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Optimizing nutrient management in dryland sugarcane: morphophysiological response of *Saccharum officinarum* l. Variety GMP-7 to NPK-S and micronutrient fertilization

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Abstract. Sugarcane (*Saccharum officinarum* L.) is a strategic plantation crop in Indonesia; however, its productivity remains constrained by suboptimal nutrient management, particularly under dryland conditions. Information regarding the effectiveness of combined NPK-S and micronutrient fertilization on the vegetative performance of sugarcane is still limited. This study aimed to evaluate the effects of different inorganic fertilization strategies on the morphophysiological characteristics of sugarcane variety GMP-7 during the vegetative phase. The experiment was conducted from September to December 2025 in Ogan Ilir, South Sumatra, using a randomized complete block design with five treatments and five replications. The treatments consisted of: 1250 kg ha^{-1} NPK-S; 1000 kg ha^{-1} NPK-S + 12 kg ha^{-1} micronutrient fertilizer; 1250 kg ha^{-1} NPK-S + 12 kg ha^{-1} micronutrient fertilizer; and two combinations of urea, potassium chloride, and triple superphosphate at different rates. The results showed that most observed variables were not significantly affected by fertilization treatments, except for leaf number at four months after planting and leaf greenness. The application of 1250 kg ha^{-1} NPK-S consistently resulted in superior performance in stalk length, stalk diameter, chlorophyll content, leaf greenness, and total soluble solids. In contrast, the combination of urea, potassium chloride, and triple superphosphate at 450–474 kg ha^{-1} urea levels tended to enhance biomass accumulation and plant population attributes. In conclusion, NPK-S fertilization at 1250 kg ha^{-1} provided the most consistent morphophysiological response during the vegetative stage, highlighting its potential role in improving nutrient management strategies for sugarcane cultivation under dryland.

1 Introduction

Indonesia's national sugar demand remains relatively high. In 2023, national sugar demand will reach approximately 5.9 million tons, while domestic production will only reach 2.23 million tons, resulting in a significant supply deficit that must be met through imports [1]. This imbalance between consumption and production indicates that although Indonesia has extensive sugarcane land potential, national sugarcane productivity still needs to be increased [2].

To address this situation, the government has undertaken various efforts to increase sugar production through a sugar self-sufficiency program, including land intensification and extensification. The intensification program includes limiting ratoon crops, implementing appropriate planting systems, and managing fertilizers according to the needs of sugarcane plants [3].

Fertilization is a crucial factor because sugarcane plants require essential nutrients such as nitrogen, phosphorus, and potassium in large and balanced amounts, so soil nutrient availability quickly declines if not managed properly. Fertilization plays a crucial role in supporting plant growth and yield because it serves as an additional source of nutrients for plants according to their growth phase [4]. In sugarcane cultivation, the fertilizers commonly used consist of single fertilizers and compound fertilizers. Single fertilizers are fertilizers that contain only one nutrient, such as urea fertilizer, which functions as a nitrogen source [5]. Meanwhile, compound fertilizers contain macro and micro nutrients arranged in a specific composition so that they can meet plant nutritional needs more completely [6]. Compound fertilizers have the advantage of being able to release nutrients gradually, making them suitable for sugarcane plants that require a continuous supply of nutrients. One type of compound fertilizer widely used in sugarcane cultivation is NPK fertilizer containing sulfur, such as the 15N: 15P: 15K: 10S formulation, which has been applied in various sugarcane growing areas [3].

