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Effect of Integrated Nutrient Management on Growth, Yield, and Economics of Tomato under Polyhouse Conditions

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

A two-year experiment was conducted at the Hi-Tech Greenhouse, College of Horticulture, Junagadh Agricultural University, Junagadh, Gujarat, during 2021-22 and 2022-23 to evaluate nutrient-management strategies for tomato under polyhouse conditions. The experiment was arranged in a completely randomised design with eight treatments and three replications. Treatments included the recommended dose of fertiliser (RDF; 25.0-12.5-12.5 kg N-P_2O_5-K_2O per 1000 m^2) alone or in combination with micronutrients, Panchgavya, seaweed extract, banana pseudostem sap, Go Krupa Amrutam, a microbial formulation, and a natural-farming nutrient package. Pooled analysis showed that 100% RDF + Panchgavya 3% (T3) recorded the highest plant height (281.69 cm) and number of branches per plant (11.73), together with the earliest flowering (40.30 days) and first picking (95.53 days); these growth and phenological responses were statistically at par with T8. T3 also recorded the highest fruit weight (69.65 g), number of fruits per plant (61.02), total soluble solids (4.28 °Brix), and pooled fruit yield (4.13 kg/plant; 26.24 t/1000 m^2). The pooled fruit yield of T3 was significantly higher than that of the other treatments at the 5% level. The highest net realization was also obtained with T3 (INR 350,331 per 1000 m^2). The results indicate that integrating RDF with a 3% Panchgavya foliar spray is a promising nutrient-management option for tomato under the tested polyhouse conditions.

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Keywords: Integrated nutrient management; Panchgavya; polyhouse; tomato; yield.

1. Introduction

Tomato (Solanum lycopersicum L.) is an important high-value vegetable crop for protected cultivation because greenhouse and polyhouse systems can extend production windows, moderate exposure to adverse weather, and improve the consistency of marketable produce. The magnitude of the advantage over open-field production depends on structure design, cultivar, season, and crop management; therefore, protected cultivation should be viewed as a management-intensive production system rather than as an assurance of uniformly higher yield (Sabir & Singh, 2013; Sotelo-Cardona *et al.*, 2021; Stoleru *et al.*, 2020).

Nutrient management is a major determinant of tomato productivity under protected conditions. Exclusive reliance on mineral fertilisers can provide readily available nutrients, whereas organic amendments can contribute organic matter, nutrients, and biologically active substrates. Evidence from field, greenhouse, and meta-analytical studies indicates that integrated use of organic nutrient sources and mineral fertilisers can maintain or improve tomato growth, yield, selected quality attributes, and soil biological properties, although responses vary with nutrient source, application rate, soil fertility, and production environment (Durmuş & Kızılkaya, 2022; Fan *et al.*, 2023; Gao *et al.*, 2023; Li *et al.*, 2023; Mengistu *et al.*, 2017). This context dependence is reinforced by a global meta-analysis showing that organic and combined organic–inorganic fertilisation can improve selected tomato quality attributes, although the magnitude of the response varies with soil properties and management conditions (Yang *et al.*, 2023). Long-term evidence from India likewise indicates that the choice of organic nutrient source can influence tomato yield, fruit quality, profitability, and post-harvest soil fertility, emphasizing the importance of evaluating both agronomic and economic outcomes of nutrient-management strategies (Gourkhede *et al.*, 2026). Recent greenhouse evidence further indicates that combining organic and inorganic nutrient sources can improve tomato productivity relative to individual nutrient sources, supporting the evaluation of integrated nutrient-management strategies under protected cultivation (Thapa & Chand, 2026).

