Effect of Vermicompost and *Azotobacter chroococcum* on Soil Biological Health and Yield of *Solanum lycopersicum* L.

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ABSTRACT

Background: The increasing use of synthetic fertilizers in tomato (*Solanum lycopersicum* L.) cultivation has posed a serious threat to soil biological quality, thus combining organic amendments and biofertilizers has been recommended as a sustainable approach for nutritional management.

Objective: The study aimed to examine the effect of vermicompost and the nitrogen-fixing bacteria *Azotobacter chroococcum* on the soil microbial and enzymatic characteristics, vegetative growth, and yield of tomatoes.

Methods: In the current study, a field experiment was carried out in a complete Randomized Block Design involving six treatments (absolute control, recommended fertilizer dose, total vermicompost treatment, total Azotobacter treatment, combined treatment of vermicompost + Azotobacter, and combined treatment of vermicompost + Azotobacter + 50% recommended fertilizer) replicated four times. Soil microbial biomass carbon, dehydrogenase, urease and phosphatase activities, microbial populations, and plant growth and yield traits were recorded and analyzed with ANOVA followed by Tukey's HSD test at $p < 0.05$.

Results: The T4 treatment, consisting of the combined use of vermicompost and *Azotobacter chroococcum* (T4), showed the maximum values of microbial biomass carbon, enzyme activities and microbial population, as well as a 71.5% increase in fruit yield as compared with the control. Additionally, measurable changes were observed regarding plant height, chlorophyll content and root development, which were higher than those for any of the treatments used alone.

Conclusion: The integrated application of vermicompost and *Azotobacter chroococcum* significantly improves the biological health of soil and tomato productivity and can be an effective eco-friendly alternative to the traditional cultivation approach based on the use of chemical fertilizers.

Keywords: Tomato (*Solanum lycopersicum* L.); Vermicompost; *Azotobacter chroococcum*; Integrated nutrient management; Soil enzyme activity; Soil microbial biomass; Biofertilizer; Sustainable agriculture

1. Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most popular vegetables cultivated worldwide because it is rich in nutrients such as lycopene, vitamin C, and antioxidants and plays an important role in farmers' income generation worldwide in both tropical and subtropical agro-ecosystems [1]. Due to increasing demand for tomatoes, the production has been steadily increasing, which is usually achieved at the expense of applying huge amounts of synthetic fertilizers, including nitrogen, phosphorus, and potassium fertilizers [2]. Though such technologies have increased production rates, continued adoption of chemical fertilizers leads to degradation of soil structure, reduction in organic carbon levels in the soil, loss of microbial diversity, and degradation of soil productivity [2, 3].

As a result of these concerns, sustainable agriculture starts employing integrated nutrient management (INM), which is known to use organic fertilizers, biofertilizers, and less amount of synthetic fertilizers not to only lessen the influence of fertilizers but preserve the function of soils [3]. One of the organic amendments that have received a lot of attention lately is vermicompost which is a rich source of nutrients and it improves such properties of soils as aggregation, water-holding capacity, cation exchange capacity, and microbial richness [4, 5].

In addition to conventional organic inputs, bio-fertilizers containing free-living nitrogen-fixing organisms like *Azotobacter chroococcum* provide an alternative biological method to enhance soil fertility. *Azotobacter chroococcum* fixes the nitrogen from the atmosphere in a non-symbiotic manner, produces phytostimulating hormones such as indole-3-acetic acid and gibberellins, generates siderophores that stimulate the availability of iron, and can mobilize phosphorus fixed in the soil [6, 7]. The biological health of soil, which can be measured by microbial biomass carbon, enzyme activity (dehydrogenase, urease, phosphatase), and microbial diversity, can give information about soil quality changes even before the changes in chemical and physical properties are detected [8].

In spite of the presence of sufficient evidence on the efficacy of vermicompost and *Azotobacter chroococcum* as good soil inputs, there are not many practical experiments conducted to establish the combined, and possibly synergistic effect of both fertilizers on biological indicators of soil, tomato growth, and yield. Thus, the objective of this study was to assess the individual and synergistic effects of vermicompost and *Azotobacter chroococcum* on microbial biomass, enzymatic activity, microbial diversity, vegetative growth, and fruit yield of tomato crops.

