 at a rate of 1000 kg ha⁻¹ is the recommended formulation for sugarcane grown in Inceptisols in Seyegan, Sleman. The application of this fertilizer formulation significantly increased stalk diameter, leading to significant increases in sugarcane yield and brix at six months after ratooning.

REFERENCES

- Adji, I.S., Susila, A.D., dan Purnamawati, H. (2024). Pengaruh Kandungan P dan K Tanah terhadap Pertumbuhan dan Hasil Tanaman Tomat (*Lycopersicon esculentum*) pada Tanah Andisol. Buletin Agrohorti, 12(3): 327-335. <https://doi.org/10.29244/agrob.v12i3.54543>
- Alloway, B. J. (2008). Soil factors associated with zinc deficiency in crops and humans. Environmental Geochemistry and Health, v.31, n.5, p.537-548. <http://dx.doi.org/10.1007/s10653-009-9255-4>
- Anbarasan, S., and Ramesh, S. (2021). The Role of Plant Roots in Nutrient Uptake and Soil Health. Plant Science Archives, 6(1): 05-08. DOI: <https://doi.org/10.51470/PSA.2021.6.1.05>
- Assagaf, S.A. (2017). Pengaruh pemberian pupuk NPK Mutiara terhadap pertumbuhan dan produksi tanaman jagung (*Zea Mays* L.) di Desa Batu Boy Kec. Namlea Kab. Buru Said. Agrikan, 10(1):72-78.
- Bado, V. B., & Bationo, A. (2018). Integrated Management of Soil Fertility and Land Resources in Sub-Saharan

- Africa: Involving Local Communities. *Advances in Agronomy*, 150, 1-33. <https://doi.org/10.1016/bs.agron.2018.02.001>
- Balemi T, and Negisho, K. (2012). Management of soil phosphorus and plant adaptation mechanisms to phosphorus stress for sustainable crop production: a review. *Journal of Soil Science and Plant Nutrition*, 12 (3):547-562.
- Budi, S., dan Laliyah, W. N. (2023). Growth and Production Performance of Sugarcane (*Saccharum officinarum* L.) Clon SB 01, SB 04, sb 19, SB 20 in the Village Curahmalang, Jombang Regency. *KONTRIBUSIA*, 6 (1): 134-144.
- Bonnett, M. (2013). Sustainable development, environmental education, and the significance of being in place. *The curriculum journal*, 24(2):250-271.
- Chairuman, N., Batubara, S., Aryati, V., Siagian, D. R. (2023). Enhancing the maize growth and production by applying the phosphorus and potassium nutrients in inceptisol of Langkat Regency. *IOP Conference Series: Earth and Environment*. doi:10.1088/1755-1315/1172/1/012042
- Chandrakar, K., Verma, S. K., Kesari, R., and Dubey, S. (2018). Assessment of macronutrients and soil fertility status of an Inceptisol: A review. *International Journal of Chemical Studies*, 6(4): 3216-3222.
- Damanik, M.M.B., E.H. Bachtiar., Fauzi., Sarifuddin dan H. Hamidah. (2011). *Kesuburan Tanah dan Pemupukan*. USU Press, Medan.
- Diana, N. E., Supriyadi., & Djumali. (2016). Pertumbuhan, Produktivitas, dan Rendemen Pertanaman Tebu Pertama (Plant Cane) Pada Berbagai Paket Pemupukan. *Jurnal Ilmu Pertanian Indonesia*, 21(3), 159-166. <https://doi.org/10.18343/jipi.21.3.159>
- Elephant, D. E., Miles, N., & Muchaonyerwa, P. (2023). Effect of Potassium Application Rates on Sugarcane Yield in Soils with Different Non-Exchangeable Potassium Reserves and Fixation Capacity. *Agronomy*, 13(8), 1969. <https://doi.org/10.3390/agronomy13081969>
- Fageria, N.K., Slaton, N., and Baligar, V. (2003). Nutrient Management for Improving Lowland Rice Productivity and Sustainability. *Advances in Agronomy*. 80: 63-152. 10.1016/S0065-2113(03)80003-2.
- FAO, (2022). Key facts of the economic dimension of the Statistical Yearbook of World Food and Agriculture 2022.
- Fathin, S. L., Purbajanti, E. D., dan Fuskhah, E. (2019). Pertumbuhan dan hasil Kailan (*Brassica oleracea* var. Alboglabra) pada berbagai dosis pupuk kambing dan frekuensi pemupukan Nitrogen. *Jurnal Pertanian Tropik*, 6 (3):438-448.
