Organic inputs with reduced chemical fertilizers improve yield, antioxidant components, and defense mechanisms in Tomato (*var. Pusa Sheetal*)

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Abstract: Abstract: Chemical fertilizers are widely used to meet the nutritional needs of crops and increase yields; but, due to their high cost and abuse, certain adverse effects are causing the soil to deteriorate. A decline in soil organic carbon is being addressed through the use of vermicompost and farmyard manure as organic amendments, potentially reducing chemical fertilizer usage and ensuring sustainable crop nutrient supply. A study utilizing cattle farmyard manure and vermicompost, along with reduced chemical fertilizers, demonstrated that organic inputs significantly enhance tomato growth, physiology, yield, nutritional, and defense attributes. The study found that using farmyard manure and vermicompost in combination with reduced chemical fertilizers significantly increased plant height (14.2%), number of branches (26.7%), number of leaves (18.1%), fruit weight (30.7%), yield (89.4%), ascorbate peroxidase (15.4%), carotenoids (11.6%), vitamin C (15.4%), lycopene (17.2%), superoxide dismutase (18.5%), total antioxidant activity (55.4%), total soluble solids (9.9%), and vitamin C 7.9% in tomatoes, potentially reducing the need for chemical fertilizers. In addition, soil pH was slightly neutralized and soil organic carbon and available N, P, and K status of soils significantly improved. Tomatoes with higher levels of ascorbate peroxidase, carotenoids, lycopene, superoxide dismutase activity, total antioxidant activity, total soluble solids, and vitamin C, showed higher yields.

Keywords: Antioxidant activity; farmyard manure; inorganic fertilizer; lycopene, soil health; yield

1. Introduction

Conventional agriculture heavily relies on chemical fertilizers, causing environmental issues like pollution and denitrification. Tomato cultivation, a crop cultivated under field and greenhouse conditions, also significantly impacts the environment. Tomatoes are a valuable vegetable crop with numerous health benefits [1] due to their nutritional value and diverse culinary applications. However, current cultivation methods, which heavily rely on chemical fertilizers, can have negative effects on soil health, the environment, and human health. Organic farming methods using sustainable organic fertilizers like Farm Yard Manure (FYM) and Vermicompost (VC) have emerged as a viable alternative [2]. Vermicompost, a nutrient-rich organic amendment, reduces chemical fertilizer use, improves soil health [3], and promotes sustainable crop production. Its integrated use with chemical fertilizers can significantly enhance tomato growth and yield [4-6]. Organic inputs enhance plant growth, and improve chlorophyll content, leaf area, and fruit yield in various crops, including sorghum and tomato [7]. The present study explores the impact of farmyard manure and vermicompost on tomato plants' morphological, biochemical, and defense responses, aiming to improve yield and reduce environmental risks.

2. Materials and Methods

2.1. Preparation of vermicompost:

Cow dung was collected from Shree Jee Gausadan in sector 124 Noida and earthworms from the National Institute of Organic Farming Ghaziabad. Vermicompost preparation was carried out in the VC unit built in the South Eastern part of Amity Organic Farm Amity University, Noida, India. The material was pre-composed in six pits, then added with 800 earthworms for 20 days [8], water was sprinkled, and the final form of VC (vermicast) was collected after 80 days [9, 10].

2.2. Composition of FYM and Vermicompost

The study examined the chemical properties of farmyard manure and vermicompost, analyzing EC by Wheatstone bridge, pH by digital pH meter, available moisture by gravimetric method, available nitrogen by Kjeldahl method [11], available phosphorus by Olsen method, available potassium by 1N ammonium acetate method, and organic carbon by chromic acid digestion method, using standard methods [9, 12, 13]. The physicochemical analysis of the farmyard manure and vermicompost is presented in Table 1.

2.3. Soil Sampling and Preparation

Manures and soils were collected by a sterilized auger and spade and uniform composite samples were prepared for analysis. Soil available nitrogen, available phosphorus [14], available potassium, and organic carbon [15] were analyzed using standard methods. The nutrient status of the soil samples is provided in Table 2.

Table 1: Analysis of physicochemical properties of the farmyard manure and vermicompost.