2. Related Work

Vermicompost is produced through the joint action of earthworms and associated microflora on organic residues, yielding a finely granulated, humus-rich product containing available nitrogen, phosphorus, potassium, and micronutrients in plant-accessible forms [1, 4]. Numerous studies report that vermicompost incorporation increases soil organic carbon, improves aggregate stability and porosity, and enhances water retention, thereby creating a more favorable microhabitat for beneficial soil organisms [4, 5, 9]. Bhattacharyya *et al*. demonstrated that vermicompost application substantially elevated microbial biomass carbon and dehydrogenase activity relative to unamended soils under tropical conditions [13], while Kumar *et al*. reported parallel increases in urease and phosphatase activities following repeated vermicompost application in agricultural fields [5].

Azotobacter chroococcum has been extensively investigated as a plant growth-promoting rhizobacterium (PGPR) capable of non-symbiotic biological nitrogen fixation, contributing modest but agronomically meaningful quantities of fixed nitrogen to the rhizosphere [7, 8]. Beyond nitrogen fixation, Azotobacter strains are recognized for producing indole acetic acid, gibberellins, cytokinins, and siderophores, mechanisms that collectively stimulate root elongation, lateral root formation, and nutrient uptake efficiency [6, 9, 10]. Aasfar *et al*. reviewed the multifunctional plant growth-promoting traits of Azotobacter species, emphasizing their potential as biological enhancers of crop nutrition and yield stability across diverse cropping systems [10].

Several investigators have explored combined organic-biofertilizer regimes across vegetable crops. Singh *et al*. observed that partial substitution of chemical fertilizer with vermicompost improved fruit yield and quality attributes in strawberry [19], while Reddy and Reddy documented enhanced growth and yield of okra following combined vermicompost and biofertilizer application [16]. Comparable synergistic responses have been reported in onion, where vermicompost combined with reduced inorganic fertilizer improved both productivity and nutrient uptake efficiency [15]. These findings collectively suggest that organic amendments and nitrogen-fixing biofertilizers act through complementary mechanisms—vermicompost primarily enriching substrate quality and microbial habitat, and Azotobacter directly contributing fixed nitrogen and phytohormonal stimulation.

Soil microbial biomass and enzyme activities are widely accepted as sensitive, integrative indicators of soil biological health, responding more rapidly to management changes than bulk physicochemical properties [8, 20, 21]. Nannipieri *et al*. emphasized that microbial diversity underpins numerous soil functions including nutrient cycling and organic matter decomposition, reinforcing the value of biological indicators in evaluating nutrient management strategies [21]. Nonetheless, existing literature reveals a comparative scarcity of controlled field trials directly contrasting sole and combined application of vermicompost and *Azotobacter chroococcum* on both soil biological parameters and tomato yield within a single experimental framework, representing the principal knowledge gap addressed by the present investigation.

