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*Research Article*

# Organic nutrient management affects growth and yield in strawberry plants (*Fragaria× ananasa* Duch.) *cv*. Flavia under Punjab conditions

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## Abstract

Organic farming is an eco-friendly farming strategy involving balanced application of organic manures, biofertilizers and organic formulations to boost plant growth and yields. The present study aimed to investigate the effect of different organic sources of nutrients, alone or in combination, on the growth and yield attributes of the strawberry cultivar Flavia. The study comprised ten treatments and laid in a randomized block design (RBD). The results indicated that, compared with the control treatment ($T_{10}$), all the treatments ($T_1$ to $T_9$) enhanced the growth and yield. The combination comprising 60% RDN – 30% through vermicompost (90 g/m$^2$) + 30% through neem cake (45 g/m$^2$) and biochar (800 g/m$^2$) + *Panchgavya* + Vesicular Arbuscular Mycorrhiza (VAM)*,* each @ 50 mL/plant ($T_9$), resulted in a significant increase in vegetative growth and yield attributes. The vegetative parameters included highest plant height (6.7 and 13.33 cm), plant spread in East-West direction (EW ) (15.87 and 24.63 cm), plant spread in North-South (NS) (14.00 and 25.59 cm), number of trifoliate leaves (5.97 and 17.40) at 45 and 90 days after planting (DAP), respectively and stem girth (3.41 cm). Similarly, this treatment combination also contributed to the maximum chlorophyll index (57.90 SPAD), leaf area (48.76 cm$^2$), along with highest number of fruits per plant (28.14), average berry weight (16.53 g), yield per plant (447.88 g) and yield efficiency (0.47 kg/cm$^2$), compared to the other treatment combinations and the control. These results offer practical guidance for sustainable strawberry cultivation and lay the groundwork for future research on organic nutrient management in various crops.

**Keywords**: Organic formulations, Organic manures, Strawberry, Vegetative growth, Yield

## INTRODUCTION

Strawberries are in greater demand worldwide due to their high nutritional value, antioxidant content, and delightful taste. Since strawberry production primarily occurs on small rural holdings, it is crucial for economic and social reasons to aggregate family labor (Bengtsson, 2021). It is commonly known that fertilization, which supplies plants with vital nutrients, is crucial for achieving maximum development and increased output, but the excessive use of chemical fertilizers and pesticides in conventional strawberry cultivation is one

issue. (Dangi *et al*., 2015; Sharma and Singhvi, 2017).
According to the Directorate of Plant Protection, Quarantine and Storage (2023), approximately 2449 million tons of chemical pesticides and biopesticides are consumed annually for fruit production in India. As a result of the heavy loads of fertilizers and pesticides used in the predominant cultivation system, strawberries are among the four crops with the most outstanding levels of pesticide contamination (Cecatto *et al*., 2013). Despite these negative impacts, the use of inorganic fertilizers for strawberry production is increasing significantly to achieve greater yields per hectare (Yatoo *et al*., 2021). Many solutions have been proposed for minimizing these issues, but organic farming stands out because it not only safeguards the ecosystem but also produces better crops, reduces the prevalence of pests and diseases, improves total fructification, and increases commercial production (Stagnari *et al*., 2010; Khandaker *et al*., 2017).

Organic farming is based on management techniques that restore, maintain, and improve ecological equilibrium with minimal usage of off-farm inputs (Fess and Benedito, 2018). Organic resources, ranging from animal manure to crop residue, leguminous cover crops, household composts, and leguminous and non-leguminous trees and shrubs, are frequently employed as significant nutrient sources for crops. However, their combined use is more efficient than their sole application (Sileshi *et al*., 2019; Singh *et al*., 2019). In addition to these common organic resources, several other advanced amendments, such as biochar, biofertilizers, neem cake, and organic formulations, including *Panchgavya*, *Jeevamrita* and *Amritpani,* are frequently utilized for agricultural purposes. (Yuvasri *et al*., 2024).