Efficient placement and timing of nutrients are particularly important in protected cultivation. Drip fertigation can deliver soluble nutrients with irrigation water close to the active root zone and can improve water and fertiliser management when application rates are matched to crop demand (Wang & Xing, 2016). The contribution of biologically based nutrient inputs may also depend on water management; under greenhouse conditions, microbial fertiliser application improved tomato root development, nitrogen accumulation, and nutrient-use efficiency, with the magnitude of the response varying among irrigation regimes (Liu *et al.*, 2024). Organic nutrient sources and biologically derived formulations are also being evaluated as complements to mineral fertilisation. In a greenhouse tomato experiment, the use of vermicompost and biologically based formulations containing plant-growth-promoting microorganisms, either alone or in combination with mineral fertilisation, improved plant growth and nutritional status, illustrating the potential value of integrating complementary nutrient sources (Cheraghi *et al.*, 2023). In organic greenhouse tomato systems, nutrient release from organic inputs can increase soil nitrogen availability and yield, but the response depends on synchronisation between nutrient mineralisation and crop demand (Gatsios *et al.*, 2021). The importance of such synchronisation is also evident from experiments in which organic nutrient sources did not match the performance of mineral fertilisation; for example, solid anaerobic digestate supplied to tomato produced lower biomass and harvestable-fruit yield than a mineral-fertiliser reference when nutrient availability was insufficiently aligned with crop demand (Asp & Bergstrand, 2024).

Despite increasing interest in integrated nutrient management, comparative information on combinations of RDF with Panchgavya, micronutrient mixtures, seaweed extract, banana pseudostem sap, microbial formulations, and natural-farming nutrient packages remains limited under polyhouse conditions in western India. The present study was therefore conducted to evaluate the effects of selected nutrient-management treatments on tomato growth, phenology, fruit attributes, yield, and economic returns under polyhouse conditions.

2. Materials and Methods

The investigation was conducted at the Hi-Tech Greenhouse, College of Horticulture, Junagadh Agricultural University, Junagadh, Gujarat, during 2021-22 and 2022-23. A commercially available, government-approved indeterminate tomato type was used. The experiment was laid out in a completely randomised design with three replications and eight treatments: T1, 100% RDF (25.0-12.5-12.5 kg N-P_2O_5-K_2O/1000 m²); T2, 100% RDF + micronutrient mixture Grade-IV at 1% as three foliar sprays at 45, 60, and 75 days after transplanting (DAT); T3, 100% RDF + Panchgavya 3% as three foliar sprays at 45, 60, and 75 DAT; T4, 100% RDF + seaweed extract 3.5% as three foliar sprays at 45, 60, and 75 DAT; T5, 100% RDF + banana pseudostem sap 3% as three foliar sprays at 45, 60, and 75 DAT; T6, 100% RDF + Go Krupa Amrutam at 250 L/1000 m² through drip irrigation at 30 DAT; T7, 75% RDF + 500 mL of the Azotobacter + PSB + KMB formulation Gir Savaj/1000 m² through drip irrigation at 30 DAT; and T8, no RDF + 25 kg FYM/1000 m² + 25 kg Ghan Jivamrut/1000 m² + Bijamrut seed treatment + Jivamrut at 5 L/1000 m² through drip irrigation at 45, 60, and 75 DAT. A basal dose of 2 t FYM/1000 m² was applied to all treatments except T8. Plants were established at 45 cm × 30 cm × 60 cm spacing in a paired-row configuration.

Growth and phenological observations included plant height (cm), number of branches per plant, days to flowering, and days to first picking. Fruit observations included fruit length (cm), fruit girth (cm), fruit weight (g), number of fruits per plant, total soluble solids (TSS; °Brix), and fruit yield (kg/plant and t/1000 m²). Five plants were observed within each plot in each replication, and the mean of these five plants was used as the replication value for statistical analysis. Fruit weight and number of fruits per plant were similarly averaged within each replication before yield was summarised.

2.1 Economics

The cost of cultivation for each treatment was calculated from the costs of field and crop operations and treatment-specific inputs from crop establishment through the final harvest. Fixed and variable costs were summarised separately for each treatment.
Gross realization was calculated from the treatment yield using the average tomato price applied in the economic analysis (INR 20/kg).

Net realization was calculated as gross realization minus the total cost of cultivation for each treatment and was expressed per 1000 m^2.

2.2 Statistical Analysis

Replication means for all measured traits were subjected to analysis of variance appropriate to a completely randomised design following Panse and Sukhatme (1985). For the pooled analysis across the two study years, treatment, year, and treatment × year effects were evaluated. Significance was assessed using the F test, and the standard error of the mean (SEm) and critical difference (CD) at the 5% significance level were calculated where applicable. The statistical analysis was carried out in the Department of Agricultural Statistics, College of Agriculture, Junagadh Agricultural University, Junagadh.

