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Integrated application of compost and potassium fertilizer enhances soil fertility and stevia productivity in Inceptisols

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ABSTRACT

Inceptisols is among the predominant soil types in Indonesia; however, they are characterized by low fertility, which constrains their agricultural productivity. To address these limitations, this study aimed to assess the effects of organic amendments and K fertilization on the soil chemical properties and growth performance of stevia. A factorial randomized block design was employed, incorporating three types of compost: No compost, rice straw compost, and leucaena compost, combined with four levels of K_2O application (0, 75, 150, and 225 kg/ha). Soil parameters (pH, EC, CEC, and exchangeable K) and plant traits (height, biomass, and total soluble solids – TSS) were assessed. Both compost types significantly improved soil chemical properties, with leucaena compost yielding the highest pH and nutrient availability. Potassium fertilization significantly increased plant biomass, K uptake, and TSS content, particularly at 225 kg K_2O/ha. The combined application of organic and inorganic fertilizers yielded the most favorable outcomes for both soil health and stevia productivity. These findings underscore the complementary benefits of integrating organic and inorganic fertilization strategies to optimize stevia cultivation. This approach enhances soil health and nutrient availability, promotes sustainable agricultural practices, and contributes to addressing the national sugar supply gap by producing healthier natural sweeteners. Future studies should focus on long-term field trials to assess the residual effects of compost application, track changes in soil microbial communities under prolonged integrated fertilization, and evaluate the agronomic and economic feasibility of scaling up these practices across diverse agroecological regions.

Keywords: cation exchange capacity, Inceptisols, potassium, soil amendment, stevia.

INTRODUCTION

In Indonesia, Inceptisols constitute one of the most widespread soil orders, covering approximately 70.52 million hectares and accounting for about 37.5% of the nation's total land area (Herviyanti et al., 2023). These soils are predominantly found in volcanic regions formed from volcanic ash and basaltic andesitic parent materials (Hindersah et al., 2023; Muslim et al., 2020). Their distribution spans major islands, such as Java, Sumatra, Kalimantan, and Papua, making them a significant component of Indonesia's agricultural landscape (Sofyan et al., 2023; Wulansari et al., 2022). However, despite their vast extent, Inceptisols is typically characterized by low fertility, posing challenges for crop cultivation. Chemically, they contain low levels of organic carbon, nitrogen, and phosphorus, which leads to slightly acidic soil conditions (Fitriatin et al., 2024; Joy et al., 2023). Studies have indicated that Inceptisols usually contain less than 20% organic matter, classifying them as marginal soils (Mushalin, 2024). Their poor nutrient-holding capacity further limits agricultural productivity unless effective soil management practices, such as fertilization and organic matter enrichment, are implemented (Setiawati et al., 2018; Sihite et al., 2024).

Given the fertility limitations inherent in Inceptisols, it is imperative to enhance soil conditions to achieve sustainable agricultural development. Among the crops that can be produced under well-managed inceptisol conditions, *Stevia rebaudiana*, commonly referred to as stevia, has emerged as a promising alternative. In 2023, Indonesia's sugar demand reached 7.1 million tons, while national production was only 2.2 million tons, resulting in a significant supply deficit (Pusat Data dan Sistem Informasi Pertanian, 2024). This disparity underscores a country's substantial reliance on sugar imports. In response, stevia has gained increasing attention owing to its zero-calorie content and significantly higher sweetness level than sugarcane. Furthermore, its potential health benefits, including anticancer properties, make it particularly suitable for individuals with diabetes and obesity (Sari and Rejeki, 2021). Considering these advantages, optimizing stevia cultivation offers a viable strategy to reduce Indonesia's dependence on imported sugar while promoting a healthier, more sustainable sweetener alternative.

Stevia grows optimally in highland regions at elevations between 800 and 2,000 m above sea level (masl) and requires well-drained soils with moisture levels between 43% and 47% (Azkiyah and Tohari, 2019). However, soil fertility remains a crucial determinant of stevia productivity. The essential soil fertility parameters included soil pH, CEC, and exchangeable K. Stevia requires a pH range of 6.5 to 7.5 for optimal growth, while higher CEC values indicate enhanced nutrient retention and exchange. A combination of organic and inorganic fertilizers is necessary to improve soil fertility and maximize crop yield.

Organic fertilizers, such as compost, manure, and bokashi, improve soil structure, increase porosity, and enhance water retention, all of which are critical for stevia growth (Pan and Huang, 2024). Among organic fertilizers, compost derived from rice straw and *Leucaena leucocephala* (leucaena) leaves has proven to be particularly effective in replenishing soil nutrients. Rice straw compost is composed of 39.73% organic carbon, 2.09% nitrogen, has a C/N ratio of 18.96, and contains 0.487% phosphorus and 0.846% potassium (Tamtomo et al., 2015). Its application improves soil physical properties and supports root system development (Sulaeman et al., 2016). Compost derived from Leucaena leaves, a nitrogen-rich leguminous plant containing 2.0–4.3% nitrogen, 0.2–0.4% phosphorus, and 1.3–4.0% potassium, has been shown to enhance soil fertility and significantly improve the growth performance of *Stevia rebaudiana*, as evidenced by increases in plant height (21.7 cm), stem diameter (2.0 cm), leaf number (152 leaves), fresh weight (16.54 g), and dry weight (3.58 g) (Siregar and Wijayanto, 2024).

In addition to organic fertilizers, inorganic fertilizers play an essential role in providing macronutrients that are crucial for plant development. Potassium (K) is one of the primary macronutrients required for stevia growth and contributes to various physiological and biochemical processes, including protein transport and enzyme activation (Mahdi et al., 2023). Potassium fertilizers not only improve soil fertility by neutralizing pH and increasing CEC, but also enhance crop quality. Plants assimilate potassium in the form of K^+ ions, which are essential components of plant metabolism. A deficiency in K leads to weakened plant structures, as K is crucial for regulating turgor pressure and preventing lodging. Furthermore, K enhances the sweetness of stevia, thereby improving its commercial value as a natural sweetener.

Recognizing the critical role of soil fertility management in addressing the challenges associated with Inceptisols, this study sought to investigate effective strategies for enhancing soil conditions through organic fertilization. Additionally, we aimed to determine the optimal potassium dosage to maximize stevia productivity. The outcomes of this research are anticipated to contribute to the sustainability of domestic sugar supply while simultaneously improving both the quality and quantity of stevia production in Indonesia.

