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INTEGRATED NUTRIENT MANAGEMENT: A SUSTAINABLE APPROACH TO IMPROVE GROWTH AND QUALITY OF POMEGRANATE (*PUNICA GRANATUM* L.)

Vinay V. Turudagi^{1*}, Anand G. Nanjappanavar², S.N. Patil³, I.B. Biradar⁴ and D.L. Rudresh⁵

¹Department of Fruit Science, College of Horticulture, Bagalkot, Karnataka, India.

²Department of Fruit Science, Main Horticulture Research and Extension Center, Bagalkot, Karnataka, India.

³Department of Fruit Science, College of Horticulture, Bagalkot, Karnataka, India.

⁴Department of N.R.M., College of Horticulture, Bagalkot, Karnataka, India.

⁵Department of Microbiology, College of Horticulture, Bagalkot, Karnataka, India.

*Corresponding author E-mail: vinayturudagi123@gmail.com

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ABSTRACT

This investigation assessed the influence of Integrated Nutrient Management (INM) on the growth and fruit quality of pomegranate (*Punica granatum* L.) cv. Bhagwa during the hasta bahar season of 2024–25 at MHREC, Bagalkot. The experiment was laid out in a Randomized Complete Block Design with seven treatments on five-year-old tissue-cultured plants. The treatments involved different proportions of recommended fertilizer dose (RDF) combined with organic manures, biofertilizers and micronutrients. INM practices showed marked improvements in vegetative growth, flowering, yield and fruit quality compared with sole RDF. The most effective treatment (T7: 50% RDF + neem cake + vermicompost + biofertilizers + micronutrients) resulted in superior plant height (2.69 m), canopy volume (4.37 m³), leaf area (16.09 cm²), yield (14.60 kg/plant; 5.75 t/ha), total soluble solids (15.75 °Brix), anthocyanin content (8.92 mg/100 g), and shelf life (25.18 days), alongside lower acidity (0.42%). Overall, balanced INM strategies proved beneficial for enhancing yield, quality and soil sustainability.

Key words : Pomegranate, Bhagwa, Integrated nutrient management, Growth, Quality.

Introduction

Pomegranate (*Punica granatum* L.), a member of the family Lythraceae, is one of the most significant fruit crops thriving in arid and semi-arid ecosystems. It holds considerable nutritional, medicinal and economic value and is widely cultivated across India. The major producing states include Maharashtra, Karnataka, Gujarat, Andhra Pradesh and Madhya Pradesh, which together contribute the bulk of national production and export. The fruit is highly regarded for its attractive appearance, unique flavor, extended shelf life and its abundance of bioactive compounds such as anthocyanins, tannins and phenolics. These phytochemicals are well known for their antioxidant properties and their role in promoting human health.

Over the past decade, the acreage and output of

pomegranate in India have shown a consistent upward trend. Reports from ICAR–National Research Centre on Pomegranate (2021–22, third advance estimate) indicate that the crop covered nearly 2.76 lakh hectares with an annual production of 31.48 lakh metric tonnes (NHB 2021-22). In comparison, the area during 2020–21 was 2.70 lakh hectares, producing about 30.88 lakh tonnes with an average productivity of 6.9 t/ha. This steady expansion is attributed to increasing demand in domestic and international markets, the availability of improved planting material, advances in orchard management and supportive government policies.

Pomegranate, though well-suited to various agro-climatic conditions, is highly dependent on proper nutrient supply and soil fertility for maintaining yield and fruit

quality. Overuse of chemical fertilizers has led to issues like nutrient imbalance, soil degradation and declining orchard sustainability. To overcome these problems, Integrated Nutrient Management (INM) has emerged as a sustainable approach, integrating organic manures, biofertilizers and inorganic fertilizers in appropriate proportions. This balanced strategy improves soil health, enhances nutrient-use efficiency and ensures long-term crop productivity.