3. Results and Discussion

3.1 Growth and Phenology

Nutrient-management treatments significantly influenced the pooled growth and phenological traits (Table 1). T3 (100% RDF + Panchgavya 3%) recorded the highest plant height (281.69 cm) and number of branches per plant (11.73), and the earliest flowering (40.30 days) and first picking (95.53 days). For all four traits, the differences between T3 and T8 were smaller than the corresponding CD values; therefore, T3 and T8 were statistically at par. Comparable improvements in tomato growth and phenology under Panchgavya- and Jeevamrit-based treatments have been reported previously (Singh *et al.*, 2022).

The growth response under T3 is biologically plausible because integrated organic-mineral nutrient supply can combine readily available mineral nutrients with biologically active organic inputs. Molecular characterisation of Panchagavya has identified diverse microbial communities and plant-growth-associated metabolites, including indole-3-acetic acid and gibberellin-related compounds, although the composition of the formulation used in the present experiment was not independently characterised (Muthukapalli Krishnareddy *et al.*, 2022). More broadly, greenhouse and field studies have reported improvements in tomato growth, nutrient status, and productivity when organic nutrient sources are used alone or in combination with mineral fertilisers (Gatsios *et al.*, 2021; Li *et al.*, 2023; Stoleru *et al.*, 2020).

Neither the year effect nor the treatment × year interaction was significant for plant height, number of branches per plant, days to flowering, or days to first picking (Table 1), supporting the interpretation of the pooled means for these traits. The earlier flowering and first picking observed under T3 may reflect improved crop nutritional status, but this explanation remains inferential because plant nutrient uptake, endogenous hormones, chlorophyll, and photosynthetic rate were not measured directly in the present experiment.

3.2 Fruit Attributes and Yield

Fruit attributes also responded to nutrient management (Table 2). T3 recorded the highest fruit length (5.94 cm), fruit girth (4.81 cm), fruit weight (69.65 g), number of fruits per plant (61.02), and TSS (4.28 °Brix). T3 was statistically at par with T8 and T6 for fruit length, fruit girth, and TSS, and with T5 for fruit length. In contrast, the fruit weight and number of fruits per plant under T3 exceeded the corresponding values of the remaining treatments based on the reported CD values. Similar tomato responses to Panchgavya application have been reported in independent experiments, although treatment concentrations and production environments differed among studies (Prathima *et al.*, 2022; Singh *et al.*, 2022).

Fruit yield followed the same general pattern (Table 3). T3 produced 3.98 and 4.28 kg/plant in 2021-22 and 2022-23, respectively, with a pooled yield of 4.13 kg/plant (26.24 t/1000 m^2). The pooled T3 yield was higher than the other treatment means by more than the reported CD (0.22 kg/plant; 1.40 t/1000 m^2). The yield response is consistent with broader evidence that integrated organic and mineral nutrient management can enhance tomato yield formation through effects on nutrient supply, soil organic matter, and rhizosphere processes (Fan *et al.*, 2023; Gao *et al.*, 2023; Mengistu *et al.*, 2017). Complementary evidence also indicates that the source of organic nutrient inputs can influence tomato growth and yield attributes, with Dhaker *et al.* (2025) reporting significant responses to organic manure treatments and the highest fruit yield with poultry manure among the organic sources evaluated.

The year effect was significant for fruit yield, whereas the treatment × year interaction was nonsignificant (Table 3), indicating that overall yield level differed between years but the relative treatment response was sufficiently consistent to support pooled interpretation. For the fruit attributes in Table 2, the year effect was nonsignificant except for the number of fruits per plant, and treatment × year interactions were nonsignificant for all traits. Greenhouse studies likewise show that fertilisation responses can vary with cultivar and production environment while integrated or organic nutrient inputs can maintain or improve yield and selected quality characteristics (Li *et al.*, 2023; Stoleru *et al.*, 2020).

