Biological Forum

an International Journal 17(6): 53-58(2025)

ISSN No. (Print): 0975-1130
ISSN No. (Online): 2249-3239

Impact of Organic and Inorganic Nutrient Sources on Soil Physico-chemical properties and Productivity of (*Stevia rebaudiana* Bertoni)

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(Received: 20 March 2025; Revised: 26 April 2025; Accepted: 23 May 2025; Published online: 14 June 2025)
(Published by Research Trend)

ABSTRACT: The present study evaluated the effects of integrated nutrient management (INM) strategies on soil physico-chemical properties and yield performance of *Stevia rebaudiana* Bertoni under field conditions at Khalsa College, Amritsar, Punjab, India, during the 2022–2023 cropping season. A total of twelve treatment combinations integrating varying proportions of inorganic fertilizers (RDF) with farmyard manure (FYM) and vermicompost (VC) were assessed in a randomized block design with three replications. Results revealed that the combined application of 100% RDF with 2 t ha^{-1} VC (T_3) significantly enhanced fresh and dry leaf yield (18.65 q ha^{-1} and 5.16 q ha^{-1}, respectively) compared to control and sole fertilizer treatments. Soil health indicators also improved markedly under INM, with T_3 and T_2 (100% RDF + 5 t ha^{-1} FYM) treatments showing the highest gains in water holding capacity (41.29% and 41.65%, respectively), organic carbon content (0.44% and 0.47%), and available NPK. Integrated treatments notably reduced soil bulk density while improving porosity, pH balance, and macronutrient availability. These results suggest that INM approaches incorporating VC or FYM can sustainably improve soil quality and stevia productivity, offering a viable alternative to sole chemical fertilizer use in medicinal crop cultivation.

Keywords: Stevia, Organic, Inorganic, Soil Health, Integrated Nutrient Management.

INTRODUCTION

The rising demand for medicinal plants highlights the importance of sustainable cultivation methods, as relying solely on wild sources cannot fulfill this rising need. By cultivating these plants, we can ensure a consistent supply while also helping to preserve biodiversity (Kumar *et al.*, 2024). *Stevia rebaudiana* Bertoni, commonly known as "sweet herb of Paraguay," is a perennial herbaceous plant belonging to the Asteraceae family. Native to the semi-arid mountainous regions of northeastern Paraguay, it also occurs in adjacent areas of Brazil and Argentina. It is a perennial plant (Peteliuk *et al.*, 2021) and is now commonly used as a natural preference to synthetic sweeteners like aspartame, saccharin and acesulfame-K. Stevia is prized for its possible health advantages in addition to its ability to sweeten food. It has been used to treat various conditions, including cancer, obesity, hypertension, fatigue, and depression. Additionally, stevia has applications in cosmetics and dental care. Many researchers have confirmed that it is safe for use by children (Carrera-Lanestosa *et al.*, 2017). Stevia is now successfully cultivated in several Indian states, including Rajasthan, Maharashtra, Punjab, and Orissa (Goyal *et al*., 2010). It is believed that stevia can serve as a profitable diversification option in Punjab because of its agronomic and economic advantages over the current cropping cycle of paddy and wheat (Minhas *et al*., 2023).

Stevia grows well in a semi-humid subtropical climate and is best suited to well-drained soils, especially red and sandy loam types, with a preferred pH range of 6.5 to 7.5 (Kumar and Simon 2024). Stevia's growth is influenced by both environmental factors and agricultural practices, particularly nutrient management, which can improve both growth and yield (Kumar *et al*., 2024). While chemical fertilizers enhance plant growth and active compounds, their excessive and unbalanced use - without assessing soil health - can harm groundwater, disrupt soil biodiversity and reduce organic matter, threatening long-term sustainability (Calapardo and Manigo 2024). Additionally, the excessive use of inorganic fertilizers in modern farming-especially for medicinal crops-can result in harmful residues in medicinal products, posing a potential threat to human health and the environment. Therefore, it is crucial to transition towards safe and sustainable organic farming practices (Umesha *et al.*, 2011). Integrated nutrient management (INM), which combines inorganic fertilizer with organic manure, is an approach designed to maximize crop yield while maintaining soil health (Kumar *et al*., 2024). Research has demonstrated that optimal nutrient management during the cultivation of *Stevia rebaudiana* can significantly influence the plant's overall productivity (Sniegowska *et al*., 2024).