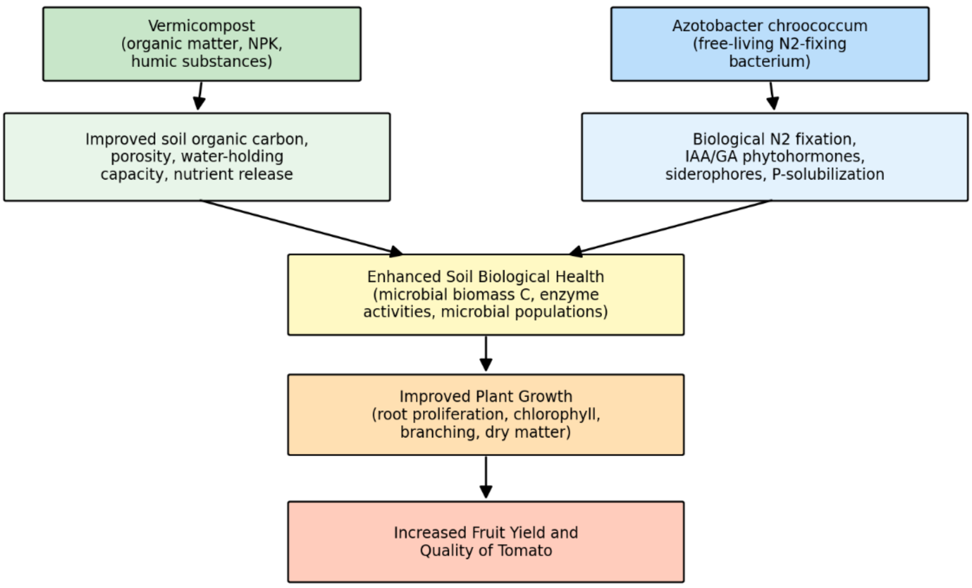

Fig 1: Mechanism of Action of Vermicompost and *Azotobacter chroococcum* in Enhancing Soil Biological Health and Plant Growth.

The field experiment was conducted during the winter (rabi) growing season at a research farm situated in the sub-tropical agro-climatic zone, characterized by a mean annual rainfall of approximately 850 mm, mean maximum temperature of 32°C, and mean minimum temperature of 14°C during the crop growth period. The experimental soil was sandy loam in texture, slightly alkaline (pH 7.6), with initial organic carbon content of 0.48%, available nitrogen of 218 kg/ha, available phosphorus of 16.4 kg/ha, and available potassium of 224 kg/ha.

3.2 Experimental Design and Treatments

The trial was laid out in a Randomized Complete Block Design (RCBD) comprising six treatments replicated four times, giving twenty-four plots of 12 m² (4 m × 3 m) each, with a plant spacing of 60 cm × 45 cm. Treatment details are summarized in Table 1 and the field layout is illustrated in Figure 1.

Table 1: Treatment Details and Experimental Design (RCBD, four replications)

Code	Treatment Description	Replications
T0	Absolute control (no fertilizer, no amendment)	4
T1	Recommended dose of fertilizer (RDF): 120:60:60 kg N:P2O5:K2O/ha	4
T2	Vermicompost alone @ 5 t/ha	4
T3	*Azotobacter chroococcum* seedling-root dip inoculation (10 g/L carrier-based inoculant)	4
T4	Vermicompost (5 t/ha) + *Azotobacter chroococcum* inoculation	4
T5	Vermicompost (5 t/ha) + *Azotobacter chroococcum* + 50% RDF	4

3.3 Crop Husbandry

A determinate, high-yielding tomato variety was raised in a protected nursery for 28 days prior to transplanting. Seedlings were transplanted onto raised beds, followed by immediate light irrigation. Vermicompost was incorporated into the soil two weeks before transplanting; *Azotobacter chroococcum* inoculation was applied as a seedling root-dip treatment (10 g carrier-based inoculant per litre of water) immediately before transplanting. Irrigation was scheduled at seven-day intervals through drip lines, weeds were controlled through two manual hoeings, and recommended integrated pest and disease management practices were followed uniformly across all plots to avoid confounding effects.

3.4 Soil Biological Analysis

Rhizosphere soil samples were collected at 60 days after transplanting (DAT) for determination of microbial biomass carbon (chloroform fumigation-extraction method), soil respiration (alkali absorption method), dehydrogenase activity (triphenyl tetrazolium chloride reduction assay), urease activity (colorimetric indophenol method), and acid/alkaline phosphatase activity (p-nitrophenyl phosphate method). Bacterial, fungal, and actinomycete populations were enumerated on nutrient agar, Martin's rose bengal agar, and Kenknight's agar media, respectively, using the standard serial dilution plate count technique.

3.5 Plant Growth and Yield Parameters

Plant height, number of primary branches, leaf area (leaf area meter), root length, and SPAD-based chlorophyll content were recorded at 60 DAT, while dry matter accumulation was determined after oven-drying at 65°C to constant weight. At harvest, number of fruits per plant, average fruit weight, fruit diameter, total fruit yield, marketable yield, and harvest index were recorded from five randomly tagged plants per plot.

