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Assessing Integrated Nutrient Management Strategies for Improved Growth Rates and Nutrient Uptake in Stevia (*Stevia rebaudiana* Bertoni)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

With the increasing demand for stevia as a natural sweetener among health-conscious diabetics, a field trial was conducted in 2022 and 2023 at the Agronomy farm, College of Agriculture, Vellanikkara, to evaluate the impact of integrated nutrient management (INM) on growth rates and nutrient uptake of stevia (*Stevia rebaudiana* Bertoni). The experiment followed a factorial randomized block design (FRBD) with two factors: manure (no manure, vermicompost at 2.5 t ha^{-1}, and farmyard manure at 5 t ha^{-1}) and NPK levels (20:10:10, 40:20:20, and 60:30:30 kg ha^{-1}). The

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highest crop growth rate (CGR) was observed with FYM @ 5 t ha^{-1} and 60:30:30 NPK kg ha^{-1}, particularly at the 30-45 DAP stage. Relative growth rate (RGR) was significantly influenced only during the first growth period, with the highest RGR observed under FYM @ 5 t ha^{-1} and 60:30:30 NPK kg ha^{-1}. Pooled mean nitrogen and phosphorus uptake was highest with FYM @ 5 t ha-¹, and higher potassium uptake was with FYM @ 5 t ha-¹ and vermicompost @ 2.5 t ha-¹ among manures The highest NPK uptake was obtained with 60:30:30 NPK kg ha^{-1} among NPK levels. In conclusion, the combined application of FYM @ 5 t ha-¹ and NPK @ 60:30:30 kg ha-¹ resulted in better growth performance and nutrient absorption by stevia.

Keywords: Stevia; INM; CGR; RGR; nutrient uptake.

1. INTRODUCTION

The growing demand for medicinal plants has underscored the need for sustainable cultivation methods, as relying on wild sources alone is insufficient to meet this increasing demand. Cultivating these plants ensures a steady supply and contributes to the preservation of biodiversity. *Stevia rebaudiana*, a sweet herb originally from the northeastern region of Paraguay, is one such plant that gained significant popularity in the late 20th century (Brandle & Rosa, 1992). Famous for its low-calorie sweetness, the primary sweetening compounds in *Stevia rebaudiana* Bertoni are stevioside, rebaudioside-A, rebaudioside-C, and dulcoside-A, which are, respectively, 210, 242, 30, and 30 times sweeter than sucrose (Kinghorn, 1987). These sweet compounds are distinctive because they remain unaltered as they pass through the digestive system, making them a safe choice for individuals dealing with managing blood glucose levels. In addition to its sweetening properties, stevia is also valued for its potential health benefits, including its use in treating conditions such as cancer, obesity, hypertension, fatigue, and depression, as well as its applications in cosmetics and dental care and many researchers have confirmed to be safe for child use (Carrera-Lanestosa *et al.*, 2017; Aguero *et al.*, 2014). The growing popularity of stevia, due to its appealing taste, wide range of uses and zero-calorie natural sweetener properties, has led Indian farmers to cultivate it commercially, resulting in its successful cultivation across several states, including Rajasthan, Maharashtra, Punjab, and Orissa (Goyal *et al.*, 2010).

Implementing effective cultivation strategies is necessary to optimize the yield. Stevia, which naturally grows in the low-quality soils of its native Paraguay, has relatively low to moderate nutritional requirements (Geonadi, 1987). However, successful commercial cultivation demands the addition of external fertilizers to sustain high yields (Rashid *et al.*, 2013). While chemical fertilizers can boost production, their prolonged use may result in soil degradation. As a solution, integrated nutrient management, combining organic and inorganic fertilizers, is a vital strategy for increasing yield while preserving soil health. Although the precise nutrient requirements of stevia, especially with South Indian soils, remain unclear, the recommended dose of fertilizers (RDF) is estimated to be 60:30:45 kg NPK per hectare (Farooqi and Sreeramu, 2004).

Crop growth rate (CGR) and relative growth rate (RGR) are critical metrics for evaluating the viability and productivity of agricultural practices. These indicators offer insights into how effectively a plant adapts to different cultivation methods and environmental conditions, essential for optimizing yield. Furthermore, analyzing growth rates at various developmental stages enhances our understanding of a plant's nutritional needs and capacity to endure abiotic stressors, informing effective crop management strategies. Understanding nutrient uptake is essential for developing fertilization strategies that align with the crop requirement. The primary nutrients like nitrogen (N), phosphorus (P), and potassium (K) are crucial for photosynthesis, energy transfer, and growth, while their dynamics help identify deficiencies and optimize plant productivity (Angelini & Tavarini, 2014). Against this background, this study was conducted to understand the influence of integrated nutrient management on the crop and relative growth rates and primary nutrient uptake by stevia.