Materials and Methods

The current study was conducted during the *hastha bahar* season of 2024–2025, at the Main Horticultural Research and Extension Centre (MHREC), University of Horticultural Sciences, Bagalkot, Karnataka. The experiment was conducted using a Randomized Complete Block Design (RCBD) with seven treatments, each replicated three times. A five-year-old pomegranate orchard, developed from healthy tissue-cultured plants, was selected for the study. The total numbers of trees included in the experiment were 105 and were spaced at 4.5 m × 4.5 m. The experiment consist of 7 treatments viz., T₁ - 100% RDF (400:200:200 g NPK/plant), T₂ - 75% RDF (300:150:150 g NPK/plant) + 25 % through organic source *i.e.*, vermicompost (3.3 kg/plant) + *Trichokawach* (100 g/plant) + *Penicillium pinophilum* (20 g/plant) + VAM (50 g/plant) + PSB (20 g/plant) + KSB (20 g/plant), T₃ - 50% RDF (200:100:100 g NPK/plant) + 25% through neem cake (1 kg/plant) + 25% through vermicompost (3.3 kg/plant) + *P. pinophilum* (20 g/plant) + VAM (50 g/plant) + PSB (20 g/plant) + KSB (20 g/plant), T₄ - 100% RDF through organic sources, 50 % through vermicompost (6.6 kg/plant) + 50% through neem cake (2 kg/plant) + *P. pinophilum* (20 g/plant) + VAM (50 g/plant) + PSB (20 g/plant) + KSB (20 g/plant) + T₅ - T₁ + Micronutrients 100 g through soil application (Zinc sulphate @ 25 g+ Boric acid 25 g+ Manganese Sulphate 25 g + Iron sulphate 25 g per plant), T₆ - T₂ + Micronutrients 100 g through soil application (Zinc sulphate @ 25 g + Boric acid 25 g + Manganese Sulphate 25 g + Iron sulphate 25 g per plant), T₇ - T₃ + Micronutrients 100 g through soil application (Zinc sulphate @ 25 g + Boric acid 25 g+ Manganese Sulphate 25 g + Iron sulphate 25 g per plant). Organic manures and biofertilizers were applied at the time of pruning, biofertilizers are mixed thoroughly with the farm yard manures 15 days before the application and kept under shade. The micronutrients were applied once during vegetative stage along with basal dose of NPK. Inorganic fertilizers were applied in three different growth stages as per the following ratio *i.e.*, at vegetative stage (3:2:1), at flowering (1:3:2) and during fruit development stage (2:1:3 NPK).

Some of the growth parameters like Plant height, Plant spread, Leaf area and chlorophyll content. Plant height and canopy volume were recorded with the help of a measuring tape and a long stick. Leaf area was estimated using the linear method (LBK method) by sampling ten leaves from each plant, calculating their average and expressing the values in square centimetres.

The mathematical equation to calculate it is as follows:

$$\text{Leaf area (LA)} = L \times B \times K$$

Where, L = maximum length, B = maximum breadth and K = Correction factor

Chlorophyll content was measured in fully matured leaves with the help of a SPAD-502 chlorophyll meter.

The various yield attributing observations like Number of hermaphrodite flowers, Fruit set (%) and Fruit yield. For biochemical parameters like TSS, Titratable acidity, TSS to acid ratio, pH and shelf life. Five healthy fruits were selected randomly from each tree at full maturity stage. A hand refractometer was employed to measure the total soluble solids (TSS). Fruit acidity was determined through a standard acid–alkali titration procedure, while ascorbic acid content and pH were analysed following the method outlined by Ranganna (1986). Shelf life was assessed by recording the number of days from harvest until the fruits stayed in acceptable edible condition without signs of spoilage under ambient storage.

Results and Discussion

The INM modules had a significant impact on the growth parameters the maximum plant height (2.69 m), Canopy volume (4.37 m³), leaf area (16.09 cm²) and chlorophyll content (64.68 SPAD values) were recorded in T₇ (Table 1).

In the present study, the highest plant height canopy volume due to the combined use of inorganic nutrients with organic amendments proved more effective, as it enhanced the supply of both macro- and micro-nutrients and improved their availability in the soil. The incorporation of organic sources along with bio-inoculants likely stimulated the production of growth-promoting substances and antifungal compounds, which in turn contributed to better vegetative vigour. Thus, it can be inferred that the judicious use of inorganic fertilizers in combination with neem cake, organic manures and micronutrients substantially improved nutrient availability and overall plant growth (Kurer and Patil, 2018). The increase in canopy volume may be attributed to an improved nutritional environment created through the addition of organic matter, which improves soil health by boosting its physical, chemical and biological properties. Vermicompost, in

Table 1 : Plant height, canopy volume, leaf area and chlorophyll content as influenced by INM module in pomegranate cv. Bhagwa.