The application of organic manure not only provides plants with essential nutrients but also enhances soil fertility by improving soil structure and increasing organic matter concentration (Kok *et al*., 2023). Vermicompost application stimulates root growth and nutrient absorption, resulting in increased production (Lim *et al*., 2015), while biochar, a byproduct of biomass pyrolysis, aids in long-term carbon sequestration, as it holds water and nutrients and releases them slowly over time (Shukla *et al*., 2019; Yang *et al*., 2020). Neem cake enhances the rhizosphere microbiota, soil structure, aeration, and water-holding capacity, promoting root development and providing vital nutrients for crop growth while minimizing pest attack (Gupta, 2022).

*Panchgavya* contains essential macro- and micronutrients and growth hormones crucial for plant development, enhancing soil biological activity and promoting beneficial microorganisms. In addition to bulky organic manures, biofertilizers such as vesicular arbuscular mycorrhizae (VAM) aid in the uptake of essential elements, particularly phosphorus, in the soil (Kok *et al*., 2023).

Although strawberries' average and marketable yields are lower under organic cultivation than under conventional cultivation (Samtani *et al*., 2019), market conditions led to higher returns per hectare because the prices were 50% greater. However, research on organic manures' single and combined application to various strawberry cultivars is still in its infancy. Even though Punjab has many great sources of organic matter, particularly animal manure and plant residues such as paddy straws, wheat straws etc. that are cheap and easily available (Walia and Kaur, 2022; Anand and Kaur, 2024), very few studies on the cultivation of crops through organic means have been conducted in the region (Kumar *et al*., 2023). Therefore, an experiment was conducted to understand better the effect of combinations of different organic matter resources and organic formulations on strawberry growth and yield under Punjab conditions.

## MATERIALS AND METHODS

### Growth conditions and plant material

The present experimental study was conducted under the open field conditions of the Punjab in Research and Teaching Farms of Lovely Professional University, Punjab (India), from 2022–2023. This region has a subtropical climate and experiences mostly hot and dry summers and cold and foggy winters. The soil on the experimental plot had a silty loam texture and a pH ranging from slightly acidic to neutral, which made it ideal for strawberry cultivation. The experimental site is located in the Doaba region of Punjab (geographical position 30Â° 57` to 32Â° 7` N and 75Â° 4` to 76Â° 30` E), which is located at an altitude of 270-300 m above MSL and experiences ~2029 mm of annual precipitation. Punjab experiences a semi-arid climate characterized by extreme temperatures and distinct seasonal variations. Summers are hot and dry, with temperatures often soaring above 40°C (104°F) between April and June. The monsoon season follows from July to September, bringing much-needed rainfall, though the amount can vary significantly yearly. Winters are cool to cold, with temperatures occasionally dropping near freezing, especially in December and January. Overall, Punjab's climate is heavily influenced by its location and topography, with the Himalayas to the north affecting weather patterns and rainfall distribution. This climate significantly impacts the region's agriculture, which is a crucial part of its economy. As strawberry cultivation in the Punjab region is limited to a few areas due to high humidity and hot temperatures, strawberries are predominantly cultivated in greenhouses. For the experimental purpose, healthy runners of the cultivar Flavia were procured from a certified organic nursery located in Hoshiarpur district of Punjab, which is suitable for this area.