Several studies have shown that applying fertilizers with the right dosage and combination can increase the growth and productivity of sugarcane. [7] the combination of ZA, NPK, and dolomite provided the best growth and productivity results, while certain combinations were able to increase the brix value of sugarcane. Similar results were stated by [8], who stated that the use of 75% of the recommended dose of NPK provided a significant response to the vegetative growth of sugarcane plants. The use of inorganic fertilizers,

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especially nitrogen with the appropriate dosage, has also been shown to support the vegetative growth of sugarcane plants [9]. This shows that setting the right dosage and type of fertilizer plays an important role in improving the performance of sugarcane plants. Based on the above research, it is necessary to conduct research related to the effect of the combination of NPK-S compound fertilizer application (14:9:18:4) and micro fertilizer on the vegetative growth of Sugarcane (*Saccharum officinarum* Linn) GMP-7 variety with the aim of testing the effectiveness of NPK-S fertilizer for sugarcane plants, which is expected to be a necessary material for sugarcane plantations during their growth period so that sugarcane production can be maximized and become a solution to the imbalance between sugar production and national sugar consumption.

2 Materials and methods

This research was conducted at the plantation of PT. Sinergi Gula Nusantara, Cinta Manis Sugar Factory, in Ketiau Village, Lubuk Keliat District, Ogan Ilir, South Sumatra. The research period was four months, from September 2025 to December 2025.

The tools and materials in this study were: 1) Coolbox, 2) Vernier Caliper, 3) Camera, 4) Meter, 5) Oven, 6) Refractometer, 7) Spectrophotometer, 8) SPAD Meter (Soil Plant Analysis Development), 9) GMP-7 variety sugarcane seeds, 10) Labels, 11) Acetone solution, 12) Ethanol solution, 13) Dolomite fertilizer, 14) NPK-S fertilizer (14:9:18:40), 15) Potassium fertilizer, 16) Phosphorus fertilizer, 17) Nitrogen fertilizer, 18) Micro fertilizer (Nutremag), and 19) Plastic.

This research method was conducted using a Randomized Block Design (RBD) method consisting of 5 treatments with 5 replications, resulting in 25 research plots. The treatments used were: P1= 1250 kg ha^{-1} NPK-S, P2=1000 kg ha^{-1} NPK-S + 12 kg ha^{-1} Nutremag, P3=1250 kg ha^{-1} NPK-S + 12 kg ha^{-1} Nutremag, P4=450 kg ha^{-1} Urea (46%), 300 kg ha^{-1} KCL (60% K_2O), dan 300 kg ha^{-1} TSP (48% P_20_5), dan P5=474 kg ha^{-1} Urea (46%), 300 kg ha^{-1} KCL (60% K_2O), dan 300 kg ha^{-1} TSP (48% P_20_5).

The study began with land preparation by clearing weeds, litter, and crop residues. The soil was then tilled using a tractor in four stages: plowing once, harrowing twice, and forming furrows using a hook plow. The experimental plots were arranged in a Randomized Block Design (RBD) consisting of 25 plots (5 treatments × 5 replications) measuring 8.4 m × 10 m each and furrow spacing of 120 cm. Eight- to 12-month-old GMP-7 sugarcane seedlings were cut into 20- to 30-cm-long furrows with 2-3 buds. Planting was carried out in furrows using a double-stem system (100% overlap), then covered with soil. Fertilization was carried out according to the treatment in two stages: 50% of the dose several days after planting and the remainder at 2 months after planting, by spreading along the furrows.

Plant maintenance included watering, weed control, fertilization, and pest control. Watering was carried out after planting and adjusted to environmental conditions. Weed control was carried out using herbicides containing the active ingredients Diuron, Ametryn, paraquat, and glyphosate at recommended doses, while pest control was carried out using granular insecticides based on the level of infestation in the field. All maintenance activities were carried out to support plant growth throughout the study.

Observed parameters included vegetative growth characteristics of sugarcane plants, namely plant height, number of tillers, number of plants per meter, stem diameter, number of leaves, and leaf area. Observations were conducted from 1 month after planting (MAP) to 4 MAP at monthly intervals. In addition, the number of internodes and stem length were observed at 4 MAP as indicators of plant growth and development. Physiological and plant biomass observations were conducted at 4 MAP, leaf greenness, fresh and dry leaf weight, fresh and dry stem weight, and total soluble solids (°Brix).