MATERIAL AND METHOD

Experimental site and design

This study was conducted in Pakopen Village, Bandungan sub-district, Semarang regency, Indonesia (7.20389° S, 110.38361° E). The study site was located at an altitude of 600 m above sea level, with an average daily temperature of 20 °C, a relative humidity of 80%, and an annual rainfall of 2.200–3.000 mm. Laboratory analyses were performed at the Laboratory of Ecology and Crop Production, Department of Agriculture, Faculty of Animal and Agricultural Sciences, Universitas Diponegoro, Indonesia. A factorial randomized block design (RBD) was employed to evaluate the effects of different types of compost and potassium (K_2O) application rates. The first factor consisted of three types of compost: no compost, rice straw compost, and leucaena compost. The second factor was the K application rate, which included four levels: 0, 75, 150, and 225 kg K_2O/ha. These combinations resulted in 12 treatments, each replicated three times, yielding a total of 36 experimental units with 28 plants per unit. Prior to planting, soil samples were collected and examined to assess essential soil fertility indicators, such as nitrogen (N), phosphorus (P), potassium (K), organic carbon (C), CEC, exchangeable K, pH, and EC. The composting materials were sourced from the area surrounding the research location.

Crop management and experimental treatments

The process of land preparation involved the removal of weeds, soil tillage to a depth of 25 cm, and incorporation of organic fertilizers in accordance with the specified treatment levels. Raised beds were constructed with dimensions of 1 m width and 1.75 m length, with a spacing of 30 cm between each bed. Stevia stem cuttings were transplanted at a spacing of 25 × 25 cm in the morning to reduce transplanting stress. Each bed accommodated 28 plants, with 10 plants randomly selected for observation to ensure objective and unbiased data collection. The results of the initial soil and compost analyses are presented in Tables 1 and 2, respectively. Fertilization was conducted in two stages. Before planting, rice straw and Leucaena Compost were applied at a rate of 30 t/ha. Potassium fertilization with KCl was applied at doses of 0, 75, 150, and 225 kg K_2O/ha. Harvesting was performed 50 days after planting (DAP), before the onset of flowering, by cutting plants 10 cm above the soil surface. Following harvest, soil samples were collected and reanalyzed to determine post-experiment changes in CEC, exchangeable K, EC, and pH.

Plant growth assessment and post-harvest analyses

Various growth and productivity metrics were evaluated to assess plant performance. Weekly measurements of plant height and leaf number were performed to track growth patterns. Leaf area was calculated using the formula $LA = P \times L \times 0.656$, with 0.656 being the leaf shape correction factor specific to stevia (Susilo, 2015). Fresh weight was recorded immediately post-harvest, whereas dry weight was determined by drying the plant samples at 60 °C for 24 h, following the standardized procedure outlined by Rashwan et al., (2017). The TSS of the stevia leaves was analyzed following the procedure described by Widyasanti

Table 2. Chemical properties of leucaena and rice straw compost prior to application

Parameter	Leucaena compost	Rice straw compost
N-total (%)	4.17	1.41
P-total (%)	0.20	0.81
K-total (%)	1.76	1.59
Organic C (%)	69.18	31.54
C/N ratio	16.59	22.32
pH	8.30	9.30

Table 1. Soil chemical properties before the experiment

Soil properties	Soil analysis results	Criteria
pH	5.70	Slightly acid
N-total (%)	0.14	Low
P-total (%)	0.14	Very low
K-total (%)	0.20	Very low
Organic C (%)	1.39	Low
C/N ratio	10.38	Low
CEC (cmol/kg)	18.91	Medium
Exchangeable K (cmol/kg)	1.22	Very high
Exchangeable Na (cmol/kg)	0.24	Low
Exchangeable Ca (cmol/kg)	7.03	Medium
Exchangeable Mg (cmol/kg)	1.91	Medium
EC (mS/cm)	0.27	Low

et al., (2022). Potassium uptake was measured using the wet ashing method with HNO_3 and $HClO_3$, followed by analysis using flame photometry, as outlined by Eviati et al. (2023). For soil analysis, soil pH (pH-H_2O) was measured using a pH meter in a 1:2.5 soil-to-water suspension, following the method outlined by Webster (2008). EC was assessed in a 1:2.5 soil-to-water extract using a conductivity meter, as described by Okalebo et al., (2002). CEC was measured using the approach outlined by Rhoades (1982), whereas exchangeable K was determined through atomic absorption spectrophotometry (AAS), as described by Knudsen and Peterson (1982).

Statistical analysis

Statistical analyses were performed using analysis of variance to determine significant differences among the treatments. When significant differences were found, Duncan's multiple range test (DMRT) was applied at a 5% significance level to compare the treatment means. This approach ensured rigorous evaluation of the effects of compost type and K application on stevia growth and soil properties

RESULTS

Effects of compost type, potassium dose, and their interaction on soil and plant parameters

Analysis of variance showed that compost amendment significantly affected soil chemical properties, such as pH, EC, CEC, and exchangeable K, as well as plant growth parameters, including plant height, leaf number, leaf area, and fresh shoot weight. Potassium dosage significantly influenced potassium uptake, plant height, leaf number, shoot biomass (fresh and dry), and TSS. A significant interaction between compost and K dose was observed only for plant height and leaf number. These results indicate that the responses of soil and plant variables varied depending on the type of treatment and the parameters measured (Table 3).

Effects of compost type and potassium dose on soil pH, EC, CEC, and exchangeable K

Analysis of variance revealed that compost application had a significant effect on soil pH, EC, CEC, and exchangeable K. However, neither the K dose nor the interaction between compost and K fertilization had a significant effect on these soil properties (Figure 1).

The results indicated that compost application significantly influenced soil chemical properties, including pH, EC, CEC, and exchangeable K. Soil pH varied significantly across treatments, with leucaena compost exhibiting the highest pH (7.27), which was statistically significant compared to that of rice straw compost (6.95) and no compost (6.83). A 6.4% increase in pH was observed in the leucaena compost treatment compared to the no-compost treatment, indicating its potential buffering effect in stabilizing soil acidity and supporting microbial activity. Meanwhile, the

Table 3. Summary of analysis of variance showing the effects of compost type, K application rate, and their interaction on soil chemical properties and stevia growth parameters

Parameter	Compost	Potassium dose	Interaction
Soil pH	*	ns	ns
EC	*	ns	ns
CEC	*	ns	ns
Exchangeable K	*	ns	ns
Potassium uptake	ns	*	ns
Plant height	*	*	*
Leaf number	*	*	*
Leaf area	*	ns	ns
Fresh weight	*	*	ns
Dry weight	ns	*	ns
TSS	ns	*	ns

Note: Asterisks (*) indicate statistically significant effects at $p < 0.05$, while "ns" denotes non-significant effects. Parameters included soil pH, EC, CEC, exchangeable K, potassium uptake, plant height, number of leaves, leaf area, fresh and dry shoot weight, and TSS.

pH difference between rice straw compost and no compost was also statistically significant, indicating that both composts contributed to improving the soil pH.