Properties	Farm Yard Manure	Vermicompost
Color	Dark Brown	Dark Brown to Black
Particles size	3 mm	2 mm
Moisture %	18.15 ± 0.20	22.30 ± 0.20
pH (1:2.5 soil water extract)	7.2 ± 0.03	7.15 ± 0.05
Electrical conductivity (dS m^{-1})	3.67 ± 0.04	3.57 ± 0.07
Organic C (0-15 cm) (g kg^{-1})	126.66 ± 2.67	139.1 ± 2.50
Available nitrogen (kg ha^{-1}) (0-15 cm)	0.75 ± 0.04	1.95 ± 0.03
Available phosphorus (kg ha^{-1}) (0-15 cm)	0.36 ± 0.02	0.67 ± 0.02
Available potassium (kg ha^{-1}) (0-15 cm)	0.80 ± 0.03	0.91 ± 0.02

(± Standard deviation of three replicates)

Table 2: Physicochemical analyses of experimental soils.

Soil analysis	Pre-experiment
a. Sand (%)	32.00%
b. Silt (%)	27.00%
C. Clay (%)	40.00%
Textural class	Sandy loam
pH (1:2.5 soil water extract)	7.89 ± 0.05
Electrical conductivity (dS m^{-1})	1.13 ± 0.03
Organic C (0-15 cm) (g kg^{-1})	5.52 ± 0.11
Available nitrogen (kg ha^{-1}) (0-15 cm)	236.33 ± 0.01
Available phosphorus (kg ha^{-1}) (0-15 cm)	18.07 ± 0.23
Available potassium (kg ha^{-1}) (0-15 cm)	17.43 ± 2.66

(± Standard deviation of three replicates)

2.4. Experimental

The experiment featured four treatments utilizing a randomized complete block design, soil preparation, and the use of tomato seeds at the Amity University research farm in 2021–2023. The treatment combinations were T_1 = Control (no fertilizer and manures), T_2 = FYM + VC (15 t ha^{-1} + 3 t ha^{-1}), T_3 = FYM +VC + 40% NPK (18:18:18), and T_4 = 40% NPK (18:18:18). The required chemical fertilizer was purchased from IFFCO N:P:K (18:18:18) [16]. Tomato plant seedlings grown on a seedling tray with 98 combs per tray (7 x 14) were transplanted as part of the study [17]. To prevent any fungal growth in the roots, the seedling was dipped in a 2% solution of carbendazim and mancozeb. Fruits were harvested at the turning mature stage and stored for biochemical analyses, fruit quality, growth, and yield attributes [18].

2.4.1. Ascorbate peroxidase:

The ascorbate peroxidase activity was evaluated using a reaction mixture containing enzyme extract, potassium-phosphate buffer, ascorbic acid, hydrogen peroxide, and EDTA, with a molar extinction coefficient of 2.8 mM cm^{-1}. The ascorbate peroxidase activity was assessed using a reaction mixture containing enzyme extract, potassium-phosphate buffer, ascorbic acid, hydrogen peroxide, and EDTA. The activity was quantified using a molar extinction coefficient of 2.8 mM cm_{-1} and expressed as µmole H_2O_2 reduced min^{-1} g^{-1} FW of tomato. One unit of ascorbate was defined as the amount required to reduce one mol of H_2O_2 per minute at 25 ℃ [19].

2.4.2. Carotenoids:

The study used spectroscopy to quantify carotenoids in tomato extract. A 1ml sample was mixed with a solvent, centrifuged, and then added to double-distilled water. The upper phase was collected for analysis. The carotenoid concentration was calculated using a molar extinction coefficient of 184900 M^{-1} cm^{-1} and expressed as mg g^{-1} FW

2.4.3. Lycopene:

The study quantified the lycopene content in tomato fruit using a homogenized puree and a UV-VIS spectrophotometer. The process involved mixing tomato samples, adding a solution of butylated hydroxytoluene, shaking for 5 minutes, and observing a visible hexane layer on the upper phase. The absorbance of this layer was then measured to determine the lycopene content [20].

2.4.4. Superoxide dismutase:

The study evaluated SOD activity by inhibiting nitroblue tetrazolium chloride photochemical reduction, measuring absorbance under fluorescent lamps at 560 nm, and determining the activity of one unit of SOD [21].