2. MATERIALS AND METHODS

The field experiment titled "Effect of Integrated nutrient management on Growth, Yield, and Quality of *Stevia rebaudiana* B." was carried out at the Agronomy Farm, Department of

Agronomy, College of Agriculture, Vellanikkara, Thrissur, Kerala, from April to August in both 2022 and 2023. The experimental site is situated at a latitude of 13° 32'N and longitude of 76° 26'E, at an altitude of 40 meters above sea level. The annual rainfall recorded was 3128.3 mm in 2022 and 2697.3 mm in 2023. The soil texture of the field was sandy clay loam, with an acidic pH of 4.68, an electrical conductivity (EC) of 0.07 ds/m, 1.33% organic carbon, and available nutrient levels of 146 kg/ha nitrogen (N), 33 kg/ha phosphorus (P), and 188 kg/ha potassium (K). The experiment was conducted in a factorial randomized block design (FRBD) under two factors with three levels in each factor, forming nine treatment combinations that were replicated thrice. The first factor included manures with the levels as no manure, vermicompost @ 2.5 t ha^{-1}, and farmyard manure @ 5 t ha^{-1} and the second factor included NPK levels as 20:10:10, 40:20:20, and 60:30:30 NPK kg ha^{-1}.

The field preparation involved thorough ploughing and discing, followed by the preparation of 3m x 3m beds, which were then mulched with 30 µ plastic sheets. A green-colored shade net with 25% sunlight permeability was installed to provide artificial shading over the entire experimental area. As per the treatments, the beds were fertilized with well-decomposed farmyard manure or vermicompost applied as a basal dose two weeks before transplantation, during bed preparation, and before mulching. One-month-old rooted stem cuttings, each with 4-5 nodes raised in the nursery, were uniformly transplanted in all the beds at a spacing of 30 cm x 30 cm in both years. The full dose of P and half dose of N and K fertilizers were applied as basal and the rest was applied one month after transplanting as per the treatments. Regular intercultural operations, including irrigation and weeding, were carried out during the experimental period. A single harvest was taken 110 days after planting (DAP) by uprooting the plants in both years. Statistical analysis was conducted using analysis of variance (ANOVA) with the "grapes Agri 1" statistical package (Gopinath *et al.*, 2020), an R-based online tool developed by Kerala Agricultural University.

2.1 Growth Rates Measurement

Crop growth rate (CGR) and relative growth rate (RGR) were determined at three growth stages *i.e.* at 0-30 DAP, 30-45 DAP, and 45 DAP-harvest in both years by using the formulae given by Watson (1952) and Blackman (1919) respectively.

$$\text{CGR (g m}^{-2}\text{ day}^{-1}) = (W_2 - W_1)/ A (t_2 - t_1)$$

$$\text{RGR (g g}^{-1}\text{ day}^{-1}) = (\log_e W_2 - \log_e W_1)/ t_2 - t_1$$

Where W_1 and W_2 represent the dry weight of plants respectively at time t_1 and t_2, A is the land area.

2.2 Nutrient uptake by Plant at Harvest

Plant samples collected from each replication were cleaned, shade-dried, then oven-dried at 65±5°C to a constant weight, and ground into fine powder. The NPK content was analyzed using standard procedures (Bremner and Mulvaney, 1982; Jackson,1973). Nutrient uptake by the plant at harvest was calculated by multiplying dry matter production with the nutrient content and expressed in kg ha^{-1}.