**Table 1:** Details of different treatment combinations

| Treatment No. | Treatment details |
|---|---|
| $T_1$ | 100% RDN through vermicompost (300 g/m$^2$) |
| $T_2$ | 100% RDN through neem cake (150 g/m$^2$) |
| $T_3$ | 100% RDN through vermicompost (150 g/m$^2$) + neem cake (75 g/m$^2$) |
| $T_4$ | 80% RDN through vermicompost (240 g/m$^2$) + biochar (500 g/m$^2$) + *Amritpani* (25 ml/plant) + VAM (25 ml/plant) |
| $T_5$ | 80% RDN through neem cake (120 g/m$^2$) + biochar (500 g/m$^2$) + *Amritpani* (25 ml/plant) |
| $T_6$ | 80% RDN through vermicompost (120 g/m$^2$) + neem cake (60 g/m$^2$) + biochar (500 g/m$^2$) + *Amritpani* (25 ml/plant) + VAM (25 ml/plant) |
| $T_7$ | 60% RDN through vermicompost (180 g/m$^2$) + biochar (800 g/m$^2$) + *Panchgavya* (50 ml/plant) + VAM (50 ml/plant) |
| $T_8$ | 60% RDN through neem cake (90 g/m$^2$) + biochar (800 g/m$^2$) + *Panchgavya* (50 ml/plant) + VAM (50 ml/plant) |
| $T_9$ | 60% RDN through vermicompost (90 g/m$^2$) + neem cake (45 g/m$^2$) + biochar (800 g/m$^2$) + *Panchgavya* (50 ml/plant) + VAM (50 ml/plant) |
| $T_{10}$ | Control (Untreated) |

Where, RDN = Recommended dose of nitrogen

**Experimental design and treatment details**

The experiment included ten treatments and was laid following a randomized block design (RBD), with three replicates. Each replicate contained 10 units of plants. Table 1 outlines the various treatment combinations employed in the study. These combinations consist of different organic sources that are systematically varied and combined to investigate their effects on strawberry growth and yield traits. For control, neither organic manures nor inorganic fertilizers were applied except for the irrigation water. The uniform cultural practices, such as weeding, hoeing, and mulching, were carried out consistently across all treatments, except for the variations specific to each treatment, such as the application of manures and bioformulations.

**Soil solarization and procurement of organic amendments**

Before the commencement of the experiment, the soil at the experimental site was subjected to soil solarization using an opaque plastic sheet (black sheet) throughout the humid summer months (July to September), followed by field preparation during the last week of September. The preparation of organic formulations such as *Panchgavya* and *Amritpani* was started 15 days prior to planting as per the protocols listed by Raghavendra *et al*. (2014) and Shekh *et al*. (2018) respectively, by fermenting the different organic materials and byproducts of Indigenous cattle such as cow dung, cow urine, cow ghee, cow milk and cow curd for 2 weeks obtained from a nearby dairy farm in Phagwara city of Punjab. The supplementary organic amendments, such as vermicompost, neem cake, biochar, and vesicular-arbuscular mycorrhizae (VAM), were acquired from a local store specializing in biopesticides and biofertilizers situated in Phagwara for experimental purposes.

**Planting, treatment application and crop management**

The strawberry runners were planted in mid-October on 15 cm raised beds at a spacing of 30 × 30 cm on a clear weather day, early in the morning. Before planting, the runners were treated with different concentrations of VAM @ 25 and 50 mL/plant following treatment details. Various organic manures were applied during the crown initiation and establishment stage. Ten days after plant establishment, a 3–4 cm thick layer of chopped paddy straw mulch was applied to the beds, and the process was repeated once in the middle of the season for the remainder of the cropping period. At three different plant growth stages, namely, the emergence of new leaves, vegetative growth, and flowering, foliar spray of *Panchgavya* and *Amritpani* was done as per the treatment details (Table 1). Irrigation was applied to the alternate furrows through flooding at 3-day intervals during the early stage and at weekly intervals thereafter. Proper sanitation measures and intercultural operations were maintained during the cropping season to prevent pest attacks.