Accordingly, the response to T3 should be interpreted as treatment-specific evidence under the conditions of this experiment rather than as a universally optimal nutrient schedule. Meta-analyses show substantial heterogeneity in tomato responses to organic fertiliser according to fertiliser type, rate, soil conditions, and production environment (Fan *et al.*, 2023; Gao *et al.*, 2023). Studies involving compost and other organic amendments similarly indicate that yield benefits depend on amendment characteristics and their interaction with mineral nutrition (Durmuş & Kızılkaya, 2022).

3.3 Economics of Tomato Cultivation

The economic analysis is presented in Table 4. T3 recorded the highest gross realization (INR 524,800/1000 m²) and the highest net realization (INR 350,331/1000 m²). The total cultivation cost under T3 (INR 174,469/1000 m²) was similar to that of T1 (INR 174,289/1000 m²), indicating that the economic advantage of T3 was driven primarily by the higher yield and gross realization rather than by a lower production cost. Previous tomato studies have also reported improved economic returns when organic or biologically derived inputs were integrated with mineral nutrient management (Mengistu *et al.*, 2017; Singh *et al.*, 2022).

The economic ranking should nevertheless be interpreted within the price structure used in the present analysis. Changes in tomato price, input cost, labour cost, or treatment availability could alter treatment profitability even when the biological yield ranking remains unchanged.

Within the tested production and price conditions, the combination of 100% RDF with Panchgavya 3% provided the strongest joint agronomic and economic response. Validation across additional cultivars, locations, soil-fertility conditions, and market years would improve the generalisability of this recommendation.

Table 1. Effect of nutrient-management treatments on plant height, number of branches per plant, days to flowering, and days to first picking in tomato under polyhouse conditions (pooled over two years)

Treatment	Plant height (cm)	Number of branches/plant	Days to flowering	Days to first picking
T_1	249.71	8.91	46.43	100.62
T_2	257.99	9.34	45.90	99.56
T_3	281.69	11.73	40.30	95.53
T_4	264.79	10.46	43.64	97.87
T_5	267.06	10.87	44.38	97.63
T_6	269.19	10.97	43.92	98.57
T_7	262.99	10.51	44.17	98.73
T_8	272.13	11.10	41.48	96.33
SEm ±	3.850	0.242	0.775	0.676
CD (5%)	11.09	0.69	2.23	1.94
CV (%)	3.55	5.66	4.34	1.69
Year effect				
SEm ±	1.925	0.121	0.387	0.338
CD (5%)	NS	NS	NS	NS
Year × Treatment				
SEm ±	5.445	0.342	1.096	0.956
CD (5%)	NS	NS	NS	NS

Note. SEm = standard error of the mean; CD = critical difference; CV = coefficient of variation; NS = nonsignificant; Year × Treatment = year-by-treatment interaction

3.4 Limitations and Future Research

The findings of the present study should be interpreted within the specific polyhouse conditions under which the experiment was conducted. The investigation was carried out at a single location over two study years using one commercially available indeterminate tomato type, which limits the broader generalisation of the observed treatment responses. Although the integrated nutrient-management treatments significantly influenced growth, phenology, fruit attributes, yield, and economic returns, the physiological mechanisms underlying these responses were not directly examined. Plant nutrient uptake, endogenous hormones, chlorophyll content, and photosynthetic rate were not measured, and the composition of the Panchgavya formulation used in the experiment was not independently characterised. In addition, the economic evaluation was based on the price structure applied in the present analysis.

Future studies should therefore validate the promising treatments across additional cultivars, locations, soil-fertility conditions, production seasons, and market years to determine the consistency and wider applicability of the observed agronomic and economic responses.

Table 2. Effect of nutrient-management treatments on fruit length, fruit girth, fruit weight, number of fruits per plant, and total soluble solids in tomato under polyhouse conditions (pooled over two years)