3. RESULTS AND DISCUSSION

3.1 Crop Growth Rate (g m^{-2} day^{-1})

Crop growth rates (CGR) of stevia at (0-30 DAP), (30-45 DAP), and (45 DAP-Harvest) growth stages in two years and the pooled mean are presented in Table 1. The CGR of stevia was significantly affected by both manures and fertilizers at all three growth stages. In contrast, the interaction was found to be significant only in the first two stages in 2022 and 2023, as well as the pooled mean. Across the growth periods in both the years and pooled mean, the highest CGR was found in FYM @ 5 t h^{-1} among manures and in 60:30:30 NPK kg ha^{-1} among NPK levels. The pooled mean of CGR at 0-30 DAP and 30-45 DAP were found to be significantly higher under fertilization with FYM @5t ha^{-1} in combination with NPK @60:30:30 kg ha^{-1} which is comparable to FYM @5 t ha^{-1} along with NPK 40:20:20 kg ha^{-1} followed by VC @ 2.5 t ha^{-1} in combination with NPK @ 60:30:30 kg ha^{-1}. Regardless of the treatments, a sharp increase in the CGR was observed from the first to the second growth period, while a more gradual rise occurred from the second to the third growth period in both years. The crop growth rate of stevia was found to be highest in FYM with higher level of NPK across all the growth stages. This can be attributed to enhanced physical, chemical, and biological properties of soil by applying well-decomposed organic manures. Improved soil aeration, increased microbial activity, and greater nutrient availability likely contributed to better root development and establishment, leading to more efficient nutrient absorption (Kumar *et al.*, 2024). Also, with the high level of NPK fertilizers, the nutrient availability increased, and stevia, a herbage crop where the leaf is the economic part, utilized it thoroughly. As a result, growth parameters were enhanced, leading to increased herbage production and faster crop growth rates.

3.2 Relative Growth Rate (g g^{-1} day^{-1})

Relative growth rates (RGR) of stevia at (0-30 DAP), (30-45 DAP), and (45 DAP-Harvest) growth stages in two years and the pooled mean are presented in Table 2. The RGR of stevia, except for the first growth stage (0-30 DAP), was not significantly affected by any factors in 2022, 2023, or the pooled mean. At the 0-30 DAP stage, the RGR of stevia was significantly higher in FYM @5t ha^{-1} compared to other manure treatments, and in NPK @60:30:30 kg ha^{-1} compared to other NPK levels, in both 2022, 2023, and the pooled mean. The interaction effect on the RGR of stevia was found to be non-significant across all growth stages and years. Irrespective of the treatments, a slight increase in RGR was noted from the first to the second growth period, followed by a notable decline from the second to the third growth stage in both years. This typical pattern in relative growth rate is expected, as biomass production efficiency generally decreases over time due to plant senescence and the growth of non-photosynthetic woody tissues (Jarma-Orozco *et al.*, 2020).

3.3 Plant Nutrient uptake (NPK in kg ha^{-1})

Primary nutrient (NPK) uptake by stevia at harvest in 2022, 2023, and pooled mean data are presented in Table 3. Plant NPK uptake was significantly affected by manures and fertilizers and their combination in both years, *i.e.*, 2022, 2023, and pooled mean. Nitrogen and phosphorous uptake by stevia were found to be significantly high under FYM@5 t ha^{-1} among manures in both years and pooled mean, while the lowest was under no manure. The higher nitrogen uptake observed with farmyard manure at 5 t ha^{-1} can be attributed to the gradual and continuous release of nutrients to the crop, which improved nutrient availability in the soil, plant nutrient content, and overall biomass. The increased phosphorus concentration in stevia, resulting in higher P uptake, may be due to the enhanced solubilization of phosphorus, either through the activation of microorganisms in the soil that release organic acids (Suba Rao, 1982) or through increased phosphatase activity (Sainz *et al.*, 1998). The potassium uptake by stevia was higher in plots treated with farmyard manure and was similar to that in plots treated with vermicompost in 2022, 2023, and the pooled mean. The enhanced potassium uptake by stevia from vermicompost treatments can be ascribed to improved K availability, which shifts the soil's equilibrium from more exchangeable forms of K to more soluble ones (Basker *et al.*, 1992).

Among the different NPK levels, the highest nitrogen (N), phosphorus (P), and potassium (K) uptake by stevia were observed when 60:30:30 kg ha^{-1} of NPK was applied, in comparison to the lower doses. This increase in nutrient uptake with higher fertilizer application is likely due to the adequate supply and improved availability of nutrients to the plants throughout the growth period, leading to enhanced herbage production. Angkapradipta et al. (1986) also found that higher nitrogen supply resulted in increased nitrogen content and greater uptake in stevia. Additionally, the interaction between manures and fertilizers had a significant effect on the primary nutrient uptake in stevia. The two-year pooled mean nitrogen (N) uptake of stevia was significantly higher when fertilized with FYM @5t ha^{-1} combined with NPK @60:30:30 kg ha^{-1}, which was similar to the combination of FYM @5t ha^{-1} with NPK @40:20:20 kg ha^{-1}, and also comparable to VC @2.5t ha-1 combined with NPK @60:30:30 kg ha-1. In contrast, the pooled mean phosphorus (P) uptake by stevia was higher when fertilized with FYM @5t ha^{-1} and NPK @60:30:30 kg ha^{-1}, which was comparable to the combination of FYM @5t ha^{-1} with NPK @40:20:20 kg ha^{-1}. However, the pooled mean potassium (K) uptake was higher with both FYM and VC when combined with NPK @60:30:30 kg ha^{-1} and NPK @40:20:20 kg ha^{-1}. Similar results were reported by Rashid *et al*. (2013), who observed increased NPK uptake by stevia under integrated nutrient management (INM) with organic manures and higher NPK levels.