- Hardjowigeno, S., (2003). *Ilmu Tanah*. Penerbit Akademika Pressindo. Jakarta.
- Havlin, J.L., Beaton, J.D., Tisdale, S.L. and Nelson, W.L. (2014). *Soil Fertility and Fertilizers. An Introduction to Nutrient Management*. New Jersey: 6th Edition, Prentice Hall, Upper Saddle River
- Heldt, H.W., and Piechulla, B. (2011). Phloem transport distributes photoassimilates to the various sites of consumption and storage (pp. 337–348). <https://doi.org/10.1016/B978-0-12-384986-1.00013-2>
- Herawati and Syafruddin. (2024). Determination of potassium fertilizer requirement for maize hybrid in inceptisol soil. *AIP Conference Proc.* 6 February 2024; 2957 (1): 040023. <https://doi.org/10.1063/5.0184194>
- Hu, W., Lu, Z., Meng, F., Li, X., Cong, R., Ren, T., Sharkey, T. D., & Lu, J. (2020). The reduction in leaf area precedes that in photosynthesis under potassium deficiency: the importance of leaf anatomy. *The New phytologist*, 227(6), 1749–1763. <https://doi.org/10.1111/nph.16644>
- Jackson, P.A. (2005). Breeding for Improved Sugar Content in Sugarcane. *Field Crops Research*, 92(2-3): 277-290. ISSN 0378-4290, <https://doi.org/10.1016/j.fcr.2005.01.024>.
- Jana, S., Dhar, A., Dey, S., Garai, S. and Sarkar, S. (2024). Customized Fertilizer: An Overview and Contribution in Sustainable Crop Nutrition. *Vigyan Varta* 5(2): 145-151.
- Jayadi, M., Juita, N., & Wulansari, H. (2023). Analisis Fosfor Tanah pada Lahan Sawah Irigasi dan Sawah Tadah Hujan di Kecamatan Duampanua Kabupaten Pinrang. *Jurnal Ecosolum*, 11(2):191-207. DOI: 10.20956/ecosolum.v11i2.24460
- Juliati, S. (2008). Pengaruh Pemberian Zn dan P terhadap Pertumbuhan Bibit Jeruk Varietas Japanese citroen pada Tanah Inseptisol. *J. Hort.* 18(4):409-419.
- Khan, Q., Qin, Y., Guo, D-J., Zeng, X-P., Chen, J-Y., Huang, Y-Y., Ta, Q-K., Yang, L-T., Song, X. P., Xing, Y-X., and Li, Y-R. (2022). Morphological, agronomical, physiological and molecular characterization of a high sugar mutant of sugarcane in comparison to mother variety. *PLoS ONE* 17(3): e0264990.

- https://doi.org/10.1371/journal.pone.0264990
- Lisowska, A., Filipek-Mazur, B., Kalisz, A., Gorczyca, O., and Kowalczyk, A. (2023). Changes in Soil Sulfate Sulfur Content as an Effect of Fertilizer Granules Containing Elemental Sulfur, Halloysite and Phosphate Rock. *Agronomy*, 13, 1410. https://doi.org/10.3390/agronomy13051410
- Medina, N.H., Branco, M.L.T., da Silveira, M.A.G., Santos, R.B.B. (2013). Dynamic distribution of potassium in sugarcane. *J Environ Radioact*, 126 : 172 – 5 . https://doi.org/10.1016/j.jenvrad.2013.08.004.
- Mulyani, N.S., Suryadi, M.E., Dwingsih, S., dan Haryanto. (2001). Dinamika Hara Nitrogen pada Tanah Sawah. *Jurnal Tanah dan Iklim*, No.19. ISSN 1410-7244.
- Narayan, O. P., Kumar, P., Yadav, B., Dua, M., and Johri, A. K. (2022). Sulfur nutrition and its role in plant growth and development. *Plant signaling & Behavior*, 18(1): 1-11. https://doi.org/10.1080/15592324.2022.2030082
- Nurmala, T., Septian, F.I., Wahyudin, A., Wicaksono, F.Y. (2023). Effect of NPK fertilizer dose and GA3 concentration on growth, yield, and yield quality of *Coix lacryma-jobi* L. var. *ma-yuen* from ratoons. *Jurnal Kultivasi* Vol. 22(1): 101-107.