2.4.5. Total antioxidant activity:

The ABTS technique measures total antioxidant activity by assessing the efficacy of antioxidant compounds in quenching a radical cation of 2,2'-azinobis 3-ethylbenzthiazoline-6-sulphonic acid (ABTS). A novel solution, composed of 7 mM ABTS and 140 mM potassium persulfate, was incubated for 16 hours without light. The reaction was initiated with extract and monitored for 6 minutes.

2.4.6. Total Soluble Solids:

The study utilized a hand refractometer to measure TSS in homogenized tomato fruits, calculating the value using the °Brix incidence line.

2.4.7. Vitamin C:

The protocol for converting ascorbic acid to dehydroascorbic acid involves homogenizing 1g of pulp, adding 3% bromine water solution, eliminating excess bromine with 10% thiourea, and creating osazone with 2,4-DNPH solution. Samples are maintained at 37 °C for 3 hours, then treated with 85% H_2SO_4 and stirred. The reading was expressed in mg g^{-1} FW after absorbance was measured at 521 nm.

2.4.8. Hydrogen Peroxide:

Velikova et al. [22] used potassium iodide oxidation to estimate the concentration of hydrogen peroxide (H_2O_2), measured spectrophotometrically at an absorbance of 390 nm.

2.4.9. Malondialdehyde (MDA)

The study measured the levels of oxidative stress caused by several environmental factors in tomato leaves using the thiobarbituric acid reactive substances (TBARS) method. TSS in homogenized tomato fruits was measured in the study using a hand refractometer, and the value was computed using the °Brix incidence line. The last picking of tomato fruit also completed the recording of plant height and other morphological characters [23].

2.5. Statistical Analysis Pictorial presentation

The experiment's data was analyzed using ANOVA and LSD tests, with a p-value of 0.05 for multiple comparisons, using Microsoft Excel 365, WASP, Origin 6.1, and Sigma Plot.

3. Results and Discussion

3.1. Biometric parameters of tomatoes:

The optimized treatment increased plant height (14.2%) (Figure 1a), number of branches (26.7%) (Figure 1b), number of leaves (18.1%) (Figure 1c), number of fruits (45.0%) (Figure 1d), fruit weight (30.7%) (Figure 1e), and yield (89.4%) (Figure 1f). The maximum plant height was recorded in T_3, where a combination of organic and inorganic fertilizers was applied with reduced doses of NPK, resulting in a significant increase compared to the control. The study revealed that the application of recommended doses of Farm Yard Manure (FYM) and vermicompost (VC) and reduced doses of NPK significantly enhanced tomato plant growth [24], yield, and physiological attributes [25].

The correlation analysis results show that plant height, number of branches, and number of leaves are perfectly and positively correlated, suggesting that the taller the plant is equal to the larger the canopy size to capture more available resources and nutrients (Sunlight, moisture, nutrients, etc.), leading to a boosted growth and productivity of the plant (Figure 1) [26]. The increased growth of the plant is always correlated to the healthy and abundant availability of plant inputs. The application of the T_3 yielded a significant increase in morphological and yield, number of fruits compared to the rest of the treatments. Results show a strong positive correlation of plant height with number of branches (r=***924), leaves (r=***969), fruits (r=***994), fruit weight (r=***982) and yield (r=***999) (Table 3).

The plant growth parameters were positively correlated with plant physiological attributes. For example, plant height was positively correlated with APX (r=***0.935), carotenoids (r=***0.995), lycopene (r=***0.962), SOD (r=***0.970), TAA (r=***0.972), TSS (r=***0.994) and Vit-C (r=***0.918). The oxidative stress impacted statistically negatively on hydrogen peroxide (r=*-0.783) and malondialdehyde (r=***-0.955). A similar trend was reported by Aslam et al. [27].