Table 1. Effect of Integrated nutrient management on the crop growth rate of stevia at (0-30 DAP), (30-45 DAP), and (45 DAP – Harvest) in 2022, 2023 and pooled mean

Treatments	2022			2023			Pooled		
	0-30 DAP	30-45 DAP	45 DAP - Harvest	0-30 DAP	30-45 DAP	45 DAP - Harvest	0-30 DAP	30-45 DAP	45 DAP - Harvest
Factor A – Manures									
A_1- No manure	0.284	1.800	2.227	0.323	1.959	2.434	0.304	1.880	2.331
A_2- Vermi compost @ 2.5 t ha^{-1}	0.364	2.136	2.646	0.408	2.287	2.856	0.386	2.212	2.751
A_3- FYM @ 5 t ha^{-1}	0.400	2.270	2.737	0.440	2.430	2.927	0.420	2.350	2.832
CD (0.05)	0.027	0.111	0.186	0.03	0.109	0.188	0.017	0.066	0.115
SE (m) ±	0.009	0.037	0.062	0.01	0.036	0.063	0.006	0.023	0.04
Factor B - Levels of NPK									
B_1- NPK @ 20:10:10 kg ha^{-1}	0.292	1.786	2.281	0.329	1.952	2.474	0.311	1.869	2.378
B_2- NPK @ 40:20:20 kg ha^{-1}	0.356	2.132	2.572	0.395	2.290	2.783	0.376	2.211	2.677
B_3- NPK @ 60:30:30 kg ha^{-1}	0.400	2.288	2.757	0.446	2.434	2.960	0.423	2.361	2.858
CD (0.05)	0.027	0.111	0.186	0.03	0.109	0.188	0.017	0.066	0.115
SE (m) ±	0.009	0.037	0.062	0.01	0.036	0.063	0.006	0.023	0.04
Treatment combination									
A_1B_1	0.238	1.562	2.002	0.271	1.740	2.108	0.254	1.651	2.055
A_1B_2	0.261	1.708	2.144	0.299	1.869	2.442	0.280	1.788	2.293
A_1B_3	0.353	2.130	2.537	0.401	2.269	2.752	0.377	2.199	2.644
A_2B_1	0.320	1.820	2.431	0.362	1.978	2.651	0.341	1.899	2.542
A_2B_2	0.371	2.284	2.704	0.411	2.442	2.900	0.391	2.362	2.802
A_2B_3	0.402	2.305	2.802	0.451	2.442	3.015	0.426	2.373	2.909
A_3B_1	0.317	1.975	2.411	0.356	2.138	2.661	0.336	2.056	2.536
A_3B_2	0.436	2.406	2.868	0.477	2.561	3.006	0.457	2.483	2.937
A_3B_3	0.447	2.428	2.932	0.486	2.590	3.113	0.466	2.509	3.022
CD (0.05)	0.047	0.192	NS	0.051	0.188	NS	0.03	0.115	NS
SE (m) ±	0.016	0.064	0.107	0.017	0.063	0.109	0.01	0.04	0.069

Table 2. Effect of Integrated nutrient management on the relative growth rate of stevia at (0-30 DAP), (30-45 DAP), and (45 DAP – Harvest) in 2022, 2023 and pooled mean

