Optimizing Growth Rates and Nutrient Uptake in Stevia (*Stevia rebaudiana* Bertoni) through Integrated Nutrient Management

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Abstract: Field trials wereconducted from April to August of 2022 and 2023 at the Agronomy farm, Department of Agronomy, College of Agriculture, Vellanikkara, Thrissur, to assess the impact of fertilization through a blend of organic and inorganic sources on growth rates and primary nutrient uptake of stevia (S*tevia rebaudiana* Bertoni). The experiment was conducted in a factorial randomized block design (FRBD) undertwofactorswith three levels in each, where the firstfactor includes manures with no manure, vermicompost (VC)@2.5 t ha^{-1} and farmyard manure (FYM) @ 5t ha^{-1}and the second factorincludesNPK levels with 20:10:10; 40:20:20; and 60:30:30ka ha^{-1}. Significantly highest pooled mean of CGR in all the growth stages was found in FYM@5 t ha^{-1} among manures and in 60:30:30 NPK kg ha^{-1} among fertilizer levels. The relative growth rate (RGR) of stevia was not affected by manures and fertilizers except for the first growth period in both years. Like CGR, the highest RGR of stevia at 0-30 DAP stage was found under FYM @5 t ha^{-1} among manures and in 60:30:30 NPK kg ha^{-1} among fertilizers in both years and pooled. Two-year pooled mean N and P uptake was significantly highest in FYM @5 t ha^{-1} among manures, whereas K uptake was found higher in FYM @5 t ha^{-1} and was on par with VC @2.5 t ha^{-1}. However, the pooled mean highest NPK uptake by stevia was found under 60:30:30 NPK kg ha^{-1} among fertilizer levels. The pooled mean interaction effect on NPK uptake by stevia was found to be significantly higher under FYM @5t ha^{-1} in combination with NPK @60:30:30 kg ha^{-1} treatment.

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 India 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 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). With its wide range of uses, the demand for stevia continues to grow.The growing popularity of stevia, due to its appealing taste 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).

To optimize the yield of its economically valuable components, it is necessary to implement effective cultivation strategies. 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} andthe 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 across 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 and raised in the nursery, were uniformly transplanted in all the beds at a spacing of 30 cm x 30 cm in both years.Thefull 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) weredetermined at three growth stages *i.e.*at 0-30 DAP, 30-45 DAP, and at 45 DAP to 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_2represent the dry weight of plants respectivelyat 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 (di- and tri-acid digestion followed by analytical procedures). Nutrient uptake by the plant at harvest was calculated by multiplying dry matter production by 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 thepooled mean are presented in Table 1. The CGR of stevia was significantly affected by both manures and fertilizers at all three growth stages, whereas the interaction was found to be significant only in the first two stages in 2022 and 2023, as well as the pooled mean. 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. 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 fertilizers. The pooled mean of CGR at 0-30 DAP and 30-45 DAPwere 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 @ NPK @ 60:30:30 kg ha^{-1}. The crop growth rate of stevia was found to be highest in FYM, and the dose of NPK fertilizer was highest across all the growth stages. This can be attributed to enhancing soil's physical, chemical, and biological properties 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 herbagecrop where the leaf is the economic part, utilized it thoroughly.As a result, growth parameters improved, fostering higher herbage production and 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 thepooled mean are presented in Table 2.The RGR of stevia, except for the first growth stage (0-30 DAP), was not significantly influenced by any factors in 2022, 2023, and pooled mean. RGR of stevia in 2022, 2023, and pooled mean was found to be significantly superior in FYM @5t ha^{-1} among manure and in NPK @60:30:30 kg ha^{-1} among fertilizers at 0-30 DAP stage. However, the interaction effect on the RGR of stevia was found to be non-significant among all the growth stages across years.Regardless of the treatments, a small increase in RGR was observed across all treatments from the first to the second growth period, followed by a sharp decline from the second to the third growth stage in both years. This pattern in relative growth rate is considered normal, as the efficiency of biomass production typically decreases over time due to plant senescence and the increased growth of non-photosynthetic woody tissues (Jarma-Orozco*et al.*, 2020).

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

Primary nutrient 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 werefound 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 increased N uptake under farmyard manure at 5 t ha^{-1} was due to the slow and sustained release of nutrients to the crop, thereby increasing nutrient content and overall biomass.The higher phosphorus concentration in stevia from farmyard manure, leading to increased P uptake, mightbe due to improved solubilization of phosphorus, either through the activation of microorganisms that release organic acids (Suba Rao, 1982) or by enhanced phosphatase activity(Sainz*et al.*, 1998).

Meanwhile,the potassium uptake by stevia was found to be higher in farmyard manure applied plots and was comparable to vermicompost applied plots in 2022, 2023, and 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 fertilizer treatments, the highest N, P, and Kuptake by stevia was observed when 60:30:30 kg ha^{-1} NPK was applied compared to lower doses. This increase in nutrient uptake at higher quantities of fertilizers could be due to sufficient supply and better availability of nutrients to plants throughout the growth period,resulting in better herbage production.Angkapradipta*et al.* (1986) also noted that increased nitrogen supply led to higher plant nitrogen content and greater uptake by stevia. The interaction effect of manures and fertilizers was also significant in stevia's primary nutrient uptake. The two-year pooled mean N uptake wassignificantly 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} which was again comparable to VC @ 2.5 t ha^{-1} in combination with NPK @60:30:30 kg ha^{-1}. Whereas, pooled mean P uptake by stevia was found higher under fertilization with FYM @5t ha^{-1}along with NPK @60:30:30 kg ha^{-1},which was on par with FYM@5 t ha^{-1} alongwith NPK 40:20:20 kg ha^{-1}.However, the pooled mean K uptake was higher under fertilization with both FYM and VC in combination with NPK @@60:30:30 and 40:20:20 ka ha^{-1}. Rashid *et* *al.*(2013) reported similar results withincreased NPK uptake under INM with organic manures and higher NPK levels.

Table 1. Effect of Integrated nutrient managementon 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 in kg ha^{-1}

Treatments	2022			2023			Pooled		
	N (kg ha $^{-1}$)	P (kg ha $^{-1}$)	K (kg ha $^{-1}$)	N (kg ha $^{-1}$)	P (kg ha $^{-1}$)	K (kg ha $^{-1}$)	N (kg ha $^{-1}$)	P (kg ha $^{-1}$)	K (kg ha $^{-1}$)
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 organic fertilization, particularly with FYM at 5 t ha^{-1} in conjunction with NPK fertilization at 60:30:30 kg ha^{-1}, promotes better overall growth of stevia, as reflected in the crop and relative growth rates. In addition to improved plant growth, crop nutrient uptake also significantly increased with organic manures and higher levels of NPK. Further research is necessary to assess the long-term effects of integrated nutrient management on soil health, the nutritional profile of stevia, and overall sustainability.

Acknowledgement: The study is a part of a PhD research work and the authors greatly acknowledgeKeralaAgricultural University for providing researchfacilities and financial support.

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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