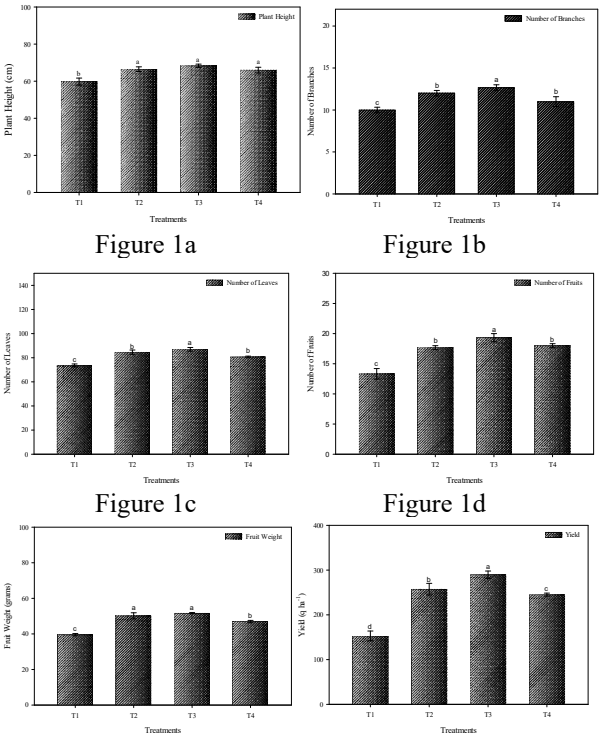

Figure 1a Figure 1b

Figure 1c Figure 1d

Figure 1e Figure 1f

Figure 1: Morphological characteristics results of tomato plant obtained after different treatments – a = Plant Height (cm); b = Number of Branches; c = Number of leaves; d = Number of fruits; e = Fruit weight (g) and f = Yield (q ha^{-1}). The vertical bars show the values of obtained findings, variables above the bars show statistically significant difference in treatments, and caped bars "I" show the standard errors.

3.2. Nutritional analyses of tomatoes

The study assessed the nutritional and quality attributes of tomatoes using ANOVA at 95% level of significance. Results showed that treatments positively affected the fruits' nutritional and quality parameters. The highest value of ascorbate peroxidase (Figure 2a), carotenoids (Figure 2b), lycopene (Figure 2c), superoxide dismutase activity (Figure 2d), total antioxidant activity (Figure 2e), total soluble solids (Figure 2f) and vitamin C (Figure 2g) was observed in T_3 which was calculated 17.2%, 11.6%, 20.3%, 24%, 55.4%, 18.9%, and 7.9% respectively, higher than control. These results suggest that the combination treatment can significantly improve the nutritional values of tomatoes [27]. The study reveals that using organic fertilizers significantly boosts tomato productivity and fruit quality, and factors like soil

organic matter and fertilizer types also influence tomato quality [28].

3.2.1 Ascorbate Peroxidase: APX exhibited a strong positive correlation with various morphological and biochemical parameters as plant height (r=***935), number of branches (r=*729), number of leaves (r=**826), number of fruits (r=***954), fruit weight (r=**870), yield (r=***915), carotenoids (r=***925), lycopene (r=**805), superoxide dismutase (r=**824), total antioxidant activity (r=***950), and total soluble solids (r=***948). However, it showed a negative correlation with malondialdehyde (r=***-0.982) and a positive correlation with vitamin C (r=*0.728).

3.2.2 Carotenoids: Carotenoids were highly correlated with other plant antioxidant compounds; however, they were negatively correlated with H_2O_2 (r=**-0.840) and malondialdehyde (r=***-0.963). They demonstrated a strong positive correlation with yield (r=***0.993) and total soluble solids (r=***0.998). Tomatoes, rich in carotenoids, are essential for sensory, nutritional, and flavor. To combat deficiency, sustainable management strategies like biofortified cultivar breeding, suitable cultivation methods, and post-harvest handling, are recommended [29].

3.2.3 Lycopene (LYC): Lycopene displayed strong positive correlations with all variables except H_2O_2 (r=*-0.785) and Malondialdehyde (r=**-0.843). It had its highest correlations with NOB (r=***0.987) and SOD (r=***0.992). Tomato plants treated with combination of farmyard manure vermicompost and reduced fertilizer showed higher yield, soluble solids, vitamin C, soluble sugar, and lycopene compared to other treatments [30].

3.2.4 Superoxide Dismutase (SOD): Plants, under abiotic stresses, produce reactive oxygen species (ROS). Superoxide dismutase (SOD) is an antioxidant protein that combats stress, aids growth and is stable across various pH and temperature ranges [31]. SOD was strongly positively correlated to all variables of antioxidants excluding stress markers hydrogen peroxide (r=**-0.877) and malondialdehyde (r=**-0.877) where it had a strong negative correlation. The strongest positive and highly significant correlation between SOD and the number of leaves (r=***0.999) indicates its direct role in plant physiological and biochemical pathways.