3.6 Statistical Analysis

Data were subjected to Analysis of Variance (ANOVA) appropriate for RCBD using standard statistical software, and treatment means were compared using Tukey's Honestly Significant Difference (HSD) test at a 5% probability level ($p < 0.05$). Pearson correlation coefficients were computed to examine relationships among soil biological properties, plant growth parameters, and yield components.

Fig 2: Experimental Layout Showing Different Treatment Combinations across Four Replicated Blocks (RCBD).

4. Results

4.1 Soil Biological Health

All treatments involving vermicompost and/or *Azotobacter chroococcum* significantly ($p < 0.05$) increased microbial biomass carbon, enzyme activities, and microbial populations relative to the untreated control (Table 2). The combined treatment T4 (vermicompost + Azotobacter) recorded the highest microbial biomass carbon (410 µg/g soil), representing a 95.2% increase over the control, along with the greatest dehydrogenase activity (39.5 µg TPF/g/24h) and urease activity (27.6 µg NH4-N/g/h). Bacterial population counts followed a similar trend, being markedly higher under combined application than under either input applied singly.

4.2 Plant Growth Response

Vegetative growth parameters improved progressively across treatments, with T4 producing the tallest plants (84.9 cm at 60 DAT) and the highest chlorophyll content (53.4 SPAD units), representing increases of 45.4% and 38.3% over the control, respectively. Root length and dry matter accumulation showed parallel enhancement under combined vermicompost-Azotobacter application, consistent with improved nutrient availability and rhizosphere microbial activity.

4.3 Yield Performance

Fruit yield increased substantially across treatments, ranging from 28.4 t/ha in the control to 52.3 t/ha in T5 (vermicompost + Azotobacter + 50% RDF) and 48.7 t/ha in T4. The combined organic-biofertilizer treatment (T4) alone increased yield by 71.5% over the control without any inorganic fertilizer input, while the partially fertilized combination (T5) produced the numerically highest yield overall, though the difference between T4 and T5 was not statistically significant (Figure 3).

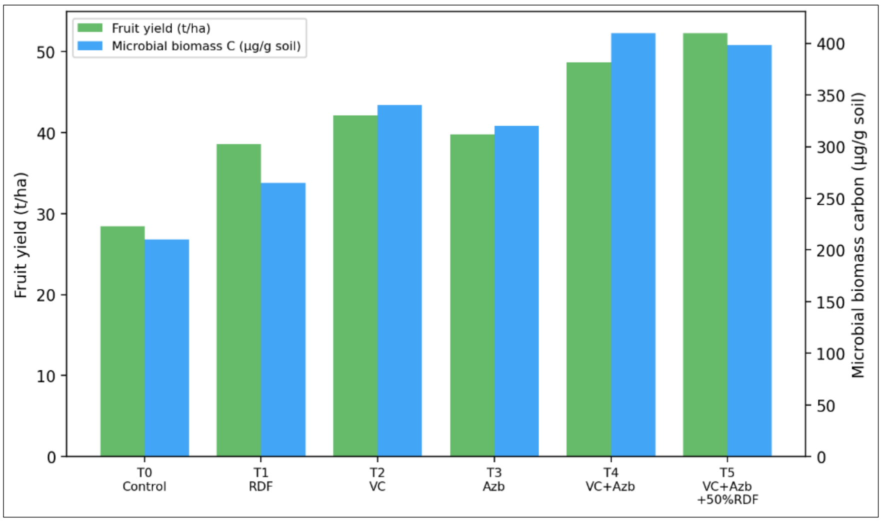

Fig 3: Comparative Performance of Different Treatments on Tomato Fruit Yield and Soil Microbial Biomass Carbon.