**Growth and yield parameters**

Data were collected at two significant time points: 45 days and 90 days after planting (DAP) to evaluate the impact of the different treatments on key plant development characteristics. The observations included plant height (cm), plant spread in both the east-west (EW) and north-south (NS) directions (cm), and the number of trifoliate leaves per plant. Some sophisticated measurement tools were employed to conduct a comprehensive analysis. Leaf area was measured using a benchtop LICOR-3100 leaf area meter, and the results were expressed in square centimeters ($cm^2$). The leaf chlorophyll index was assessed with a SPAD-502 meter during the peak vegetative growth stage (60 DAP), providing measurements in SPAD units. As the cropping season ended, stem girth was recorded, and the results were recorded in centimeters (cm). After fruiting, the data were meticulously recorded on yield-associated metrics, including average berry weight (g), number of berries per plant, yield per plant (g), and yield efficiency ($kg/cm^2$). The harvests were conducted at five-day intervals, totalling 8-10 harvests throughout the growing period. The data collected included the number of marketable berries, average berry weight (g), total yield per plant (g) and yield efficiency (YE) on a leaf area basis, representing the ratio of kilograms to square centimeters ($kg/cm^2$) of leaf area. The calculation of Yield efficiency was done using the following formula:

$$\text{Yield efficiency } (kg/cm^2) = \frac{Yield\ per\ plant}{TCSA} \qquad \text{Eq. 1}$$

Where, TCSA = Trunk cross-sectional area $[(\text{girth})^2/4\pi]$

**Statistical analysis**

The data generated during the course of the study were subjected to statistical analysis using SPSS v. 21 software, and the Duncan multiple range test (DMRT) was applied to determine the homogeneous sets of treatments to draw conclusions (P≤5%).

**RESULTS AND DISCUSSION**

**Growth parameters and chlorophyll index**

Under the organic nutrition regime, there were notable variations in plant height, plant spread in both the east-west (EW) and north-south (NS) directions, and the number of trifoliate leaves of strawberry *cv*. Flavia across the different treatments, as outlined in Table 2. In comparison with the other treatments, the combination of 60% RDN through vermicompost (90 $g/m^2$) + neem cake (45 $g/m^2$) + biochar (800 $g/m^2$) + *Panchgavya* + VAM at 50 ml/plant ($T_9$) emerged as the most favorable treatment, resulting in superior vegetative growth outcomes. In particular, $T_9$ exhibited the highest plant heights, reaching 6.73 cm and 13.33 cm at 45 and 90 days after planting (DAP), respectively. However, these results are at par with the results of $T_6$ viz. 60% RDN through vermicompost (180 $g/m^2$) + biochar (800 $g/m^2$) + *Panchgavya* + VAM at 50 ml/plant. $T_6$ recorded 6.69 cm and 12.10 cm plant heights at the indicated time points. Conversely, the control group ($T_{10}$) displayed the least impressive increase, with minimum plant heights recorded at 3.71 cm and 10.12 cm at 45 and 90 DAP, respectively.

Similarly, $T_9$ exhibited the most expansive plant spread, excelling in east-west (EW) and north-south (NS) directions. At 45 and 90 DAP, $T_9$ demonstrated remarkable plant spread values of 15.87 cm and 24.63 cm (EW) and 14.00 cm and 25.49 cm (NS), respectively. Similarly, the number of trifoliate leaves was significantly greater under $T_9$ than under the other treatments, reaching 5.97 and 17.40 at 45 and 90 DAP, respectively. Furthermore, $T_9$ exhibited superior effects on other key growth parameters, including leaf area (48.76 $cm^2$), stem girth (3.41 cm), and the chlorophyll index (57.90 SPAD), surpassing the performance of the other treatments and the control group (Table 3).

These comprehensive findings underscore the overall effectiveness of $T_9$ in promoting robust vegetative growth and physiological development across multiple aspects compared to alternative treatments and the control. The observation of the greatest vegetative growth of strawberry plants under $T_9$ suggested that this treatment combination may be effective because it incorporates an optimal nutrient concentration and an ideal blend of nutrient-supplying resources, surpassing the effectiveness of other treatment combinations. Vermicompost and neem cake provide a balanced and slow-release supply of essential nutrients, fostering sustained vegetative growth (Maliwal, 2020). The organic nature of these sources also enhances soil structure and microbial activity, contributing to long-term soil health. The inclusion of biochar aimed to improve nutrient retention, water-holding capacity, and microbial activity in the soil by acting as a stable carbon source, promoting nutrient availability and enhancing overall soil fertility (Hue, 2020; Alkharabsheh *et al*., 2021). Along with VAM, *Panchgavya* establishes a synergistic relationship with plant roots. This enhances nutrient uptake and promotes healthier vegetative growth (Sharma *et al*., 2019; Tiwari *et al*., 2016; Vallimayil and Sekar, 2012).