Data analysis used Analysis of Variance (ANOVA). If the calculated F> F table at the 1% level, then the treatment has a very significant effect (**). If the calculated F> F table at the 5% level, then the treatment has a significant effect (*). Conversely, if the calculated F < F table, then the treatment has no significant effect (tn). If the results show a significant difference, a further Least Significant Difference (LSD) test is performed to see the differences between each treatment. Data analysis was performed using r-Studio and *Microsoft Excel*.

3 Result and discussion

Based on the research results obtained, the effect of inorganic fertilizer application on the vegetative phase of sugarcane variety GMP-7 showed that most of the observed parameters had no significant effect. The results of the diversity analysis of all parameters can be seen in Table 1. This can be seen from the analysis of variance (ANOVA) which shows that the fertilizer treatment has no significant/real effect on the parameters of plant height, stem length, number of internodes, number of tillers/m, number of plants/m, leaf area, stem diameter, total soluble solids, wet and dry leaf weight, wet and dry stem weight.

However, there is a real effect on the parameters of the level of greenness and number of leaves 4 MAP, which indicates that the combination of compound fertilizers provides a certain response to the aspect of leaf greenness and the development of the number of leaves at the end of the observation phase.

Table 1. Results of Analysis of Morphophysiological Variation and Biomass of Sugarcane Plants 4 MAP

Parameter	F-value	CV (%)
Plant Height (cm)	1.15 ns	9.29
Stem Length (cm)	0.97 ns	10.25
Number of Leaves	3.13 *	4.82
Leaf Area (cm^2)	2.39 ns	3.99
Number of Plants/m	1.10 ns	17.49
Number of Seedlings/m	1.14 ns	49.71
Stem Diameter (mm)	1.05 ns	6.82
Number of Internodes	1.68 ns	13.84
Leaf Greenness	4.16 *	7.65
Total Soluble Solids (°Bx)	1.17 ns	39.41
Leaf Fresh Weight (g)	0.91 ns	13.07
Leaf Dry Weight (g)	1.31 ns	14.31
Stem Fresh Weight (g)	1.34 ns	17.67
Stem Dry Weight (g)	1.06 ns	27.79
F Table 5%	3.01	
F Table 1%	4.77	

Description: * = Significantly Influenced; ** = Very Significantly Influenced; ns = No Significantly Influenced; CV = Coefficient of Diversity; MAP = Months After Planting

3.1 Morphological Characteristics of Sugarcane

In table 2, the fertilizer given has no significant effect on the growth of plant height and sugarcane stem length at the age of 4 MAP.

Table 2. Effect of inorganic fertilizer on plant height and stem length of sugarcane plants at 4 MAP

Treatment	Plant Height (cm)	Stem Length (cm)
1250 kg/ha NPK-S	253.84 ± 8.70	114.06 ± 6.43
1000 kg/ha NPK-S+ 12 kg/ha Nutremag	252.88 ± 11.67	109.80 ± 7.64
1250 kg/ha NPK-S + 12 kg/ha Nutremag	256.28 ± 7.54	112.04 ± 9.63
450 kg/ha Urea, 300 kg/ha KCL, dan 300 kg/ha TSP	253.92 ± 9.55	111.24 ± 5.26
474 kg/ha Urea, 300 kg/ha KCL, dan 300 kg/ha TSP	229.56 ± 45.18	109.24 ± 5.93

The plant height parameter at 4 MAP shows the highest average value at P3 of 256.28 cm and the lowest at P5 of 229.56 cm, and in the stem length parameter the highest average value is at P1, namely 114.06 cm, followed by P3 at 112.04 cm, P4 at 111.24 cm, and P2 at 109.80 cm, with the lowest value at P5 at 109.24 cm. The growth of sugarcane stem height is most responsive to the environment in the age range of 2 to 6 months, while outside this period the environmental influence is relatively limited, phosphorus also plays an important role in stem growth [10]. Phosphorus is involved in the formation of new cells in growing tissues, including stems, and supports the development of the root system.