3.2.5 Total Antioxidant Activity: TAA showed strong positive correlations with other biochemical compounds except for H_2O_2 (r=***-0.850) and malondialdehyde (r=**-0.990) where it exhibited strong negative relationships. The strongest positive correlation was noted between TAA and carotenoids (r=***0.986), showing the significant impact of total antioxidant levels on carotenoid formation. The study confirms that the combination of organic inputs with 40% NPK fertilizer was the best-fit treatment for sustained tomato production with enhanced nutritional quality. This treatment has higher efficiency than sole NPK empowering antioxidant machinery in tomatoes [32, 33].

3.2.6 Total Soluble Solids (TSS): TSS demonstrated high positive correlations to other antioxidant compounds apart from hydrogen peroxide (r=**-0.822) and malondialdehyde (r=***-0.978) where the correlation was found strongly negative. Higher levels of stress markers (H_2O_2 and MDA) showed lower TSS values, indicating a decline in fruit quality. The strongest correlation of TSS was observed with carotenoids (r=***0.998), which indicated a direct role of carotenoids in the development of fruit taste, flavor, and overall quality of tomatoes. Verma et al. [34] also found improved carotenoids, total soluble solids and lycopene content under the combined treatment with FYM, vermicompost, and other concentrated organic manures. Vermicompost has been reported to promote plant growth, improve fruit quality, and improve soluble sugars in tomatoes [1].

3.2.7 Vitamin C: Vitamin C also showed significant positive correlations to other antioxidant compounds. It showed negative correlations with hydrogen peroxide (r=**-0892) and malondialdehyde (r=**-0.807) (Table 3). The strongest correlation of vitamin C was noticed with the number of branches (r=***0.996) which indicates a possible role of ascorbate biosynthesis in maintaining redox buffer and branching in tomatoes.

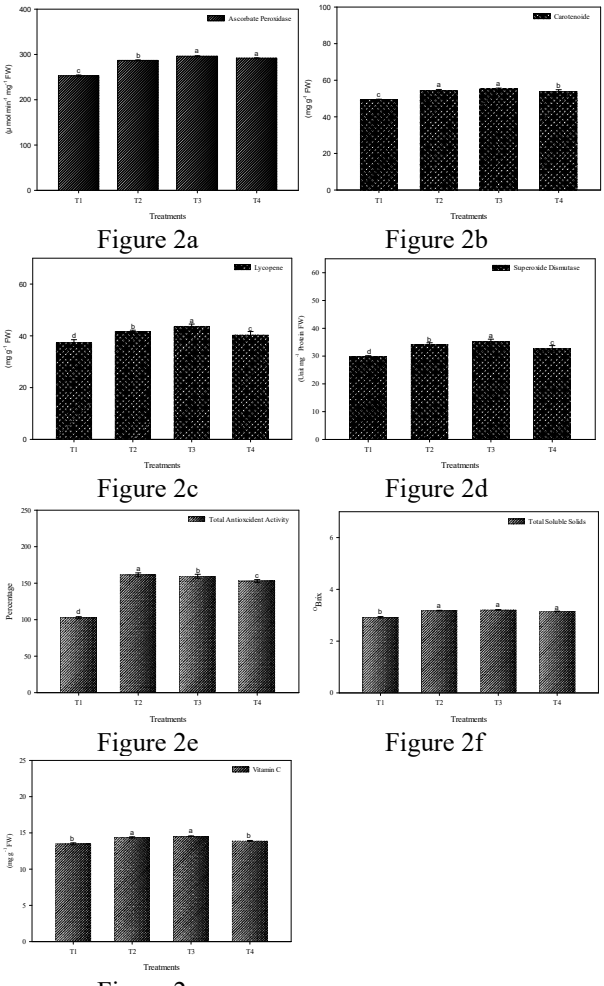

Figure 2a Figure 2b

Figure 2c Figure 2d

Figure 2e Figure 2f

Figure 2g

Figure 2: Biochemical characteristics of tomato plant obtained after different treatments: a= Ascorbate peroxidase (APX); b = carotenoid content (CCn); c = Lycopene content (LYC); d = Superoxide dismutase (SOD); e = Total antioxidant activity (TAA); f = Total soluble solids (TSS), and g = Vitamin C (Vit-C). The vertical bars show the values of obtained findings,

variables above the bars show statistically significant differences in treatments, and caped bars "I" show the standard errors.