Treatment	Fruit length (cm)	Fruit girth (cm)	Fruit weight (g)	Number of fruits/plant	TSS (°Brix)
T_1	5.11	4.16	57.42	53.43	3.52
T_2	5.14	4.22	58.33	56.55	3.57
T_3	5.94	4.81	69.65	61.02	4.28
T_4	5.50	4.44	63.26	56.42	3.68
T_5	5.75	4.49	64.50	56.72	3.69
T_6	5.60	4.58	62.74	57.47	4.08
T_7	5.47	4.31	60.63	55.48	3.65
T_8	5.81	4.70	65.51	57.88	4.19
SEm ±	0.127	0.086	1.319	0.906	0.091
CD (5%)	0.36	0.24	3.80	2.61	0.26
CV (%)	5.63	4.72	5.15	3.90	5.82
Year effect					
SEm ±	0.063	0.043	0.659	0.453	0.045
CD (5%)	NS	NS	NS	1.30	NS
Year × Treatment					
SEm ±	0.180	0.121	1.865	1.282	0.128
CD (5%)	NS	NS	NS	NS	NS

Note. SEm = standard error of the mean; CD = critical difference; CV = coefficient of variation; NS = nonsignificant; Year × Treatment = year-by-treatment interaction

Table 3. Effect of nutrient-management treatments on fruit yield in tomato under polyhouse conditions during 2021-22 and 2022-23 and pooled over years

Treatment	Fruit yield (kg/plant)			Fruit yield (t/1000 m²)		
	2021-22	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**
T_1	3.12	3.32	3.22	19.79	21.10	20.45
T_2	3.35	3.61	3.48	21.27	22.89	22.08
T_3	3.98	4.28	4.13	25.29	27.20	26.24
T_4	3.37	3.62	3.50	21.37	23.01	22.19
T_5	3.48	3.75	3.62	22.12	23.80	22.96
T_6	3.42	3.68	3.55	21.71	23.37	22.54
T_7	3.44	3.70	3.57	21.85	23.51	22.68
T_8	3.57	3.90	3.74	22.69	24.75	23.72
SEm ±	0.099	0.117	0.076	0.633	0.743	0.488
CD (5%)	0.29	0.35	0.22	1.89	2.22	1.40
CV (%)	4.98	5.43	5.23	4.98	5.43	5.23
Year effect						
SEm ±			0.038			0.244
CD (5%)			0.11			0.70
Year × Treatment						
SEm ±			0.108			0.690
CD (5%)			NS			NS

Note. SEm = standard error of the mean; CD = critical difference; CV = coefficient of variation; NS = nonsignificant; Year × Treatment = year-by-treatment interaction

Table 4. Economics of nutrient-management treatments in tomato under polyhouse conditions

Treatment	Yield (t/1000 m²)	Fixed cost (INR)	Variable cost (INR)	Total cultivation cost (INR)	Gross realization (INR)	Net realization (INR)
T1	20.45	171,104	3,184.54	174,289	409,000	234,711
T2	22.08	171,104	8,264.54	179,369	441,600	262,231
T3	26.24	171,104	3,364.54	174,469	524,800	350,331
T4	22.19	171,104	3,983.74	175,088	443,800	268,712
T5	22.96	171,104	5,654.54	176,759	459,200	282,441
T6	22.54	171,104	3,184.54	174,289	450,800	276,511
T7	22.68	171,104	2,698.40	173,802	453,600	279,798
T8	23.72	171,104	712.50	171,817	474,400	302,584

Note. The average tomato price used for gross-realization calculations was INR 20/kg

4. Conclusion

Under the tested polyhouse conditions, 100% RDF (25.0-12.5-12.5 kg N-P_2O_5-K_2O/1000 m²) combined with Panchgavya 3% applied as foliar sprays at 45, 60, and 75 DAT produced the strongest overall response among the evaluated nutrient-management treatments. The treatment recorded high vegetative growth, earlier flowering and first picking, favourable fruit attributes, the highest pooled fruit yield (4.13 kg/plant; 26.24 t/1000 m²), and the highest net realization (INR 350,331/1000 m²). The nonsignificant treatment × year interactions for the reported growth, fruit, and yield variables indicate that treatment responses were broadly consistent across the two study years. These findings support the integration of RDF with Panchgavya as a promising option for tomato under comparable polyhouse conditions. Further validation across cultivars, locations, soil-fertility conditions, and production seasons is warranted before a broader recommendation.

Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. Grammarly and ChatGPT were used solely to assist with grammatical refinement and reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript

Competing Interests

The authors declare that they have no known competing financial or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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