In Table 3, the treatment for the number of leaves shows a significant effect, where the results of the Least Significant Difference (LSD) test indicate that P2 and P3 are significantly different from P5.

Table 3. Effect of inorganic fertilizer on the number of leaves and leaf area of sugarcane plants at 4 MAP

Treatment	Number of Leaves	Leaf Area (cm^2)
1250 kg/ha NPK-S	8.60 ± 0.63 ab	563.99 ± 39.17
1000 kg/ha NPK-S+ 12 kg/ha Nutremag	8.20 ± 0.60 b	569.22 ± 40.36
1250 kg/ha NPK-S + 12 kg/ha Nutremag	8.12 ± 0.36 b	551.54 ± 34.82
450 kg/ha Urea, 300 kg/ha KCL, dan 300 kg/ha TSP	8.52 ± 0.39 ab	576.06 ± 35.72
474 kg/ha Urea, 300 kg/ha KCL, dan 300 kg/ha TSP	8.92 ± 0.44 a	537.19 ± 40.13

Description: Numbers followed by the same letter in the same row do not have a significant difference in the LsD test at the 5% level.

Conversely, P1 and P4 do not differ significantly from P2, P3, and P5. The highest average value for the number of leaves was observed in P5, with a value of 8.92 leaves. The elevated number of leaves in this specific treatment was triggered by the high supply of nitrogen (N) from the Urea fertilizer (474 kg/ha). A balanced availability of high-amount N and phosphorus (P) from single-nutrient fertilizers has been proven effective in increasing the leaf emergence rate during the early vegetative phase [11]. On the other hand, the lowest number of leaves was recorded in treatment P3, with 8.12 leaves. The reduction in leaf number upon the addition of micronutrients when the NPK-S dose was already high indicates nutrient saturation or nutrient antagonism within the rhizosphere.

Regarding the leaf area parameter, the data distribution exhibits an inverse trend compared to the number of leaves. The application of resulted in the highest leaf area, which was found in treatment P4 (576.06 cm²), followed by treatment P2 (569.22 cm²). Interestingly, the treatment with the highest leaf quantity (P5) conversely produced the lowest average leaf area, at 537.19 cm². Physiologically, this phenomenon reflects a morphological trade-off resulting from photoasimilat partitioning (source-sink relationship). Conversely, slightly lower nutrient concentrations or precise macro-micronutrient combinations (such as low-dose NPK-S + Nutremag) are capable of optimizing cell turgor pressure, there by generating wider leaf sizes that are more efficient in intercepting solar radiation for photosynthesis [12].

In table 4, the stem diameter parameter shows the highest average value in P1, namely 25.57 mm and the lowest in P2 at 23.78 mm, while in the parameter number of internodes the highest average value is in P5, namely 3.56 internodes and the lowest in P2 and P3 at 2.96 internodes, but in general the results of the analysis show that the inorganic fertilizer treatment given has no significant effect on both parameters. The growth of stem internodes, number of internodes, stem length, and stem diameter in sugarcane plants is highly dependent on the clone or plant variety used, especially in Inceptisol soil conditions [13].

Table 4. Effect of inorganic fertilizer on stem diameter and number of segments of sugarcane plants at 4 MAP

Treatment	Stem Diameter (mm)	Number of Internodes
1250 kg/ha NPK-S	25.57 ± 2.37	3.20 ± 0.55
1000 kg/ha NPK-S+ 12 kg/ha Nutremag	23.78 ± 1.90	2.96 ± 0.57
1250 kg/ha NPK-S + 12 kg/ha Nutremag	24.88 ± 1.19	2.96 ± 0.33
450 kg/ha Urea, 300 kg/ha KCL, dan 300 kg/ha TSP	25.27 ± 2.26	3.04 ± 0.38
474 kg/ha Urea, 300 kg/ha KCL, dan 300 kg/ha TSP	24.06 ± 1.83	3.56 ± 0.62

Description: Numbers followed by the same letter in the same row do not have a significant difference in the BNT test at the 5% level.