INM combining fertilizers and organic manures, offers an effective approach to preserving soil health and rectifying crop productivity (Bajpai *et al*., 2006). In addition to lowering the requirement for inorganic fertilizers, using crop residues, vermicompost (VC), farmyard manure (FYM), organic manures, and green manures combined with inorganic fertilizers enhances nutrient efficiency. This improvement occurs due to the positive impact of organic materials on the physical, chemical, and biological properties of the soil (Prasad *et al*., 1992). VC contains vital nutrients such as N (in the form of nitrate or ammonium), P and K, along with a rich diversity of beneficial microorganisms. These elements help support plant health and enhance recovery from pesticide exposure and various environmental stresses (Calapardo and Manigo 2024). An integrated approach that combines organic manures with chemical fertilizers can significantly enhance soil fertility on a long-term basis. This system provides nutrients in a balanced manner, leading to improved nutrient uptake by crops (Hussainy *et al*., 2019). This study examines how INM techniques alter the characteristics of the soil and *Stevia rebaudiana* productivity.

MATERIAL AND METHODS

A field trial was subjugated during the 2022–2023 growing season at the Student's Research Farm, Khalsa College, Amritsar, Punjab, India. The study employed a randomized block design (RBD) with three replications, encompassing twelve treatment combinations that integrated varying proportions of chemical fertilizers and organic manures *viz.*, T_1: 100 % RDF alone, T_2: 100 % RDF + 5 t ha^{-1} FYM, T_3: 100 % RDF + 2 t ha^{-1} VC, T_4: 50 % RDF + 5 t ha^{-1} FYM, T_5: 50 % RDF + 2 t ha^{-1} VC, T_6: 50 % RDF alone, T_7: 25 % RDF + 5 t ha^{-1} FYM T_8: 25 % RDF + 2 t ha^{-1} VC, T_9: 25 % RDF alone, T_{10}: 5 t ha^{-1} FYM alone, T_{11}: 2 t ha^{-1} VC alone and T_{12}: absolute control. The experimental field soil had an alkaline pH of 8.3, moderate amounts of accessible P (14.06 kg ha^{-1}) and K (247.11 kg ha^{-1}), and low amounts of available N (177.27 kg ha^{-1}) and organic carbon (0.39 %). The soil texture was sandy loam. Farmyard manure was incorporated into the field one week prior to transplanting at the recommended rate of 25 tonnes per hectare. As per the recommendation of Pal *et al*. (2017), the fertilizer dose applied was 110:45:55 kg ha^{-1} of N:P:K. At the time of transplantation, a half dose of N was administered as a basal dose together with the full amounts of K and P. Throughout the crop growth period, maximum temperatures ranged between 18.97°C and 38.44°C, while minimum temperatures fluctuated from 2.4°C to 28.05°C. Relative humidity during the season varied between 50.42% and 95.57%. Post-harvest, observations were recorded to assess changes in available NPK, organic carbon, bulk and particle density, porosity, water holding capacity, electrical conductivity (EC), soil pH, micronutrient levels, and stevia crop yield. Soil samples from each plot were analyzed to assess various parameters indicative of soil fertility and characteristics. Available N was determined using the alkaline permanganate method, as described by Subbiah and Asija (1956). P content was estimated through the colorimetric technique outlined by Olsen *et al.* (1954). K levels were measured using flame photometry, following the procedure established by Merwin and Peech (1951). EC and soil pH were measured using a digital pH meter and conductivity meter respectively (Jackson, 1973), and organic carbon content was estimated via the Walkley and Black rapid titration method (Walkley and Black 1934). Bulk density was determined using the core method (Prihar and Hundal 1971), while particle density was measured with the PAU moisture gauge (Prihar and Sandhu 1968). Water holding capacity was assessed through the Keen box method (Keen and Raczkowski 1921). The data collected during this study were subjected to statistical analysis using Microsoft Excel, incorporating techniques from Exploratory Data Analysis (EDA) to examine and interpret the dataset's underlying patterns and relationships. Treatment effects on soil fertility parameters, physical properties, and yield were evaluated at a 5% significance level using the Randomized Block Design (RBD) for assessing differences among treatment means.