EC also showed significant differences, with leucaena compost (0.51 mS/cm) being statistically higher than that of no compost (0.39 mS/cm), but this difference was not statistically significant relative to that of rice straw compost (0.43 mS/cm). The increase in EC by 30.8% compared with no compost and 18.6% compared with rice straw compost indicated greater nutrient solubility and ion availability in the soil solution, which can enhance plant nutrient uptake. Statistically significant differences among the treatments confirmed that compost application played a crucial role in improving soil fertility.

CEC varied significantly among the treatments. Leucaena compost exhibited the highest CEC at 21.11 cmol/kg, which was statistically significant when compared to the no compost treatment (19.41 cmol/kg), but not statistically significant in comparison to rice straw compost (20.91 cmol/kg). The observed 8.8% increase in CEC with leucaena compost relative to no compost implies an enhancement in the soil structure and organic matter content, thereby improving nutrient retention. Nonetheless, the absence of a significant difference between rice straw compost and leucaena compost suggests that both organic amendments effectively enhanced the nutrient-holding capacity of the soil.

Exchangeable K was also significantly influenced by compost application. Leucaena compost (1.66 cmol/kg) had the highest exchangeable K, which was statistically higher than no compost (1.37 cmol/kg) but not was statistically significant relative to rice straw compost (1.63 cmol/kg). This suggests that while both compost treatments contributed to increasing potassium availability, Leucaena compost had a slightly greater effect. The 21.2% increase in exchangeable K under leucaena compost compared with no compost highlights its role in enhancing soil nutrient supply, although the statistical similarity between rice straw compost and leucaena compost indicates comparable effectiveness in potassium enrichment.

Effects of compost type and potassium dose on plant height, leaf area and number of leaves

Based on the analysis of variance, a significant interaction was observed between the two factors affecting plant height and number of leaves, whereas leaf area was significantly influenced only by the type of compost. In contrast, the K dose (0, 75, 150, and 225 kg/ha) and its interaction with compost type did not have a significant effect on leaf area. The data on plant height

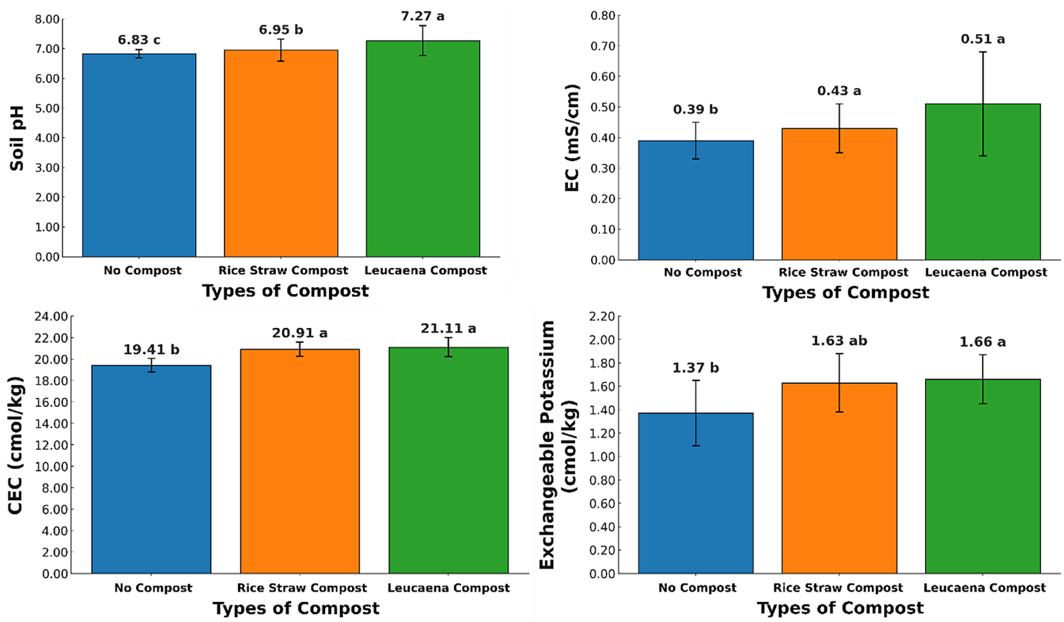

Figure 1. Effects of compost type on soil pH, EC, CEC, and exchangeable K. Error bars represent standard deviation. Different letters above the bars indicate statistically significant differences among treatments based on DMRT at $p < 0.05$

and leaf count are presented in Figure 1, and the leaf area results are shown in Figure 2.

The greatest plant height was recorded in the treatment involving leucaena compost combined with 225 kg/ha potassium (34.10 cm). However, this measurement did not exhibit statistical significance when compared to the treatments of rice straw compost with 225 kg/ha of potassium (33.21 cm), leucaena compost with 150 kg/ha of potassium (33.94 cm), and rice straw compost with 150 kg/ha of potassium (32.11 cm). Nevertheless, it was significantly greater than that in all treatments that did not include compost across all K application levels, including no compost with 0 kg/ha of K (25.44 cm), no compost with 75 kg/ha of K (27.66 cm), no compost with 150 kg/ha of K (28.61 cm), and no compost with 225 kg/ha of K (31.39 cm).

The results indicated that increasing K application rates (0, 75, 150, and 225 kg/ha) enhanced both plant height and leaf number, with the most pronounced effects observed at 225 kg/ha K across all compost treatments. The absence of compost application resulted in the lowest plant height, with measurements ranging from 25.43 cm at a potassium dose of 0 kg/ha to 32.63 cm at a dose of 225 kg/ha. Conversely, the application of rice straw compost produced the greatest increase in plant height, ranging from 26.65 cm at 0 kg/ha to 35.14 cm at 225 kg/ha, indicating a synergistic interaction between potassium fertilization and compost amendments. Similarly, the use of leucaena compost also enhanced plant height, though to a lesser extent, with values ranging from 28.44 cm at 0 kg/ha to 31.91 cm at 225 kg/ha.