In Table 5, the number of plants/m parameter shows the highest average value at P5, at 13.64, and the lowest at P3, at 10.88. The highest average value for the number of tillers/m parameter was also found at P5, at 4.20 tillers, and the lowest at P3, at 2.64 tillers. However, statistically, the inorganic fertilizer treatment did not significantly affect the number of plants/m and the number of tillers/m of sugarcane.

Table 5. Effect of Inorganic Fertilizer on the Number of Plants and the Number of Tillers per Meter of Sugarcane at 4 MAP

Treatment	Number of Plants/m	Number of Seedlings/m
1250 kg/ha NPK-S	12,04 ± 1,58	3,20 ± 1,17
1000 kg/ha NPK-S+ 12 kg/ha Nutremag	12,24 ± 1,86	3,68 ± 1,35
1250 kg/ha NPK-S + 12 kg/ha Nutremag	10,88 ± 2,08	2,64 ± 1,56
450 kg/ha Urea, 300 kg/ha KCL, dan 300 kg/ha TSP	12,76 ± 1,21	3,80 ± 1,42
474 kg/ha Urea, 300 kg/ha KCL, dan 300 kg/ha TSP	13,64 ± 3,19	4,20 ± 2,25

Description: Numbers followed by the same letter in the same row do not have a significant difference in the BNT test at the 5% level.

The number of stems per segment in sugarcane plants is influenced by the availability of macro and secondary nutrients such as nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur in the soil. Fertilization has no significant effect on the number of sugarcane tillers. According to [14], the number of sugarcane tillers tends to decrease as the plant height increases, because some tillers experience growth retardation and eventually die due to being covered by the taller main plant.

3.2 Physiological Characteristics of Sugarcane

In Table 6, the Total Dissolved Solids parameter shows no significant effect between treatments, where P1 and P5 gave the highest value of 5.48, while P3 showed the lowest value of 3.30.

Table 6. Effect of inorganic fertilizer on total dissolved solids, and greenness level of sugarcane leaves 4 MAP

Treatment	Total Soluble Solids (Bx°)	Leaf Greenness
1250 kg/ha NPK-S	5,48 ± 2,06	40,64 ± 2,09a
1000 kg/ha NPK-S+ 12 kg/ha Nutremag	4,51 ± 1,40	37,76 ± 1,83ab
1250 kg/ha NPK-S + 12 kg/ha Nutremag	3,30 ± 0,84	34,14 ± 3,05b
450 kg/ha Urea, 300 kg/ha KCL, dan 300 kg/ha TSP	4,89 ± 2,24	39,98 ± 4,95a
474 kg/ha Urea, 300 kg/ha KCL, dan 300 kg/ha TSP	5,48 ± 2,01	40,12 ± 2,30a

Description: Numbers followed by the same letter in the same row do not have a significant difference in the BNT test at the 5% level.

When compared to the standard set by the company of 18%, all treatments in this study have not fully achieved this standard, this indicates that the plants are still in the optimal immature phase. Sugarcane plant maturity occurs gradually, starting from the lower stem to the upper stem as the plant ages. Sugarcane plants are said to be mature when the brix value in the upper and lower stems is relatively the same [7]. In the vegetative phase, sugar accumulation in the stem is still limited because the results of photosynthesis are mostly used to support the growth of vegetative organs.