RESULTS AND DISCUSSION

A. Physical properties of soil

The data conferred in Table 1 demonstrate that the application of various organic and inorganic nutrient sources significantly influenced soil physical properties, including bulk density, porosity, and water holding capacity, at the time of stevia harvest. Among the different treatments, the highest bulk density (1.45 g cm^{-3}) was observed in the control treatment (T_{12}), which was statistically comparable to T_1 (1.43 g cm^{-3}), T_6 (1.43 g cm^{-3}), and T_9 (1.44 g cm^{-3}). Conversely, the lowest bulk density (1.35 g cm^{-3}) was recorded in T_2, with values in T_3 (1.37 g cm^{-3}), T_4 (1.36 g cm^{-3}), T_7 (1.36 g cm^{-3}), and T_{10} (1.37 g cm^{-3}) not differing significantly. The reduction in bulk density under integrated treatments, compared to the control and sole application of inorganic fertilizers, may be accredited to increased organic matter content resulting from the addition of organic manures. This likely promoted better soil aggregation and increased pore space, thereby improving soil physical properties. Similar results were also documented by Yadav *et al*. (2024).

Soil porosity varied between 45.28 and 49.18 per cent across treatments. The highest porosity (49.18%) was recorded in treatment T_2 (100% RDF + 5 t ha^{-1} FYM), which was statistically comparable to T_4 and T_7 (both 48.68%). The lowest porosity was observed in the unfertilized control (T_{12}) at 45.28%, which was statistically similar to T_9 (45.79%). The improvement in porosity under integrated treatments may be attributed to the enhanced formation of soil aggregates resulting from the inclusion of organic amendments such as farmyard manure and VC. These organic inputs contribute to improved soil structure by reducing bulk density and enhancing aggregate stability, ultimately increasing pore space. Furthermore, FYM and vermicompost enhance soil porosity by improving structure and aggregation. This increased porosity boosts soil aeration, facilitating better root respiration and microbial activity, ultimately contributing to improved soil productivity (Yadav *et al*., 2024).

Water holding capacity (WHC) of the soil also responded positively to integrated nutrient management practices. The highest WHC (41.65%) was observed in T_2 (100% RDF + 5 t ha^{-1} FYM), which was statistically comparable to T_3 (41.29%) and T_4 (40.72%). The lowest WHC was recorded in T_{12} (unfertilized control) at 32.35%, followed by T_9 (35.36%). The observed increase in WHC under INM treatments may be linked to improved root proliferation, greater porosity, enhanced aggregate formation, and reduced bulk density due to the incorporation of organic manures. Also, the higher water holding capacity observed under INM practices can be attributed to the application of organic manures, which enhance soil fertility, boost microbial biomass, support beneficial organisms, and significantly improve the soil's ability to retain moisture (Devi *et al*., 2021).

B. Chemical properties of soil

The data presented in Table 2 showed the effect of INM on pH, EC and organic carbon of soil. The highest pH (8.30) was recorded under treatment T_9 (25% RDF alone) whereas lowest pH (8.23) recorded under T_2 (100% RDF + 5 t ha^{-1} FYM). The degradation of organic manures likely leads to the formation of organic acids, contributing to the slight decrease in soil pH. The reduction in soil pH may be attributed to the release of organic acids such as humic and carbonic acids during the mineralization of organic manures. Similar findings were reported by Roy and Kashem (2014).

The highest EC value (0.39 dS m^{-1}) was observed in treatment T_1 where only recommended dose of fertilizers was applied and the lowest EC (0.35 dS m^{-1}) was observed in T_5 where 50% RDF + 2 t ha^{-1} VC, T_{10} where 5 t ha^{-1} FYM and T_{12} where no fertilizer was applied. Similar results were shown by Thite *et al.* (2023).