A similar trend was observed for the number of leaves. The no compost treatment resulted in the lowest leaf count, increasing from 128.30 leaves at 0 kg/ha of potassium to 146.67 leaves at 225 kg/ha. In contrast, the rice straw compost treatment produced the highest number of leaves, ranging from 134.57 at 0 kg/ha to 149.70 at 225 kg/ha, highlighting its effectiveness in promoting vegetative growth. Leucaena compost also contributed positively, although its effect was relatively moderate, with leaf numbers ranging from 137.13 to 138.30 across the same potassium levels (Figure 3).

The leaf area was significantly affected by compost application, whereas K fertilization did not yield significant differences among the K dose treatments. The application of leucaena compost resulted in the highest leaf area (3.50 cm²), followed by rice straw compost (3.20 cm²), while the no compost treatment exhibited the lowest value (2.78 cm²), indicating a 25.9% increase with leucaena compost. However, K fertilization did not significantly affect leaf area, as evidenced by the similar values recorded across all K doses. Although 225 kg/ha resulted in the highest leaf area (3.31 cm²) and 0 kg/ha had the lowest (3.00

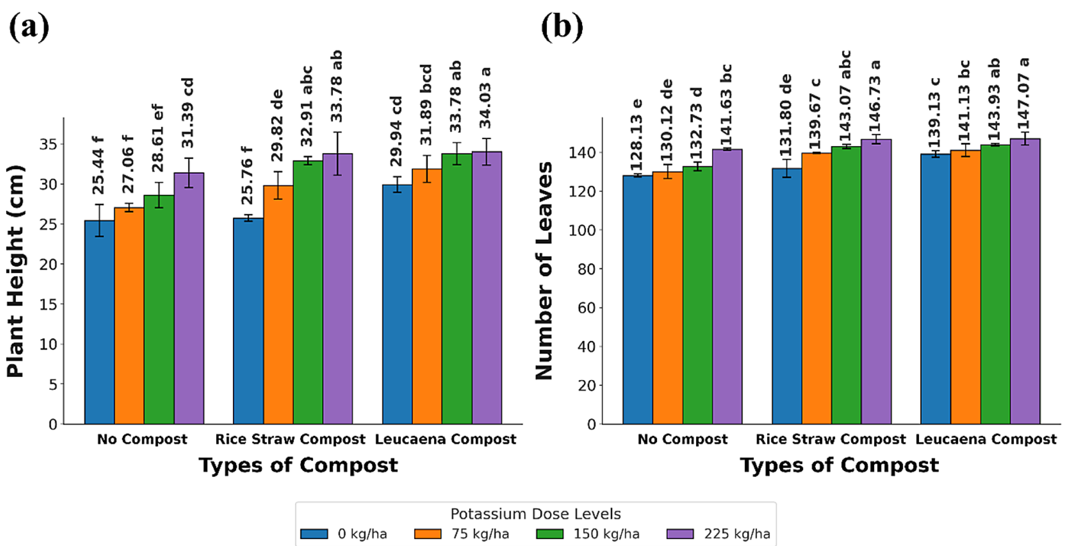

Figure 2. Effects of compost type and potassium fertilization on (a) plant height and (b) number of leaves in stevia. Bar charts illustrate the interaction effects of compost type (no compost, rice straw compost, and leucaena compost) and potassium (K_2O) application rates (0, 75, 150, and 225 kg/ha) on plant height (cm) and number of leaves in stevia. Error bars represent the standard deviation. Different letters above the bars indicate statistically significant differences among treatments based on DMRT at $p < 0.05$

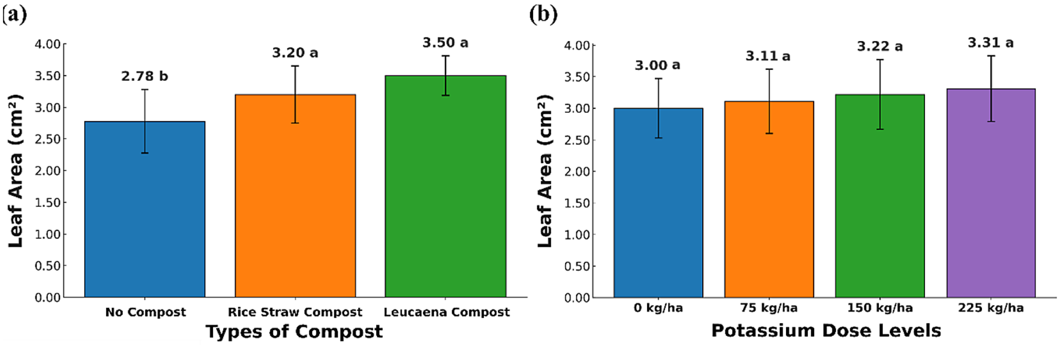

Figure 3. Effects of compost type and potassium fertilization on the leaf area of stevia. Bar charts illustrate the effects of (a) compost type (no compost, rice straw compost, and leucaena compost) and (b) potassium (K_2O) application rates (0, 75, 150, and 225 kg/ha) on leaf area (cm²) in stevia. Error bars represent standard deviation. Different letters above the bars indicate statistically significant differences among treatments based on DMRT at $p < 0.05$

cm²), the differences were not statistically significant. The minor variation observed could be attributed to the role of K in regulating stomatal function and enhancing photosynthetic efficiency, which indirectly affected leaf expansion.

Yield, potassium uptake and TSS content in stevia under compost type and K fertilization

Based on the analysis of variance, fresh weight was significantly influenced by both compost application and K fertilization. In contrast, dry weight, potassium uptake, and TSS were significantly affected by potassium fertilization alone. No interaction effects were detected for any of the parameters, indicating that the effects of compost and K application were independent.

Fresh weight responded positively to both compost and K fertilization. The highest fresh weight was recorded for leucaena compost (7.30 g), followed by rice straw compost (7.14 g), whereas No compost had the lowest fresh weight (6.10 g), representing increases of 19.7% and 17.0%, respectively. The organic matter supplied by the compost likely improved the soil structure, water-holding capacity, and nutrient availability, contributing to enhanced plant growth. Similarly, K fertilization significantly increased fresh weight, with 225 kg/ha producing the highest value (8.19 g), which was 47.3% higher than that of the 0 kg/ha treatment (5.56 g). The application of 150 kg/ha (7.13 g) and 75 kg/ha (6.52 g) also resulted in improvements, confirming the essential role of K in regulating osmotic balance, improving water uptake, and enhancing metabolic processes (Figure 4).