The study investigated the impact of vermicompost application on antioxidant compounds, and their positive correlation with antioxidant capacity, finding the optimized treatment plants with higher potential and stability [35]. These findings suggest intricate interdependencies between these biochemical markers indicative of their roles in plant physiology under various environmental conditions.

3.3. Plant Oxidative Stress

The results depicted that the application of treatments had a positive effect in reducing the level of oxidative stress. Hydrogen peroxide (Figure 3a) and malondialdehyde (Figure 3b) levels were found to be the lowest in T_2 with organic inputs, which were calculated 6.0% and 3.3% lower over the control, respectively. Treatment T_3 resulted in the next best-fit for reducing the stress up to 4.0% and 3.2%, respectively, compared to the control. Thus, organic fertilizers significantly increase plant resistance, according to a study [36].

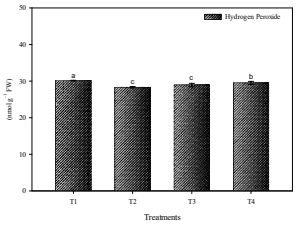

Figure 3a

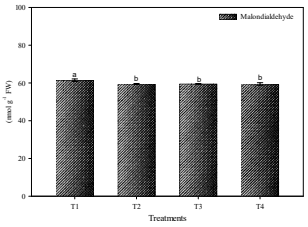

Figure 3b

Figure 3: Oxidative Stress characteristics results of tomato plant obtained after different treatments – a. Hydrogen peroxide, and b. Malondialdehyde. The vertical bars show the values of obtained findings, variables above the bars show statistically significant differences in treatments, and caped bars "I" show the standard errors.

3.4. Soil health status after the experiment:

Treatments T_2 and T_3 showed slight decreases in soil pH (Figure 4a) to the extent of 2.9 % and 3.0 %, respectively, due to organic matter buffering. Treatments T_2 and T_3 increased soil electrical conductivity (Figure 4b) by 6.2% and 7.1%, respectively, over the control. The study revealed maximum increase in soil organic carbon (Figure 4c) in treatments T_2 and T_3 to the extent of 44.6% and 44.8%, respectively, over the control. The combined treatment T_3 increased the availability of nitrogen (Figure 4d), phosphorus (Figure 4e) and potassium (Figure 4f) in soil to the extent of 44.1%, 25.4%, and 48.5% respectively over the control. This indicated enrichment of soil health in the targeted treatment. The results highlight the significance of applying a combination of organic inputs in soils to maintain neutral soil pH, stabilize electrical conductivity below 1.2 dSm^{-1}, and enhance soil organic carbon above 7.0 g kg^{-1}. The study found that post-harvest soil parameters were significantly improved by applying a combination of FYM, VC, and reduced NPK fertilization, yielding more significant results than conventional fertilizers alone (Figure 4). Similar findings have been reported by Alah et al. [37] and Paul et al. [38]. Vermicompost offers sustainable, eco-friendly solutions for improving sustainable crop production. It enhances soil quality, increases nutrient availability, and mitigates soil degradation [39]. The combination of Farmyard manure and Vermicompost significantly enhanced soil quality, maintained soil pH, and electrical conductivity, and is recommended for enhancing tomato fruit quality and yield [1]. The correlation analysis (Table 4) reveals that an increase in soil pH from the control (pH 7.89) will lead to a decline in the availability of nitrogen, phosphorus, and potassium, in the investigated soils.