The soil organic carbon content (0.47%) was observed highest in treatment T_2, which received 100% RDF along with 5 t ha^{-1} FYM, and it was statistically similar to treatments T_4 (0.46%), T_5 (0.45%), T_7 (0.46%), and T_{10} (0.45%). A significantly lower organic carbon value of 0.36 per cent was found in the control treatment (T_{12}), which was statistically on par with T_6 (0.38%). The enhanced SOC content noticed with manure treatments may result from the direct addition and gradual decomposition of organic inputs within the soil. Also, the increase in soil organic carbon is largely due to the direct input of organic matter from applied organic manures (Thite *et al*., 2023).

C. Macro nutrient availability in soil

During the investigation period, treatments exhibited significant variations in the available NPK content of the soil, as detailed in Table 3. Post-harvest analysis of stevia revealed that soil available N ranged from 174.40 to 226.15 kg ha^{-1}. Among the integrated nutrient management practices, treatment T_3 (100% RDF + 2 t ha^{-1} VC) recorded the highest available N level (226.15 kg ha^{-1}), which was statistically comparable to T_2 (223.06 kg ha^{-1}). Similarly, treatments T_1 (209.05 kg ha^{-1}), T_4 (210.05 kg ha^{-1}), and T_5 (211.81 kg ha^{-1}) showed no significant differences among them. Treatments T_6 (206.47 kg ha^{-1}), T_7 (205.98 kg ha^{-1}), T_8 (207.21 kg ha^{-1}), and T_{11} (204.47 kg ha^{-1}) were also statistically at par. The lowest N availability was observed in T_{12} (absolute control) at 174.40 kg ha^{-1}, followed by T_9 with 199.84 kg ha^{-1}. The increased N availability in treatments that received a combination of organic manures and chemical fertilizers may be attributed to both the mineralization of nutrients from the organic sources and the mobilization of native soil N. Similar results were reported by Bhanwaria and Yadav (2016).

The data indicated that an increase in soil available P levels at the time of stevia harvest compared to the initial soil status. Post-harvest available P concentrations ranged from 13.47 to 21.53 kg ha^{-1} across different treatments. The highest available P content (21.53 kg ha^{-1}) was observed in treatment T_3, which was statistically comparable to treatments T_2 (20.65 kg ha^{-1}), T_4 (19.47 kg ha^{-1}), and T_5 (20.21 kg ha^{-1}). Conversely, the lowest available P (13.47 kg ha^{-1}) was ascertained in the control treatment (T_{12}), which was statistically similar to T_9(15.61 kg ha^{-1}). The current findings suggest that the slower mineralization of FYM has led to a reduced availability of P in the soil. In contrast, plots treated with VC exhibited comparatively higher P availability, likely due to the accelerated mineralization process associated with VC application. The beheld rise in soil P content can be imputed to the combined effects of organic manures and inorganic fertilizers. Organic manures, such as farmyard manure, contribute P directly to the soil and release organic acids during decomposition. The solubility and availability of P in the soil can be increased by these organic acids' ability to chelate cations that fix P, such as calcium, iron, and aluminium. Additionally, it has been demonstrated that applying organic manures to inorganic fertilizers compliment the amount of P available in the soil. This improvement is ascribed to the increasing microbial activity and altering the pH of the soil, both of which promote the solubilization of inorganic P sources and the mineralization of organic P complexes. Our findings are in line with the findings of Thite *et al.* (2023).

The highest available K (293.78 kg ha^{-1}) was recorded in treatment T_3 (100% RDF + 2 t ha^{-1} VC), which was statistically comparable to T_2 (291.63 kg ha^{-1}). The lowest available K content (245.07 kg ha^{-1}) was observed in the control treatment (T_{12}). The increased availability of K under integrated nutrient management treatments may be associated to the interaction between organic matter and soil clay, which reduces K fixation and enhances K release. Additionally, the direct contribution of K from organic manures to the soil's available pool further explains the observed increase. Application of organic amendments thus contributed to higher available K content in the soil (Bhanwaria and Yadav 2016).

D. Yield parameters

Data on fresh leaf yield as influenced by the combined application of organic and inorganic fertilizers are presented in Table 4. The maximum fresh leaf yield (18.65 q ha^{-1}) was recorded under treatment T_3 (100 % RDF + 2 t ha^{-1} VC), which was statistically at par with T_2 (100 % RDF + 5 t ha^{-1} FYM), yielding 18.43 q ha^{-1}. The lowest fresh leaf yield (9.01 q ha^{-1}) was observed in the control treatment (T_{12}), which did not receive any organic or inorganic inputs and was statistically similar to T_{10} and T_{11}. The increased leaf yield observed under integrated nutrient management treatments can be attributed to the continuous and balanced supply of both macronutrients and micronutrients. This consistent nutrient availability supports robust plant growth, leading to enhanced leaf and branch development, and ultimately, a higher fresh yield per unit area.