The findings of the present study are comparable to those reported by Kumar *et al*. (2022) in chili using vermicompost and neem cake combined with RDF as inorganic fertilizers, which improved plant development parameters by increasing the amount of nutrients in the soil and improving plant access to those nutrients. Likewise, numerous studies have suggested that stress-free plant development can be promoted through the use of vermicompost, which serves as a source of additional nutrients and moisture, along with neem cake, which helps reduce sucking pests (Giraddi *et al*., 2007; Veena *et al*., 2017; Rohith *et al*., 2021). Similarly, Geetha and Devaraj (2013) have reported significant improvements in *Vitis vinifera* growth and nutritional content using *Panchagavya* and microbial fertigation. Yuniwati and Lestari (2021) reported better vegetative growth in kale plants (*Brassica oleracea* var. *acephala* L.) using biochar (6 t/ha) and Bio-Land organic liquid fertilizer (15 L/ha). Reddy *et al.* (2013) also reported better crop growth in Papaya *cv*. Surya with 75% RDF applied as farmyard manure + vermicompost was significantly

**Table 2.** Effect of organic nutrition management on plant height, plant spread and number of trifoliate leaves of strawberry *cv*. Flavia.

| Treatments | Plant height (cm) | | Plant spread EW (cm) | | Plant spread NS (cm) | | No. of trifoliate leaves per plant | |
|---|---|---|---|---|---|---|---|---|
| | 45 DAP | 90 DAP | 45 DAP | 90 DAP | 45 DAP | 90 DAP | 45 DAP | 90 DAP |
| $T_1$ | $4.34^{b}$ | $10.57^{ab}$ | $10.61^{ab}$ | $17.97^{b}$ | $9.90^{a}$ | $17.87^{a}$ | $4.20^{a}$ | $14.21^{a}$ |
| $T_2$ | $4.44^{bc}$ | $10.68^{ab}$ | $10.70^{bc}$ | $18.30^{b}$ | $10.33^{b}$ | $18.78^{b}$ | $4.40^{a}$ | $14.20^{a}$ |
| $T_3$ | $4.70^{cd}$ | $11.00^{b}$ | $11.03^{bc}$ | $19.27^{c}$ | $10.60^{b}$ | $19.67^{b}$ | $4.77^{b}$ | $14.27^{a}$ |
| $T_4$ | $5.04^{e}$ | $11.06^{b}$ | $14.07^{d}$ | $20.43^{d}$ | $11.83^{c}$ | $21.45^{c}$ | $5.07^{c}$ | $14.83^{ab}$ |
| $T_5$ | $4.82^{de}$ | $11.02^{b}$ | $11.53^{c}$ | $19.50^{c}$ | $10.80^{c}$ | $20.89^{c}$ | $4.87^{bc}$ | $14.30^{a}$ |
| $T_6$ | $6.69^{f}$ | $12.10^{c}$ | $14.90^{e}$ | $22.23^{e}$ | $13.63^{d}$ | $23.64^{d}$ | $5.80^{d}$ | $15.50^{b}$ |
| $T_7$ | $5.73^{e}$ | $11.89^{c}$ | $14.67^{de}$ | $21.60^{de}$ | $13.47^{d}$ | $22.78^{d}$ | $5.79^{d}$ | $15.27^{b}$ |
| $T_8$ | $5.40^{f}$ | $11.69^{c}$ | $14.40^{de}$ | $20.83^{de}$ | $13.13^{c}$ | $21.64^{c}$ | $5.77^{d}$ | $15.20^{b}$ |
| $T_9$ | $6.73^{f}$ | $13.33^{d}$ | $15.87^{e}$ | $24.63^{f}$ | $14.00^{e}$ | $25.59^{e}$ | $5.97^{d}$ | $17.40^{c}$ |
| $T_{10}$ | $3.71^{a}$ | $10.12^{a}$ | $10.23^{a}$ | $16.50^{a}$ | $8.97^{a}$ | $16.98^{a}$ | $4.17^{a}$ | $14.09^{a}$ |