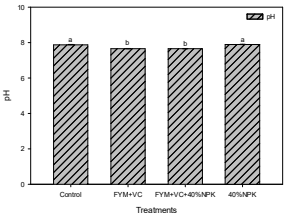

Figure 4a

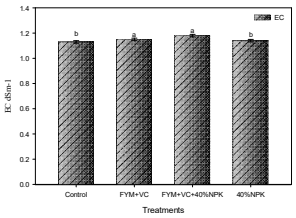

Figure 4b

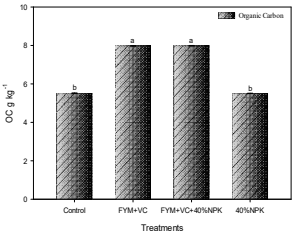

Figure 4C

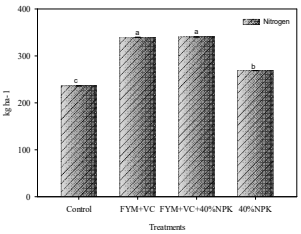

Figure 4d

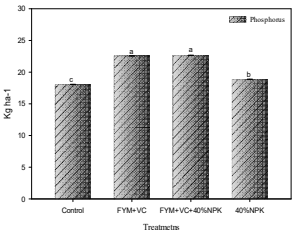

Figure 4e

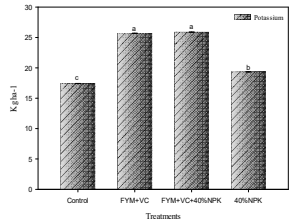

Figure 4f

Figure 4: The effects of different treatments on factors such as a. pH, b. EC, c. OC, d. available N, e. available P, and f. available K, with X-axis showing treatments, Y-axis showing factors affected by treatments. Standard error bars are calculated from the experiment with three replicates, and alphabet variables represent critical difference variation. The combined treatment of FYM, Vermicompost and reduced fertilizer significantly increased soil organic carbon, and available N, P and K nutrient status of soils.

Table 3: Correlation analysis of plant morphological and biochemical characters influenced by different treatments in correlation to the oxidative stress factors.

	PH	NOB	NOL	NOFt	FtWt	Y	APX	CCn	LYC	SOD	TAA	TSS	Vit-C	H_2O_2	MDA
PH	1														
NOB	***0.924	1													
NOL	***0.969	***0.986	1												
NOFt	***0.994	**0.888	***0.940	1											
FtWt	***0.982	***0.966	***0.995	***0.956	1										
Y	***0.999	***0.942	***0.979	***0.990	***0.987	1									
APX	***0.935	*0.729	**0.826	***0.954	**0.870	***0.915	1								
CCn	***0.995	***0.929	***0.977	***0.980	***0.992	***0.993	***0.925	1							
LYC	***0.962	***0.987	***0.987	***0.943	***0.974	***0.975	**0.805	***0.954	1						
SOD	***0.970	***0.988	***0.999	***0.944	***0.993	***0.981	**0.824	***0.974	***0.992	1					
TAA	***0.972	**0.864	***0.935	***0.957	***0.965	***0.962	***0.950	***0.986	**0.891	***0.927	1				
TSS	***0.994	***0.903	***0.961	***0.983	***0.982	***0.989	***0.948	***0.998	***0.936	***0.958	***0.992	1			
Vit-C	***0.918	***0.996	***0.988	**0.875	***0.971	***0.935	*0.728	***0.933	***0.973	***0.986	**0.878	***0.908	1		
H_2O_2	*-0.783	**-0.847	***-0.870	*-0.715	**-0.876	*-0.790	-0.645	**-0.840	*-0.785	**-0.851	**-0.850	**-0.822	**-0.892	1	
MDA	***-0.955	*-0.795	**-0.884	***-0.954	***-0.924	***-0.939	***-0.982	***-0.963	**-0.843	**-0.877	***-0.990	***-0.978	**-0.807	*0.776	1

* = Significant at $p \leq 0.05$ and $r \geq 0.666$; ** = Significant at $P \leq 0.01$ and $r > 798$; *** = Significant at $P \leq 0.001$ and $r > 898$. Significance level is irrespective of positive or negative signs. Abbreviations, PH = Plant Height, NOB = Number of Branches, NOL = Number of Leaves, NOFt = Number of Fruits, FtWt = Fruit weight, Y = Yield, APX = Ascorbate Peroxidase, CCn = Carotenoid Content, LYC = Lycopene Content, SOD = Superoxide Dismutase, TAA = Total Antioxidant Activity, TSS = Total Soluble Solids, Vit-C = Vitamin C, H_2O_2 = Hydrogen Peroxide and MDA = Malondialdehyde.

Table 4: Correlation analysis of Soil physicochemical characteristics showing the relationship between nutrients.

	pH	Electrical conductivity	Organic carbon	Available nitrogen	Available phosphorus	Available potassium
pH	1					
Electrical conductivity	**-0.796	1				
Organic carbon	***-0.999	**0.803	1			
Available nitrogen	***-0.959	**0.827	***0.966	1		
Available phosphorus	***-0.986	**0.829	***0.990	***0.993	1	
Available potassium	***-0.978	**0.833	***0.983	***0.997	***0.999	1

* = Significant at $p \leq 0.05$ and $r \geq 0.666$; ** = Significant at $P \leq 0.01$ and $r > 798$; *** = Significant at $P \leq 0.001$ and $r > 898$. Significance level is irrespective of positive or negative signs.