The scrutiny of data transpires that application of 100 % RDF + 2 t ha^{-1} VC (T_3) produced significantly highest dry yield of leaf (5.16 q ha^{-1}) which was statistically at par with T_1 (4.64 q ha^{-1}) and T_2 (4.96 q ha^{-1}) but significantly better than all other treatments. Minimum dry yield of leaf (1.84 q ha^{-1}) was observed in control treatment T_{12} which was at par with T_{10} and T_{11} *i.e.* 2.30 and 2.55 q ha^{-1} respectively. This can be attributed to the fact that VC and inorganic fertilizers increased the availability of nutrients in soil and hence we can see the better absorption and uptake by plant. Optimal maintenance of essential elements within the shoot system enhances canopy photosynthesis by increasing both the size of the functional leaf area and the assimilation rate per unit area. These findings are consistent with those reported by Negi *et al.* (2022); Sharma *et al.* (2022).

Table 1: Effect of integrated nutrient management on bulk density, porosity and water holding capacity of soil after harvest of stevia crop.

Symbol	Treatments	Bulk density (g cm^{-3})	Soil Porosity (%)	Water holding capacity (%)
T_1	100% RDF alone	1.43	46.16	37.37
T_2	100% RDF + 5 t ha^{-1} FYM	1.35	49.18	41.65
T_3	100% RDF + 2 t ha^{-1} VC	1.37	48.30	41.29
T_4	50% RDF + 5 t ha^{-1} FYM	1.36	48.68	40.72
T_5	50% RDF + 2 t ha^{-1} VC	1.38	47.92	40.45
T_6	50% RDF alone	1.43	46.04	36.56
T_7	25% RDF + 5 t ha^{-1} FYM	1.36	48.68	39.64
T_8	25% RDF + 2 t ha^{-1} VC	1.39	47.55	39.38
T_9	25% RDF alone	1.44	45.79	35.36
T_{10}	5 t ha^{-1} FYM alone	1.37	48.43	38.56
T_{11}	2 t ha^{-1}VC alone	1.39	47.67	38.35
T_{12}	Control	1.45	45.28	32.35
LSD ($p \leq 0.05$)		0.02	0.63	1.05

Table 2: Effect of integrated nutrient management on pH, EC and organic carbon of soil after harvest of stevia crop.

Symbol	Treatments	Soil pH	Soil EC (dS m^{-1})	Organic carbon (%)
T_1	100% RDF alone	8.29	0.39	0.39
T_2	100% RDF + 5 t ha^{-1} FYM	8.23	0.36	0.47
T_3	100% RDF + 2 t ha^{-1} VC	8.25	0.37	0.44
T_4	50% RDF + 5 t ha^{-1} FYM	8.26	0.36	0.46
T_5	50% RDF + 2 t ha^{-1} VC	8.26	0.35	0.45
T_6	50% RDF alone	8.28	0.38	0.38
T_7	25% RDF + 5 t ha^{-1} FYM	8.25	0.36	0.46
T_8	25% RDF + 2 t ha^{-1} VC	8.26	0.38	0.44
T_9	25% RDF alone	8.30	0.38	0.39
T_{10}	5 t ha^{-1} FYM alone	8.27	0.35	0.45
T_{11}	2 t ha^{-1}VC alone	8.26	0.36	0.44
T_{12}	Control	8.29	0.35	0.36
LSD ($p \leq 0.05$)		NS	NS	0.02

Table 3: Effect of integrated nutrient management on macronutrient availability in soil after harvest of stevia crop.