The study found that dry weight was significantly affected by K fertilization, whereas

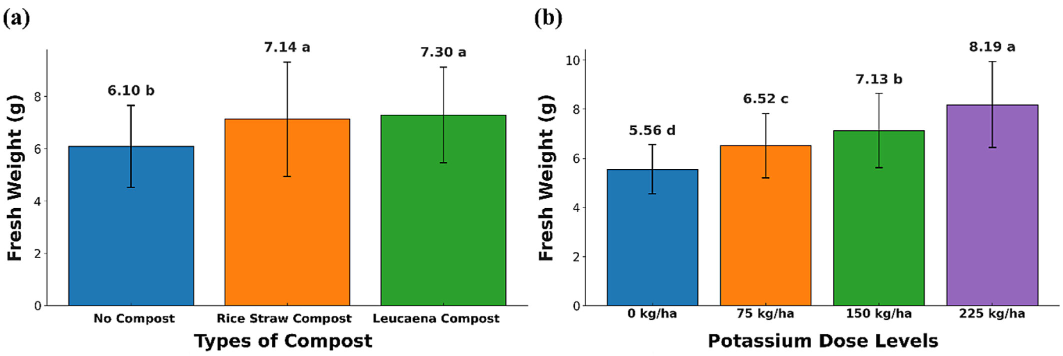

Figure 4. Effects of compost type and potassium fertilization on stevia fresh weight. Bar charts illustrate the effects of (a) compost type (no compost, rice straw compost, and leucaena compost) and (b) potassium (K_2O) application rate (0, 75, 150, and 225 kg/ha) on the fresh weight of stevia. Error bars represent standard deviation. Different letters above the bars indicate statistically significant differences among treatments based on DMRT at $p < 0.05$

compost application did not have a significant impact. Although leucaena compost (1.72 g) and rice straw compost (1.57 g) resulted in marginally higher dry weights than in the absence of compost (1.47 g), these differences were not statistically significant. In contrast, K application had a notable effect, with 225 kg/ha yielding the highest dry weight (1.82 g), representing a 41.1% increase compared to 0 kg/ha (1.29 g). The application of 150 kg/ha (1.72 g) and 75 kg/ha (1.51 g) also resulted in considerable increases. The observed progressive increase in dry weight with higher K doses suggests that K is instrumental in enhancing carbohydrate translocation and biomass accumulation, thereby contributing to overall plant productivity (Figure 5).

K uptake was significantly influenced by K fertilization but not by compost application. Although leucaena compost (0.86 kg/ha) and rice straw compost (0.79 kg/ha) showed slightly higher potassium uptake than the absence of compost (0.69 kg/ha), these differences were not statistically significant. Conversely, potassium fertilization resulted in a significant increase, with 225 kg/ha achieving the highest uptake (0.95 kg/ha), reflecting a 39.7% improvement over the lowest recorded uptake at 0 kg/ha (0.68 kg/ha). Application of 150 kg/ha (0.81 kg/ha) and 75 kg/ha (0.69 kg/ha) produced intermediate values. The increase in K uptake at higher doses underscores the role of K in nutrient absorption, enzyme activation, and overall plant metabolism (Figure 6).

TSS was also significantly influenced by K fertilization, but not by compost application. Although leucaena compost (1.83 °Brix) and rice straw compost (1.71 °Brix) recorded higher TSS than in the absence of compost (1.50 °Brix), these variations were not statistically significant. However, K fertilization led to a clear increase, with 225 kg/ha producing the highest TSS (2.17

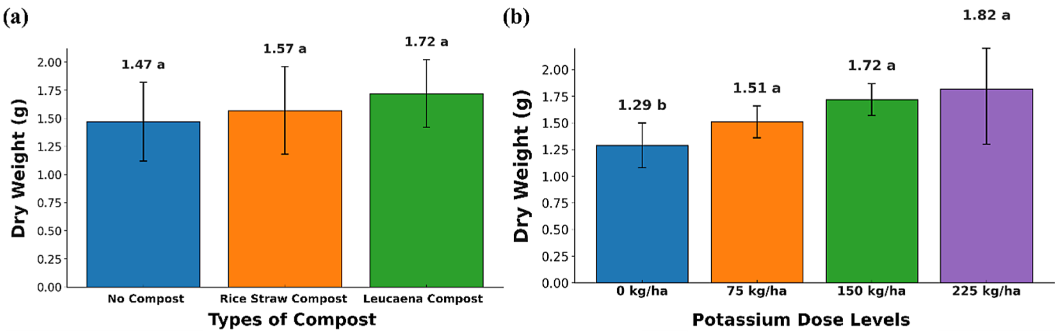

Figure 5. Effects of compost type and potassium fertilization on the dry weight of stevia. Bar charts illustrate the effects of (a) compost type (no compost, rice straw compost, and leucaena compost) and (b) potassium (K_2O) application rates (0, 75, 150, and 225 kg/ha) on the dry weight (g) of stevia. Error bars represent standard deviation. Different letters above the bars indicate statistically significant differences among treatments according to DMRT at $p < 0.05$

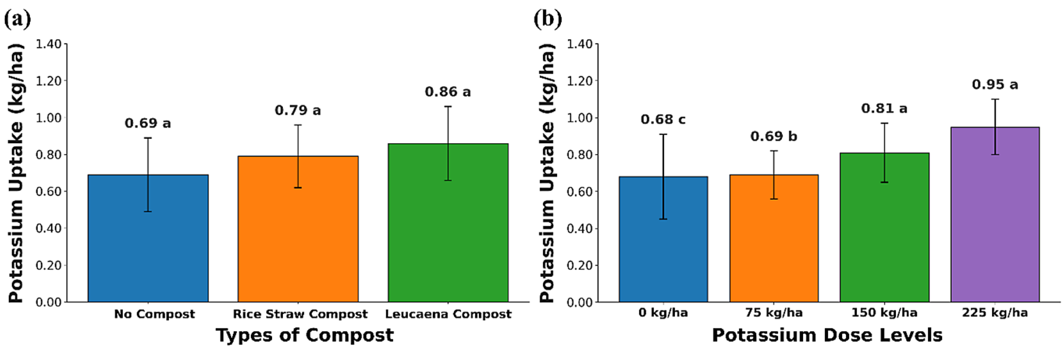

Figure 6. Effects of compost type and potassium fertilization on potassium uptake in stevia. Bar charts illustrate the effects of (a) compost type (no compost, rice straw compost, and leucaena compost) and (b) potassium (K_2O) application rates (0, 75, 150, and 225 kg/ha) on potassium uptake (kg/ha) in stevia. Error bars represent standard deviation (SD). Different letters above the bars indicate statistically significant differences among treatments based on DMRT at $p < 0.05$