Table 2: Effect of Vermicompost and *Azotobacter chroococcum* on Soil Biological Properties, Plant Growth, and Yield of Tomato

Parameter	T0	T1	T2	T4	T5
Microbial biomass C (µg/g soil)	210	265	340	410	398
Dehydrogenase activity (µg TPF/g/24h)	18.2	24.6	32.1	39.5	37.8
Urease activity (µg NH4-N/g/h)	12.4	16.8	22.3	27.6	26.9
Bacterial population (×10^6 CFU/g)	14.1	19.3	26.8	33.2	31.7
Plant height (cm) at 60 DAT	58.4	71.2	76.5	84.9	83.1
Chlorophyll content (SPAD units)	38.6	45.1	48.7	53.4	52.6
Number of fruits/plants	16.8	22.4	24.9	29.6	28.8
Fruit yield (t/ha)	28.4	38.6	42.1	48.7	52.3

4.4 Correlation Analysis

Microbial biomass carbon was significantly and positively correlated with dehydrogenase activity ($r = 0.89$), plant height ($r = 0.82$), and fruit yield ($r = 0.86$), indicating that improvements in soil biological indicators were closely associated with enhanced vegetative growth and productivity. Similarly, chlorophyll content correlated positively with both bacterial population ($r = 0.78$) and fruit yield ($r = 0.81$), reinforcing the linkage between microbially mediated nutrient availability and crop performance.

5. Discussion

The pronounced improvement in soil biological indicators under vermicompost application is attributable to its direct enrichment of labile organic carbon, which serves as an energy substrate for heterotrophic microbial populations, thereby stimulating microbial biomass turnover and associated enzyme secretion [4, 13]. The elevated dehydrogenase and urease activities observed under vermicompost treatments corroborate earlier reports that organic amendments enhance overall microbial metabolic activity more effectively than mineral fertilizers alone [5, 13].

The additional benefit conferred by *Azotobacter chroococcum* inoculation is best explained through its non-symbiotic nitrogen-fixing capacity and its production of growth-promoting phytohormones, which directly stimulate root proliferation and indirectly expand the rhizosphere volume available for microbial colonization [6, 7, 10]. When applied jointly with vermicompost, Azotobacter appears to benefit from the improved organic substrate and moisture environment provided by the organic amendment, while simultaneously supplying biologically fixed nitrogen and hormonal stimulation that vermicompost alone cannot fully replicate—a synergism consistent with the substantially higher biological and yield responses recorded under T4 relative to either sole treatment [9, 10].

These findings align broadly with previous reports of enhanced vegetable productivity under combined organic-biofertilizer regimes in strawberry, okra, and onion [15, 16, 19], while extending this evidence specifically to tomato under a systematically controlled comparison of soil biological, growth, and yield responses. Notably, the near-equivalence between the fully organic combined treatment (T4) and the partially fertilized combination (T5) suggests that chemical fertilizer input can be substantially reduced—by as much as 50%—without significant yield penalty when supported by an effective organic-biofertilizer combination, offering clear economic and environmental advantages through reduced fertilizer expenditure and diminished nutrient runoff risk [2, 3, 23].

From a practical standpoint, the integration of vermicompost and *Azotobacter chroococcum* represents a low-cost, locally implementable strategy well suited to smallholder tomato production systems, particularly where access to inorganic fertilizers is constrained or costly. Nonetheless, certain limitations warrant acknowledgment: the present study was conducted at a single site over one growing season, and long-term, multi-location trials are needed to confirm the consistency of these responses across diverse soil types and climatic conditions. Future research should additionally examine the influence of vermicompost source material and Azotobacter strain selection on the magnitude of the observed synergistic effects.

6. Conclusion

The research presented in this paper clearly indicates that the use of a mixture of vermicompost and *Azotobacter chroococcum* has led to an enhancement of soil biological quality manifested by increasing microbial biomass carbon, activities of enzymes and numbers of microorganisms, as well as taking part in improving tomato plant growth and yield. The application of the integrated organic-biofertilizer treatment has led to yields as high as those achieved using a considerable amount of a mineral fertilizer that proves its ability to minimize the use of fertilizers without losing the productivity of the crops. Thus, the results obtained in the research state the possibility of implementing vermicompost together with *Azotobacter chroococcum* in integrated nutrient management for the cultivation of tomatoes. The further application of the results obtained in the research in the field is recommended.

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