Treatment	Plant height (m)	Canopy volume (m ³)	Leaf area (cm ²)	Chlorophyll (SPAD values)
T ₁	2.48	3.20	14.21	52.60
T ₂	2.51	3.40	14.25	56.32
T ₃	2.53	3.47	14.79	59.10
T ₄	2.56	3.57	15.32	61.01
T ₅	2.58	3.69	15.43	61.21
T ₆	2.66	4.23	15.65	62.53
T ₇	2.69	4.37	16.09	64.68
S. Em±	0.03	0.06	0.16	0.79
CD at 5 %	0.10	0.20	0.51	2.45

T₁ - 100 % RDF (400:200:200 g NPK/plant)

T₂ - 75 % RDF (300:150:150 g NPK/plant) + 25 % through organic source *i.e.*, vermicompost (3.3 kg/plant) + Trichokawach (100 g/plant) + *Penicillium pinophilum* (20 g/plant) + VAM (50 g/plant) + PSB (20 g/plant) + KSB (20 g/plant)

T₃ - 50 % RDF (200:100:100 g NPK/plant) + 25 % through neem cake (1 kg/plant) + 25 % through vermicompost (3.3 kg/plant) + *P. pinophilum* (20 g/plant) + VAM (50 g/plant) + PSB (20 g/plant) + KSB (20 g/plant)

T₄ - 100 % RDF through organic sources, 50 % through vermicompost (6.6 kg/plant) + 50 % through neem cake (2 kg/plant) + *P. pinophilum* (20 g/plant) + VAM (50 g/plant) + PSB (20 g/plant) + KSB (20 g/plant)

T₅ - T₁ + Micronutrients 100 g through soil application (Zinc sulphate @ 25 g + Boric acid 25 g + Manganese Sulphate 25 g + Iron sulphate 25 g per plant)

T₆ - T₂ + Micronutrients 100 g through soil application (Zinc sulphate @ 25 g + Boric acid 25 g + Manganese Sulphate 25 g + Iron sulphate 25 g per plant)

T₇ - T₃ + Micronutrients 100 g through soil application (Zinc sulphate @ 25 g + Boric acid 25 g + Manganese Sulphate 25 g + Iron sulphate 25 g per plant)

particular, has a crucial role in promoting vegetative growth as it not only enhances soil fertility but also influences plant enzymatic activities. These biochemical changes stimulate cell elongation, root and shoot development and carbohydrate metabolism, thereby supporting canopy expansion (Marathe *et al.*, 2017).

The highest leaf area because of combined application of nutrients ensured efficient utilization in photosynthesis by enhancing leaf size, thereby expanding the photosynthetic surface. This resulted in greater production of assimilates, which in turn supported overall vegetative growth. Adequate nitrogen availability further accelerated carbohydrate synthesis and its conversion into proteins and protoplasm, contributing to cell enlargement and higher

leaf area. Additionally, the role of biofertilizers in producing growth-promoting substances in synergism with organic based manures within the rhizosphere supports root proliferation and the synthesis of hormones such as IAA, Gibberellic acid and cytokinin, ultimately leading to improved leaf expansion (Kirankumar *et al.*, 2019) in pomegranate cv. Bhagwa and Gupta *et al.* (2019) in guava), as these growth regulators they have been involved in cell division and elongation.

The synergistic combination of organic amendments, biofertilizers and inorganic fertilizers not only supplies essential macro- and micronutrients but also fosters microbial activity and soil structure, which sustain chlorophyll synthesis and leaf greenness. Supporting evidence was provided by Gajbhiye *et al.* (2020) in pomegranate, it was demonstrated that applying INM including FYM, bio-inoculants like KSB, PSB and Trichoderma along with RDF significantly improved growth traits, indirectly suggesting enhanced chlorophyll accumulation. These findings were in line with reports made by Eiada and Mustafa (2013) in pomegranate. This effect could be attributed to the application of micronutrients and their critical role in regulating auxin synthesis, which enhances cell division and chlorophyll accumulation in leaves, thereby increasing leaf area. Micronutrients also contribute to chlorophyll biosynthesis through their direct influence on amino acid, carbohydrate and energy compound composition, which are essential for chlorophyll formation. In addition, they play an essential role in RNA and protein synthesis and stimulate key enzymes that participate in biological processes associated with chlorophyll development.

The highest hermaphrodite flowers (85.16) per plant, fruit set (67.16%) and fruit yield 14.60 kg/plant and 5.75 t/ha were recorded in T₇, while the lowest values of hermaphrodite flowers and the fruit set percentage, Fruit weight and Fruit yield were observed in T₁.