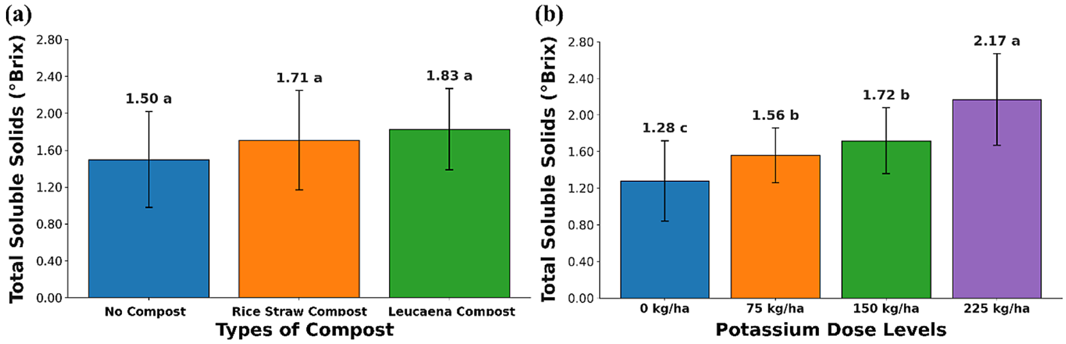

Figure 7. Effects of compost type and potassium fertilization on TSS in stevia. Bar charts illustrate the effects of (a) compost type (no compost, rice straw compost, and leucaena compost) and (b) potassium (K_2O) application rates (0, 75, 150, and 225 kg/ha) on TSS (°Brix) in stevia. Error bars represent standard deviation (SD). Different letters above the bars indicate statistically significant differences among treatments based on DMRT at $p < 0.05$

°Brix), representing a 69.5% increase compared to 0 kg/ha (1.28 °Brix). The application of 150 kg/ha (1.72 °Brix) and 75 kg/ha (1.56 °Brix) resulted in moderate improvement. Enhanced sugar accumulation with K fertilization suggests that K plays a critical role in carbohydrate metabolism by promoting efficient photosynthesis and sugar translocation within plant tissues (Figure 7).

Overall, these findings indicate that fresh weight was the only parameter that was significantly influenced by both compost and K fertilization, whereas dry weight, K uptake, and TSS were predominantly affected by K application.

Correlation analysis between soil chemical properties and stevia growth performance

The Pearson correlation matrix (Figure 8) elucidates the interrelationships among four principal soil properties: pH, EC, CEC, and exchangeable K. Statistically significant correlations ($p < 0.05$) are denoted by asterisks (*), which indicate

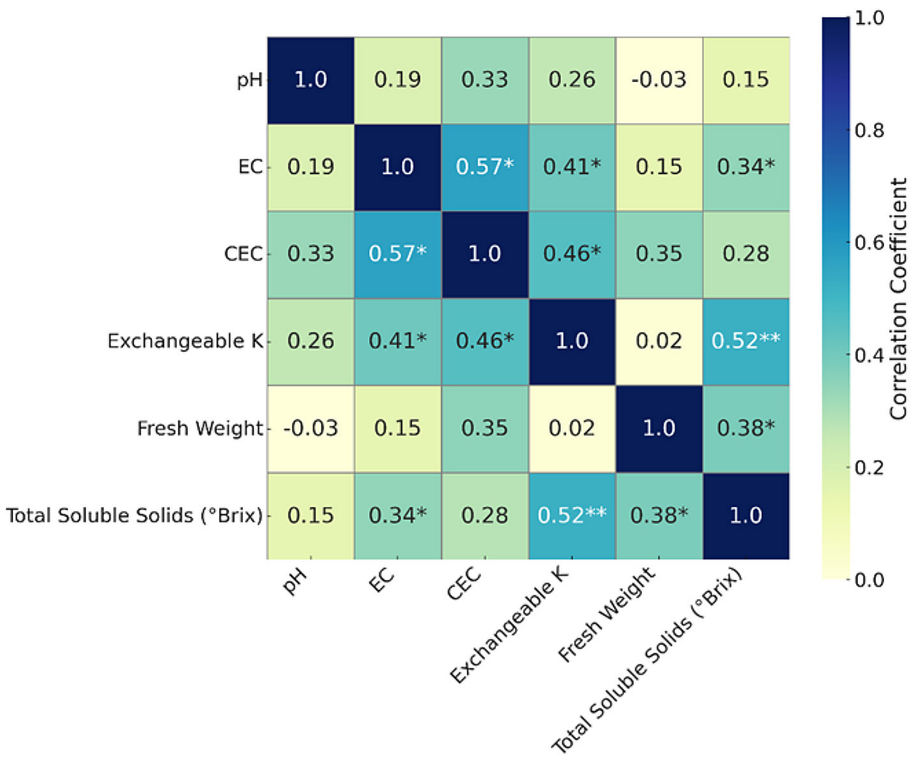

Figure 8. Heatmap showing Pearson's correlation coefficients between soil chemical properties (pH, EC, CEC, and exchangeable K), fresh weight, and TSS. The intensity of the color represents the strength of the correlation, ranging from 0 (no correlation) to 1 (perfect positive correlation). Asterisks indicate statistically significant

the strength and direction of these associations. The analysis identified a moderate and statistically significant positive correlation between EC and CEC ($r = 0.57$, $p < 0.05$), implying that soils with elevated ionic conductivity are likely to exhibit an enhanced capacity for cation exchange. Similarly, EC demonstrated a positive correlation with exchangeable K ($r = 0.41$, $p < 0.05$), suggesting that more conductive soils tend to retain higher levels of exchangeable K. Furthermore, CEC exhibited a moderate positive correlation with Exchangeable K ($r = 0.46$, $p < 0.05$), underscoring the essential role of cation exchange capacity in nutrient retention.