4.0 Discussions:

4.1 Tomato growth, yield, and biochemical parameters

A study on tomato cultivation found that vermicompost, an organic amendment, can reduce chemical fertilizer dependence [40] and improve crop growth, physiology, yield, and nutritional attributes when combined with reduced chemical fertilizer doses [41]. The study found that cow dung FYM and VC, combined with a reduced dose of NPK fertilization, significantly improved growth parameters. Organic manure application also improved growth attributes and overall plant productivity. FYM-mediated improvement in soil properties and uptake of essential nutrients has also been reported in potato tubers [42]. Vermicompost supports various microbial strains,

promoting plant growth, impacting fruit quality, and altering bacterial communities in tomato crop growth and quality. The study found that combining FYM + VC and 40% NPK fertilizers significantly improved physiological attributes in tomato crops including leaves, fruits, and carotenoid contents, lycopene content, total antioxidant activity [43], total soluble solids, and vitamin C values. The study found that using vermicompost significantly increased tomato fruit quality, and enhanced soil health, indicating its positive impact on tomato production [44]. The high lycopene content is also correlated with suitable yield, fruit weight, titratable acidity, °Brix, pulp color, and significantly higher lycopene, β-carotene, and vitamin C contents [45].
Vermicompost, derived from cow dung and farm waste, supports essential nutrients, enhancing plant growth, photosynthesis, and chlorophyll contents [46]. It improves plant nutrition by increasing chlorophyll content in bean plants. Compared to chemical fertilizers, increased doses of organic manure yield better photosynthetic attributes [47, 48]. Vermicompost uplifts soil properties, improving plant physiological attributes and nutrient uptake [49]. Studies show a strong correlation between VC application and biochemical attributes like protein, fiber, and fat. Vermicomposting organic wastes improves growth and yield, with cucumber plants showing a positive impact on their nutritional content [50, 51].

4.2 Impact on soil health

FYM and VC can improve plant growth and yield by increasing nitrogen input and total biochemical compounds. They also enhance electrical conductivity, which is positively correlated with organic carbon, which facilitates the availability of nutrients in soils. Higher levels of organic carbon in the soil facilitate the absorption of nutrients like nitrogen, phosphorus, and potassium. Vermicompost application significantly enhances plant nutritional content, including antioxidants. Organic inputs can maintain soil pH, stabilize electrical conductivity, and increase organic carbon and nutrient availability in soils.

5. Conclusion

The study suggests that using organic fertilizers such as farmyard manure and vermicompost can reduce the use of inorganic chemical fertilizers, improving soil properties and facilitating nutrient transfer to plants. When combined with less than half of the recommended doses of inorganic fertilizer, FYM + VC significantly improved tomato growth, yield, physiology, nutrient uptake, and post-harvest soil physicochemical attributes. The presence of a sufficient volume of vermicompost and farmyard manures positively affects growth promotion effects and transcriptional responses activated by biostimulants generated by organic inputs. The optimized dosage of vermicompost, farmyard manure, and reduced NPK fertilizers are crucial for developing tailored diets for tomato biostimulation.

6.0 Acknowledgement:

The authors acknowledge Amity University, Noida, India, for facilitating the Amity Institute Organic Farm to conduct field experiments.

6.1 Ethical Statement:

Ethical issues are not applicable to this review article. The paper does not involve a study on animals.

6.2 Conflict of Interest:

The authors declare that there is no conflict of interest among authors for the publication of this manuscript in this journal.

6.3 Declaration Statement:

The authors deny any financial or personal influence on their work and have not published or submitted the manuscript for publication elsewhere.

6.4 Data Statement:

The data will be made available whenever required.

6.5 Contribution of authors:

Chitranjan Kumar (CK) and Shiv Bhushan Verma (SBV) proposed the idea and the topic of this research. CK, SBV, and Raghvendra Pratap Narayan (RPN), prepared the original draft and revised it. All authors have reviewed the final version of this manuscript.

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