Treatments	2022			2023			Pooled		
	0-30 DAP	30-45 DAP	45 DAP - Harvest	0-30 DAP	30-45 DAP	45 DAP - Harvest	0-30 DAP	30-45 DAP	45 DAP - Harvest
Factor A - Manures									
A_1- No manure	0.031	0.039	0.011	0.033	0.038	0.011	0.032	0.038	0.011
A_2- Vermi compost @ 2.5 t ha^{-1}	0.034	0.038	0.011	0.036	0.037	0.011	0.035	0.037	0.011
A_3- FYM @ 5 t ha^{-1}	0.036	0.037	0.011	0.037	0.037	0.011	0.036	0.037	0.011
CD (0.05)	0.001	NS	NS	0.01	NS	NS	0	NS	NS
SE (m) ±	0	0	0	0	0	0	0.001	0	0
Factor B - Levels of NPK									
B_1- NPK @ 20:10:10 kg ha^{-1}	0.031	0.038	0.011	0.033	0.038	0.011	0.032	0.038	0.011
B_2- NPK @ 40:20:20 kg ha^{-1}	0.034	0.038	0.011	0.035	0.038	0.011	0.030	0.038	0.011
B_3- NPK @ 60:30:30 kg ha^{-1}	0.036	0.037	0.011	0.037	0.036	0.011	0.036	0.037	0.011
CD (0.05)	0.001	NS	NS	0.01	NS	NS	0	NS	NS
SE (m) ±	0	0	0	0	0	0	0.001	0	0
A x B (Interaction)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 3. Effect of organic manures on the plant nutrient uptake of stevia in 2022, 2023, and pooled mean

Treatments	2022			2023			Pooled		
	N	P	K	N	P	K	N	P	K
Factor A - Manures									
A_1- No manure	23.11	3.88	38.27	25.88	4.42	41.73	24.49	4.15	40.00
A_2- Vermi compost @ 2.5 t ha^{-1}	33.00	5.02	54.54	36.03	5.64	60.76	34.52	5.33	57.65
A_3- FYM @ 5 t ha^{-1}	35.23	5.61	54.80	38.32	6.22	60.18	36.78	5.92	57.49
CD (0.05)	2.21	0.35	3.61	2.27	0.36	3.71	1.37	0.22	2.26
SE (m) ±	0.736	0.115	1.205	0.756	0.121	1.237	0.479	0.076	0.792
Factor B - Levels of NPK									
B_1- NPK @ 20:10:10 kg ha^{-1}	24.98	3.94	37.54	27.61	4.47	42.64	26.30	4.21	40.09
B_2- NPK @ 40:20:20 kg ha^{-1}	30.93	5.01	51.52	34.02	5.62	56.48	32.47	5.32	54.00
B_3- NPK @ 60:30:30 kg ha^{-1}	35.43	5.55	58.54	38.60	6.19	63.55	37.02	5.87	61.05
CD (0.05)	2.21	0.35	3.61	2.27	0.36	3.71	1.37	0.22	2.26
SE (m) ±	0.736	0.115	1.205	0.756	0.121	1.237	0.479	0.076	0.792
Treatment combination									
A_1B_1	16.85	3.34	27.63	18.45	3.72	31.72	17.65	3.53	29.67
A_1B_2	20.56	3.59	36.06	24.37	4.25	39.14	22.47	3.92	37.60
A_1B_3	31.92	4.70	51.11	34.81	5.31	54.34	33.37	5.00	52.73
A_2B_1	28.32	4.2d	43.22	31.21	4.82	48.58	29.76	4.53	45.90
A_2B_2	34.65	5.22	58.03	37.64	5.83	65.20	36.15	5.52	61.61
A_2B_3	36.04	5.61	62.37	39.24	6.27	68.50	37.64	5.94	65.43
A_3B_1	29.77	4.25	41.78	33.18	4.88	47.62	31.47	4.57	44.70
A_3B_2	37.57	6.23	60.48	40.05	6.79	65.11	38.81	6.51	62.80
A_3B_3	38.34	6.35	62.15	41.75	7.00	67.80	40.04	6.68	64.98
CD (0.05)	3.82	0.60	6.23	3.93	0.63	6.42	2.37	0.37	3.92
SE (m) ±	1.275	0.199	2.079	1.31	0.21	2.142	0.83	0.131	1.372

4. CONCLUSION

Based on the results of the current study, integrated nutrient management involving the combined application of farmyard manure (FYM) at 5 t ha^{-1} along with NPK fertilizers at 60:30:30 kg ha^{-1}, is recommended for the successful cultivation of stevia in the acid laterite soils with low to medium fertility status. The findings indicate that the above combination promotes improved growth performance of stevia, as reflected in the crop and relative growth rates. In addition to improved plant growth, crop nutrient uptake also significantly increased with the combined application of organic manure with higher levels of NPK. Further research is necessary to evaluate the effects of integrated nutrient management on the nutritional profile of stevia, soil health, and overall sustainability in the long run.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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