Conversely, soil pH displayed weaker, non-significant correlations with other properties. Its correlations with EC ($r = 0.19$), CEC ($r = 0.33$), and exchangeable K ($r = 0.26$) were positive but did not achieve statistical significance. These correlations remained relatively weak across the observed parameters.

The correlation heatmap illustrates the relationships among selected soil chemical properties, including pH, EC, CEC, and exchangeable K, as well as plant growth and quality indicators, such as fresh weight and TSS. Moderate and statistically significant positive correlations were identified between EC and CEC ($r = 0.57$, $p < 0.05$) and between CEC and exchangeable K ($r = 0.46$, $p < 0.05$). Soils with elevated ionic conductivity tend to demonstrate enhanced nutrient retention capacity and increased levels of exchangeable K, aligning with the anticipated behavior of soils enriched with soluble salts and essential cations.

Exchangeable K also exhibited a significant and relatively strong correlation with TSS ($r = 0.52$, $p < 0.01$), suggesting a potential association between K availability and sugar accumulation in plant tissues. This relationship is biologically plausible, given the critical role of potassium in the translocation of photosynthates and carbohydrate metabolism. TSS further displayed moderately significant correlations with EC ($r = 0.34$, $p < 0.05$) and fresh weight ($r = 0.38$, $p < 0.05$), indicating that increased ion availability and biomass production may be linked to higher TSS. However, soil pH exhibited weak, non-significant correlations with all measured parameters, implying that pH variation within the studied range had a limited effect on both soil nutrient dynamics and plant performance.

Fresh weight demonstrated a weak-to-moderate positive correlation with CEC ($r = 0.35$) and TSS ($r = 0.38$, $p < 0.05$), although correlations with other soil parameters were not statistically significant. Overall, these findings underscore the functional importance of exchangeable K and CEC in influencing physiological traits related to plant growth and quality, particularly sugar accumulation.

DISCUSSION

The application of organic amendments significantly influenced soil chemical properties, highlighting their role in enhancing soil fertility. Among the treatments, leucaena compost was particularly effective in adjusting the soil pH, which is consistent with Lim et al., (2015), who reported that composting increases the pH owing to microbial activity during decomposition. This increase in pH is crucial for improving nutrient availability because micronutrient solubility is enhanced under slightly alkaline conditions (Honda and Borthakur, 2022). Additionally, leucaena compost provides a buffering effect, stabilizing soil pH and preventing extreme fluctuations that could hinder plant growth (Costa et al., 2019).

Inceptisols in Indonesian uplands are generally acidic, with moderate organic matter levels. Under such conditions, organic amendments, such as Leucaena compost, play a critical role in buffering soil pH and enhancing nutrient cycling, which is vital for improving productivity under rainfed systems. These findings confirm its value not only for improving soil structure but also for promoting sustainable agricultural practices (Endriani and Listyarini, 2023a).

Maintaining a pH range of 6.0 to 7.0 is essential for stevia cultivation, as it optimizes nutrient absorption and microbial activity in the rhizosphere, directly influencing plant growth and yield (Xu et al., 2024). The application of leucaena compost successfully maintained soil pH within this range, reinforcing its potential as an effective organic amendment for stevia production. Additionally, compost amendments influenced the EC and CEC, which are both critical factors for nutrient retention and plant uptake.

The use of leucaena compost and rice straw compost has gained significant attention owing to their positive effects on soil quality and crop productivity. Leucaena compost, which is rich in organic C and nitrogen, has been shown to improve soil fertility and maintain pH stability, thereby enhancing nutrient uptake and microbial activity

(Endriani and Listyarini, 2023b). The observed improvements in soil chemical properties following the application of leucaena compost suggest underlying biochemical interactions worth analyzing. Previous studies have demonstrated that the EC of compost varies depending on the organic materials used and the composting process (Fauzan et al., 2025). In this study, leucaena compost resulted in a slightly higher CEC than rice straw compost, improving the ability of the soil to retain K^+ and ensuring a more stable nutrient supply for stevia (Zakarya et al., 2018).

The results also showed that exchangeable K was highest in soils amended with leucaena compost, further confirming its role in K retention and nutrient availability. This finding aligns with a previous study indicating that organic amendments increase K retention, directly supporting plant growth (Chairuman et al., 2023). The enhancement in soil CEC and nutrient availability may be attributed not only to the intrinsic chemical composition of compost but also to the stimulation of beneficial microbial populations that facilitate nutrient mineralization and ion exchange.

Organic matter contributes to increased CEC through its carboxyl and phenolic functional groups, which create negatively charged sites to retain cations such as K^+, Ca^{2+}, and Mg^{2+}. Microbial decomposition further enhances mineral availability through enzymatic hydrolysis. According to Fauzan et al., (2024), higher organic matter content is positively correlated with elevated CEC. In this research, the average CEC values in compost-treated soils were higher than the initial CEC of 18.91 cmol/kg, confirming the contribution of organic inputs in improving soil CEC. However, no significant difference in CEC was found between the rice straw and leucaena compost treatments.

Leucaena compost exhibited the most pronounced effects on soil pH, EC, and CEC, whereas both compost types significantly enhanced exchangeable K. Although K fertilization did not significantly influence any of the tested soil parameters, these improvements highlight the dominant role of compost in soil chemical enhancement. Unlike calcium and magnesium, potassium is highly soluble and less likely to be retained in soil exchange complexes. This explains the minimal effect of K fertilization on soil parameters, despite its physiological importance to plants.

The absence of significant interactions between compost and K treatments further suggests that compost amendment alone is sufficient to improve soil fertility. Although the initial growth may lag owing to the slower release of nutrients from the compost, the long-term benefits include improved soil structure and enhanced microbial activity, which subsequently leads to increased fertility (El-Ghait et al., 2021). Organic fertilizers, such as composted residues and farmyard compost, have been shown to improve soil quality by enhancing the physical and biological properties of soil (El-Sirafy et al., 2015). This correlates well with findings that plant responses, including leaf biomass and overall vegetative growth, are significantly amplified by the use of organic inputs (Obidola et al., 2019). Despite a slower initial nutrient release, organic compost eventually improves plant vigor and productivity. Hence, it is vital for stevia cultivation practices to incorporate compost to harness these benefits and promote sustainable agricultural practices in the long term (Blanchet et al., 2016; Thierry et al., 2019).