*Differences marked by distinct letters in the same column are statistically significant (P<0.05); Treatment details: Refer to Table 1

**Table 3.** Effect of organic nutrition management on leaf area, stem girth and chlorophyll index of strawberry *cv*. Flavia

| Treatments | Leaf area ($cm^2$) (120 DAP) | Stem girth (cm) (120 DAP) | Chlorophyll index (SPAD) (120 DAP) |
|---|---|---|---|
| $T_1$ | $40.13^{a}$ | $2.82^{a}$ | $47.90^{b}$ |
| $T_2$ | $40.23^{a}$ | $2.96^{ab}$ | $48.90^{bc}$ |
| $T_3$ | $40.45^{ab}$ | $2.99^{ab}$ | $50.00^{bcd}$ |
| $T_4$ | $43.57^{c}$ | $3.07^{ab}$ | $51.73^{de}$ |
| $T_5$ | $41.76^{b}$ | $3.03^{ab}$ | $50.87^{cde}$ |
| $T_6$ | $46.84^{d}$ | $3.33^{cd}$ | $55.57^{ef}$ |
| $T_7$ | $44.87^{c}$ | $3.10^{bc}$ | $53.40^{ef}$ |
| $T_8$ | $46.84^{d}$ | $3.05^{ab}$ | $52.83^{e}$ |
| $T_9$ | $48.76^{e}$ | $3.41^{d}$ | $57.90^{e}$ |
| $T_{10}$ | $39.55^{a}$ | $2.84^{a}$ | $44.47^{a}$ |

*Differences marked by distinct letters in the same column are statistically significant (P<0.05); Treatment details: Refer to Table 1

greater than that with a 100% recommended dose of fertilizer and no manure/fertilizer treatment. Similarly, Devi and Singh (2023) recorded maximum values for parameters such as plant height, petiole length and plant spread, along with quality attributes and yield in papaya plants with a combination of 75% RDF through FYM + vermicompost + 3% *Panchagavya* + *Amritpani*.

### Yield and yield- attributing traits

The data pertaining to yield and associated traits revealed noteworthy variations, as outlined in Table 4. Like for vegetative growth parameters, treatment with 60% RDN in combination with vermicompost (90 g/$m^2$) + neem cake (45 g/$m^2$) + biochar (800 g/$m^2$) + *Panchgavya* + VAM at 50 ml/plant ($T_9$) had superior yield performance compared to that of the other treatments and the control group. $T_9$ exhibited significant results, with more fruits per plant (28.14), increased average berry weight (16.53 g), elevated yield per plant (447.88 g), and greater yield efficiency (0.47 kg/$cm^2$). In contrast, the control group ($T_{10}$) displayed the least favorable outcomes, with the lowest number of fruits per plant (19.08), average berry weight (11.00 g), yield per plant (198.85 g), and yield efficiency (0.29 kg/$cm^2$). This notable difference underscores the effectiveness of the treatment combination in $T_9$, highlighting its potential for enhancing yield and yield-related characteristics compared to those of the control group.