- Rahmayuni, E., Anwar, S., Nugroho, B. & Indriyati, L. T. (2023a). Characteristics of soil chemical properties associated with Inceptisols in various land use in Jasinga, Bogor. *J.Trop Soils*, 28(3), 89–97. DOI: https://doi.org/10.5400/jts.2023.v28i3.89-97
- Rianditya, O.D. (2022). Pengaruh Pemberian Pupuk Fosfor Terhadap Pertumbuhan Vegetatif Tanaman Tebu Var. Bululawang Hasil Mutasi. *Berkala Ilmiah PERTANIAN*, 5(1). DOI: https://doi.org/10.19184/bip.v5i1.29677
- Recena, R., García-López, A. M., & Delgado, A. (2021). Zinc Uptake by Plants as Affected by Fertilization with Zn Sulfate, Phosphorus Availability, and Soil Properties. *Agronomy*, 11(2), 390. https://doi.org/10.3390/agronomy11020390
- Sanches, G. M., Magalhães, P. S. G., Kolln, O. T., Otto, R., Rodrigues Jr, F., Cardoso, T. F., Chagas, M. F., and Franco, H. C. J. (2021). Agronomic, economic, and environmental assessment of site-specific fertilizer management of Brazilian sugarcane fields. *Geoderma Regional* (24): 1-11.
- Shao Q, Wang H, Guo H, Zhou A, Huang Y, Sun Y and Li M, (2014). Effects of Shade Treatments on Photosynthetic Characteristics Chloroplast Ultrastructure and Physiology of *Anoectochylus roxburgii*. *PloS one*, 9(2),p.e85996.
- Soares, A. de A.V.L., Prado R. de M., Caione, G., Rodrigues, M., Pavinato, P.S., and Campos, C.N.S. (2021). Phosphorus Dynamics in Sugarcane Fertilized with Filter Cake and Mineral Phosphate Sources. *Front. Soil Sci.* 1:719651. doi: 10.3389/fsoil.2021.719651
- Tarigan, A.P., Supriadi, dan Lubis, A. (2018). Perubahan Beberapa Sifat Kimia Tanah Inceptisol dan Pertumbuhan Tanaman Jagung (*Zea mays* L.) Akibat Pemberian Kompos Kulit Durian dan Pupuk SP-36. *Jurnal Pertanian Tropik*, 5(3): 309-317. E-ISSN NO :2356- 4725. https://jurnal.usu.ac.id/index.php/Tropik.
- Tyagi, V.K., Sharma, S., and Bhardwaj, S.B. (2013). Pattern of association among cane yield, sugar yield and their components in sugarcane (*Saccharum officinarum* L.). *J. Agric. Res.* 50:29-38.
- Wang, M., Zheng, Q., Shen, Q., Guo, S. (2013). The critical role of potassium in plant stress response. *Inter. J. Mol. Sci.*, 14: 7370–7390.
- Wang, S., Guan, K., Wang, Z., Ainsworth, E.A., Zheng, T. (2021). Unique contributions of chlorophyll and nitrogen to predict crop photosynthetic capacity from leaf spectroscopy. *Journal of Experimental Botany*, 72 (2):341–354.
- White, P. J. (2012). Long-distance Transport in the Xylem and Phloem (pp. 49–70). Academic Press. https://doi.org/10.1016/B978-0-12-384905-2.00003-0
- Yang, Z., Lu, C., & Zhang, Q. (2003). Effects of potassium on sugar accumulation in sugarcane. *Field Crops Research*, 83(3), 241–247.
- Xu, F., Wang, Z., Lu, G., Zeng, R., and Que, Y. (2021). Sugarcane Ratooning Ability: Research Status, Shortcomings, and Prospects. *Biology*, 10 (1052):1-13. https://doi.org/10.3390/biology10101052
- Xu, X., Du, X., Wang, F., Sha, J., Chen, Q., Tian, G., Zhu, Z., Ge, S., and Jiang, Y. (2020). Effects of Potassium Levels on Plant Growth, Accumulation and Distribution of Carbon, and Nitrate Metabolism in Apple Dwarf Rootstock Seedlings. *Front Plant Science*, volume 11. https://doi.org/10.3389/fpls.2020.00904
- Zhu, X. G., Long, S. P., and Ort, D. R. (2010). Improving photosynthetic efficiency for greater yield. *Annual review of plant biology*, 61, 235–261. https://doi.org/10.1146/annurev-arplant-042809-112206