The level of leaf greenness showed a significant effect between treatments with the highest value in P1 of 40.64 and the lowest in P3 of 34.14, where the results of the Least Significant Difference (LSD) test showed that P3 was significantly different from P1, P4, and P5, while P2 was not significantly different from P1, P3, P4, and P5. The increase in the level of leaf greenness is thought to be related to the role of sulfur in supporting the chlorophyll formation process. Sulfur functions in the formation and activity of enzymes and proteins, and is involved in the synthesis of various amino acids that play a role in the formation of chlorophyll and leaf tissue [15]. Sulfur deficiency can cause a more significant decrease in chlorophyll and carotenoid content compared to conditions of excess sulfur.

3.3 Sugarcane Biomass

The results of observations of leaf wet weight show variations between treatments. Table 7 shows that P4 had the highest average leaf wet weight, at 138.82 g, while P2 had the lowest value, at 120.38 g. Treatments P1, P3, and P5 showed relatively uniform values, and for leaf dry weight, the highest average dry weight was found in P4 at 40.10 g, and the lowest value was found in P2 at 34.02 g.

Table 7. Effect of inorganic fertilizer on wet leaf weight and dry leaf weight of sugarcane plants 4 MAP

Treatment	Leaf Fresh Weight (g)	Leaf Dry Weight (g)
1250 kg/ha NPK-S	137.26 ± 31.06	39.50 ± 11.04
1000 kg/ha NPK-S+ 12 kg/ha Nutremag	120.38 ± 20.23	34.02 ± 2.66
1250 kg/ha NPK-S + 12 kg/ha Nutremag	132.34 ± 28.24	35.42 ± 7.52
450 kg/ha Urea, 300 kg/ha KCL, dan 300 kg/ha TSP	138.82 ± 11.74	40.10 ± 1.81
474 kg/ha Urea, 300 kg/ha KCL, dan 300 kg/ha TSP	135.96 ± 22.92	39.32 ± 7.41

Description: Numbers followed by the same letter in the same row do not have a significant difference in the BNT test at the 5% level.

Based on the results of observations of the wet weight of the stem in table 8.

Table 8. Effect of inorganic fertilizer on the wet weight of stems and dry weight of stems of sugarcane plants 4 MAP

Treatment	Stems Fresh Weight (g)	Stems Dry Weight (g)
1250 kg/ha NPK-S	595.40 ± 115.38	109.62 ± 41.80
1000 kg/ha NPK-S + 12 kg/ha Nutremag	535.06 ± 104.09	98.74 ± 45.44
1250 kg/ha NPK-S + 12 kg/ha Nutremag	631.98 ± 105.24	98.48 ± 31.01
450 kg/ha Urea, 300 kg/ha KCL, dan 300 kg/ha TSP	636.60 ± 97.20	117.90 ± 33.83
474 kg/ha Urea, 300 kg/ha KCL, dan 300 kg/ha TSP	522.06 ± 101.63	83.44 ± 14.25

Description: Numbers followed by the same letter in the same row do not have a significant difference in the BNT test at the 5% level.

The treatment P4 shows the highest average value of the wet weight of the stem, namely 636.60 g, while the smallest average of 522.06 g is in P5 and the dry weight of the stem shows that P4 has the highest average of 117.90 g, and P5 has the lowest average value of the dry weight of the stem of 83.44 g. According to [13] in relatively homogeneous environmental conditions, the weight and number of sugarcane stems are characteristics that are closely related to genetic factors or clones used.

4 Conclusion

Inorganic fertilizers on sugarcane plants aged 4 months after planting (4 MAP) showed a significant effect on the number and level of leaf greenness but no significant effect on plant height, number of plants per meter, leaf area, stem diameter, stem length, total soluble solids, wet and dry leaf weight, wet and dry stem weight, total chlorophyll, number of internodes, and number of tillers per meter. The use of NPK-S fertilizer was able to provide growth results equivalent to a combination of Single inorganic fertilizers. The fertilizer dose of 1250 kg ha^{-1} NPK-S showed the most consistent results and the best response in most physiological and growth parameters, such as leaf greenness, stem length, stem diameter, and total soluble solids.

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