Research has established that potassium is vital for various biochemical and physiological processes in plants. It significantly affects chlorophyll synthesis, which is essential for photosynthesis. For instance, studies have shown that the application of optimal levels of potassium fertilizer leads to an increase in chlorophyll content and enhances photosynthetic rates in stevia leaves, contributing positively to biomass accumulation and overall plant growth (Correa-Villacorta et al., 2023; Hamad, 2015; Ma et al., 2011). This effect was further supported by Bidabadi et al., (2016), who highlighted that potassium is integral to enzyme functions, which are critical for enhancing the physiological and metabolic processes of stevia.

The application of potassium fertilizer enhances plant growth, as potassium plays a vital role in various physiological processes and metabolic functions, including protein biosynthesis and the regulation of turgor pressure (Benhmimou et al., 2018). Potassium also enhances photosynthetic activity and stimulates the division and elongation of meristematic cells (Gatie et al., 2021), thereby increasing stevia height.

Although K fertilization plays an essential role in enhancing biomass and sweetness in stevia, its application did not significantly influence soil parameters in the short term. This reflects the fact that K's agronomic benefits of K primarily manifest within the plant system rather than through immediate changes in soil chemistry. Therefore, combining compost with appropriate nutrient management may offer the most efficient path for improving both soil health and crop performance in the long run.

However, the results also suggest that although K fertilization plays a vital role in stevia development, particularly in enhancing biomass and TSS, it does not significantly influence leaf area formation under the tested conditions. This implies that compost application plays a decisive role in promoting leaf expansion, likely because of its effect on soil structure, water retention, and base nutrient availability, making it a cornerstone of sustainable agricultural strategies for stevia cultivation. Potassium is essential for enhancing photosynthetic efficiency, metabolic activity, and secondary metabolite production in stevia, particularly steviol glycosides, which determine its sweetening properties (Mohammed et al., 2019; Youssef et al., 2021). Our findings indicate that across all measured soil parameters, leucaena compost exhibited the highest values compared to rice straw compost. This can be attributed to the superior nutrient composition of leucaena compost (Table 2).

A positive correlation between K levels and increased fresh/dry biomass yields was evident, as K fertilization significantly improved stevia growth. Studies have demonstrated that optimal K application increases fresh leaf yield to 2.780 kg/ha and dry leaf yield to 636 kg/ha (Inugraha et al., 2014). The role of K in maximizing biomass and leaf expansion has been attributed to its effects on photosynthesis and metabolic activity (Mohammed et al., 2019; Youssef et al., 2021).

An increase in TSS, which often indicates higher sugar levels in plants, has been positively correlated with EC, as elements measured by EC, such as salts and minerals, not only influence TSS concentrations, but also affect photosynthesis and sugar accumulation (Mohamat et al., 2023). In stevia plants, an adequate nutrient supply tends to elevate EC, which subsequently leads to increased TSS levels owing to enhanced photosynthetic activity (Adainoo et al., 2022). The observed positive correlation between EC and TSS can be attributed to the role of ionic concentration in modulating osmotic pressure, enhancing sugar transport, and promoting the synthesis of steviol glycosides under adequate K nutrition.

Furthermore, potassium influences TSS in stevia, which confirms that higher potassium levels lead to a higher sugar content. TSS, commonly measured using the Brix scale, is a critical parameter for evaluating the sugar content of various substances, including plants such as stevia. Brix measurement is a quick method employed across different stages of supply chains to gauge the overall sugar concentration present in a solution, making it a suitable method for assessing the sugar content in stevia (Ahmed et al., 2022). This aligns with the findings of Sun et al., (2021) and Śniegowska et al., (2024), who reported that potassium deficiency reduces steviol glycoside synthesis, leading to a 15–25% decrease in sweetness potential. Additionally, K fertilization has been linked to improved photosynthetic rates and chlorophyll content, which further enhances plant productivity (Ma and Shi, 2011). A synergistic effect was also observed when K was combined with nitrogen, significantly boosting nutrient uptake, increasing the leaf area index, and enhancing the yield potential (Hamad, 2015). These findings reinforce the necessity of potassium in stevia cultivation, not only for biomass production but also for optimizing glycoside accumulation and enhancing overall crop quality.

CEC plays a significant role in regulating K availability, which further influences the growth performance of stevia. Higher CEC values in both rice straw compost and leucaena compost treatments improved the availability and retention of potassium ions, enabling plants to efficiently absorb nutrients. Research has shown that increased root CEC positively correlates with enhanced K uptake, as plants adaptively modify their root systems to maximize nutrient absorption (Ruan et al., 2013). Compost application further elevates CEC and improves K retention (Dotaniya et al., 2024). A similar study by Mangaraj et al., (2023) confirmed that combining compost with chemical fertilizers results in a higher CEC, leading to improved K availability in the soil.

In summary, the integration of organic amendments, particularly leucaena compost, with K fertilization presents a promising strategy to enhance both soil health and stevia productivity. Improvements in soil CEC and pH facilitate nutrient retention and uptake, whereas potassium supports physiological processes critical to biomass accumulation and sugar synthesis. These findings emphasize the importance of combining organic and mineral nutrition approaches for sustainable stevia cultivation under tropical Inceptisol conditions.

CONCLUSIONS

This study demonstrated that integrating organic amendments with K fertilization significantly enhanced the soil fertility and agronomic performance of stevia in Inceptisol. Leucaena compost was particularly effective in improving soil pH, EC, and CEC, while both leucaena and rice straw composts significantly increased exchangeable K. Potassium fertilization, especially at a dose of 225 kg K_2O/ha, substantially improved plant biomass, potassium uptake, and TSS, although its effect on soil properties was minimal in the short term. Notably, compost played a dominant role in enhancing soil chemical properties and vegetative growth, such as plant height and leaf area, whereas K application primarily influenced physiological traits, including dry weight and sugar accumulation. The absence of significant interaction effects suggests that the benefits of organic and potassium inputs are additive rather than synergistic in the short term. Correlation analysis further confirmed the importance of exchangeable K and CEC in influencing fresh weight and TSS content. These findings underscore the value of combining organic and inorganic fertilization strategies to optimize stevia productivity, support sustainable soil management, and contribute to healthier natural sweetener alternatives, particularly in marginal soils such as Inceptisols. Future studies should focus on long-term field validation and economic feasibility across diverse agroecological zones. In particular, investigations into the residual effects of compost application and shifts in soil microbial communities under prolonged treatment are essential to understand the full scope of sustainability and soil health outcomes

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