The increase in yield and yield-related characteristics may be attributed to healthy vegetative growth, resulting in greater production in $T_9$. The control group ($T_{10}$) likely performed poorly due to lack of these beneficial inputs, resulting in suboptimal soil conditions, reduced nutrient availability, and potentially higher susceptibility to stress factors. This stark contrast in results demonstrates the significant impact that integrated application

**Table 4.** Effect of organic nutrition management on number of fruits/plant, average berry weight, yield/plant and yield efficiency of strawberry *cv*. Flavia

| Treatments | No. of fruits/plant | Average berry weight (g) | Yield/plant (g) | Yield efficiency (kg/cm$^2$) |
|---|---|---|---|---|
| $T_1$ | 21.27$^{b}$ | 11.53$^{a}$ | 233.44$^{ab}$ | 0.31$^{ab}$ |
| $T_2$ | 21.28$^{b}$ | 11.60$^{ab}$ | 234.89$^{ab}$ | 0.31$^{ab}$ |
| $T_3$ | 21.30$^{b}$ | 11.90$^{ab}$ | 241.41$^{ab}$ | 0.32$^{ab}$ |
| $T_4$ | 22.15$^{bc}$ | 12.23$^{ab}$ | 259.11$^{abc}$ | 0.34$^{ab}$ |
| $T_5$ | 21.34$^{b}$ | 11.97$^{ab}$ | 243.67$^{ab}$ | 0.32$^{ab}$ |
| $T_6$ | 24.19$^{e}$ | 12.58$^{c}$ | 291.29$^{bc}$ | 0.30$^{ab}$ |
| $T_7$ | 23.06$^{c}$ | 14.87$^{bc}$ | 328.46$^{c}$ | 0.40$^{bc}$ |
| $T_8$ | 22.76$^{c}$ | 12.44$^{ab}$ | 270.47$^{abc}$ | 0.35$^{ab}$ |
| $T_9$ | 28.14$^{d}$ | 16.53$^{c}$ | 447.88$^{d}$ | 0.47$^{c}$ |
| $T_{10}$ | 19.08$^{a}$ | 11.00$^{a}$ | 198.85$^{a}$ | 0.29$^{a}$ |

*Differences marked by distinct letters in the same column are statistically significant (P<0.05); Treatment details: Refer to Table 1

of vermicompost, neem cake, biochar, *Panchgavya* and VAM at optimal levels can have on crop yield and quality.

The results of the present study are comparable to those reported by Hasan (2018) with biochar @ 6 t ha$^{-1}$ and vermicompost @ 8 t ha$^{-1}$ which resulted in a greater yield of green cabbage. Similarly, Song *et al*. (2023) reported higher yields of strawberry by applying 10 t ha$^{-1}$ biochar and anaerobic soil disinfection. El-Sayed (2024) noted a remarkable enhancement in yield characteristics, including the number of fruits per plant, fruit yield per plant, and fruit yield per feddan, through the application of treatments combining vermicompost with PSB and VAM, as well as vermicompost with *Azotobacter*, *Azospirillum*, PSB, and VAM in tomato crops. Naidu (2021) recorded the highest yield of 3.39 t/ha in sweet orange with a treatment combination of FYM @ 46 kg/plant + neem cake @ 22 kg/plant + *Azospirillum* @ 200 g/plant + PSB @ 200 g/plant. These finding align with our current results, reinforcing the positive impact of integrated organic amendments on crop productivity.

## Conclusion

The findings of the present study concluded that the treatment combinations involving 60% RDN through vermicompost (90 g/m$^2$), neem cake (45 g/m$^2$), and biochar (800 g/m$^2$), as well as *Panchgavya* and VAM, applied at 50 ml/plant ($T_9$), exhibited superior vegetative growth indexes such as plant height, spread, leaf count, stem girth, and a higher chlorophyll index, than the other treatments. Additionally, $T_9$ performed significantly better in terms of yield and yield-related attributes such as fruit weight, number of fruits per plant, fruit size, and yield efficiency. This enhancement is attributed to the optimal blend of organic sources utilized in this treatment. Consequently, treatment $T_9$ emerged as the optimal treatment for strawberry cultivation, offering significant growth, development, and yield improvements.

## Conflict of interest

The authors declare that they have no conflict of interest.

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