Symbol	Treatments	Available macronutrient ($kg\ ha^{-1}$)		
		N	P	K
T_1	100% RDF alone	209.05	18.34	271.37
T_2	100% RDF + 5 t ha^{-1} FYM	223.06	20.65	291.63
T_3	100% RDF + 2 t ha^{-1} VC	226.15	21.53	293.78
T_4	50% RDF + 5 t ha^{-1} FYM	210.05	19.47	280.64
T_5	50% RDF + 2 t ha^{-1} VC	211.81	20.21	283.54
T_6	50% RDF alone	206.47	17.73	262.87
T_7	25% RDF + 5 t ha^{-1} FYM	205.98	17.57	269.88
T_8	25% RDF + 2 t ha^{-1} VC	207.21	18.32	272.36
T_9	25% RDF alone	199.84	15.61	258.74
T_{10}	5 t ha^{-1} FYM alone	202.91	16.17	259.59
T_{11}	2 t ha^{-1}VC alone	204.47	16.81	260.67
T_{12}	Control	174.40	13.47	245.07
LSD ($p \leq 0.05$)		4.08	2.21	3.28
Initial status		177.27	14.06	247.11

Table 4: Effect of integrated nutrient management application on average leaf yield of stevia crop.

Symbol	Treatments	Average leaf yield ($q\ ha^{-1}$)	
		Fresh	Dry
T_1	100% RDF alone	16.04	4.64
T_2	100% RDF + 5 t ha^{-1} FYM	18.43	4.96
T_3	100% RDF + 2 t ha^{-1} VC	18.65	5.16
T_4	50% RDF + 5 t ha^{-1} FYM	14.71	4.05
T_5	50% RDF + 2 t ha^{-1} VC	14.99	4.24
T_6	50% RDF alone	13.52	3.83
T_7	25% RDF + 5 t ha^{-1} FYM	11.97	3.23
T_8	25% RDF + 2 t ha^{-1} VC	12.70	3.75
T_9	25% RDF alone	11.64	2.99
T_{10}	5 t ha^{-1} FYM alone	10.54	2.30
T_{11}	2 t ha^{-1}VC alone	10.66	2.55
T_{12}	Control	9.01	1.84
LSD ($p \leq 0.05$)		2.51	0.76

CONCLUSIONS

The present study, titled **"Effect of Integrated Nutrient Management (INM) Approach on Soil Properties and Yield of Stevia (*Stevia rebaudiana* Bertoni),"** underscores the efficacy of combining organic and inorganic fertilizers in improving soil physico-chemical properties and stevia crop performance. The integration of organic manures with chemical fertilizers not only ameliorated soil health but also significantly boosted the growth, yield, and quality of stevia. Among the various treatments, the application of 100% RDF + 5 t ha^{-1} FYM notably enhanced soil physico-chemical attributes compared to both the control and sole RDF application. Furthermore, the consolidation of 100% RDF with 2 t ha^{-1} of VC (T_3) markedly improved vegetative growth, yield, and quality parameters of stevia over RDF alone and the control. Based on overall performance metrics, treatment T_3 (100% RDF + 2 t ha^{-1} VC) emerged as the most effective strategy for augmenting soil health, yield, and quality of stevia. These findings suggest that the continued application of VC in conjunction with recommended fertilizer doses could offer sustainable improvements in stevia cultivation under long-term field conditions.

FUTURE SCOPE

The present findings demonstrate that integrating organic and inorganic nutrient sources can significantly improve soil physico-chemical properties and enhance the productivity of *Stevia rebaudiana* Bertoni. Future research could explore long-term impacts of INM strategies on soil microbial dynamics, enzyme activity, and carbon sequestration under stevia-based cropping systems. Evaluating the economic feasibility and environmental sustainability of INM practices across diverse agro-ecological zones will also be crucial. Moreover, integrating biofertilizers and precision nutrient management tools may further enhance nutrient use efficiency and crop quality. This approach could be extended to other medicinal and cash crops, supporting holistic and sustainable agricultural practices that align with climate-resilient farming goals.

Conflict of Interest. None.

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How to cite this article: Ekamjot Kaur, Saurabh Sharma, Manpreet Singh, Arshdeep Singh, Manisha Negi and Navneet Kaur (2025). Impact of Organic and Inorganic Nutrient Sources on Soil Physico-chemical properties and Productivity of (*Stevia rebaudiana* Bertoni). *Biological Forum, 17*(6): 53-58.