The combined use of organic manures, chemical fertilizers and biofertilizers provides a balanced supply of essential macro- (N, P, K) and micronutrients, which promotes flower bud differentiation and encourages the development of functional hermaphrodite flowers rather than sterile male flowers (Naik *et al.*, 2024). The higher proportion of hermaphrodite flowers under INM contributed directly to an increased fruit set, as these flowers are capable of developing into fruits. Adequate nutrient availability, improved hormonal balance (including auxins, cytokinins and gibberellins) and more efficient allocation of assimilates under INM creates favourable conditions for fruit development, reduce flower drop and

improve fruit retention Gajbhiye *et al.* (2020) and Seifi and Feizi (2024) in pomegranate. Therefore, T₇ not only enhanced the production of hermaphrodite flowers but also resulted in higher fruit set, highlighting the strong link between flower quality and reproductive success. These results corroborated with Kurer *et al.* (2017) who reported that higher number of productive flowers recorded by the plants supplied with 100% RDP through poultry manure in pomegranate (Marathe *et al.*, 2017). In addition to macronutrients, the role of micronutrients such as ZnSO₄, FeSO₄ and boric acid was evident in enhancing yield. Zinc improved pollen viability, stigma receptivity and auxin synthesis, thereby increasing fruit set, iron enhanced chlorophyll formation and energy transfer, supporting higher assimilate production and boron facilitated pollen germination, sugar translocation and cell wall stability, reducing fruit drop and cracking. Applications of these micronutrients during flowering synergistically improved fruit set and retention, leading to higher yield. These findings are in agreement with Yugandhar *et al.* (2024) and Guleria *et al.* (2025).

The highest TSS (15.75 °Brix), lowest titratable acidity (0.42 %) and TSS: acid (37.50) was recorded in T₇, while lowest TSS (14.57 °Brix), highest titratable acidity (0.55 %) and TSS: acid (26.49) was recorded in T₁ (Table 3). The increase in TSS could be attributed to the breakdown of complex compounds into simple sugars facilitated by the integrated use of organic manures, inorganic fertilizers and micronutrients, which enhance the metabolic activity of fruits and thereby increase TSS levels. The role of micronutrients such as zinc, boron and manganese are also critical, as they participate in various metabolic and enzymatic processes. For instance, zinc is involved in enzymatic functions like hexokinase activity, contributes to carbohydrate formation and plays a part in protein synthesis, all of which collectively improve fruit quality. Boron is essential for the translocation of sugars and also aids in the hydrolysis of saccharides into simpler sugars, thereby enhancing sweetness and TSS of fruits. Manganese, on the other hand, plays a pivotal role in the photosynthetic process. By improving photosynthetic efficiency, manganese increases the production of carbohydrates, which ultimately contributes to higher sugar accumulation and improved TSS in the fruit. as reported Hasani *et al.* (2012) in pomegranate. A similar line of work was reported by Yadav *et al.* (2022) and Maity *et al.* (2021). The reduction in acidity during fruit ripening can be attributed to the breakdown of starch into simple sugars, which not only elevates the total sugar content but also lowers acidity, as these sugars are further utilized as respiratory substrates during fruit growth and

Table 2 : Number of hermaphrodite flowers, fruit set (%) and fruit yield as influenced by INM module in pomegranate cv. Bhagwa.

Treatment	Number of hermaphrodite flowers/plant	Fruit set (%)	Fruit yield	
			Kg/plant	t/ha
T ₁	63.00	52.55	5.25	2.59
T ₂	66.21	59.42	7.13	3.52
T ₃	69.16	60.37	8.15	4.02
T ₄	67.08	63.90	9.04	4.45
T ₅	75.45	63.92	11.04	4.34
T ₆	83.12	66.19	13.71	5.40
T ₇	85.16	67.16	14.60	5.75
S. Em±	1.15	0.88	0.16	0.04
CD at 5%	3.54	2.70	0.50	0.13

T₁ - 100 % RDF (400:200:200 g NPK/plant)

T₂ - 75 % RDF (300:150:150 g NPK/plant) + 25 % through organic source *i.e.*, vermicompost (3.3 kg/plant) + Trichokawach (100 g/plant) + *Penicillium pinophilum* (20 g/plant) + VAM (50 g/plant) + PSB (20 g/plant) + KSB (20 g/plant)

T₃ - 50 % RDF (200:100:100 g NPK/plant) + 25 % through neem cake (1 kg/plant) + 25 % through vermicompost (3.3 kg/plant) + *P. pinophilum* (20 g/plant) + VAM (50 g/plant) + PSB (20 g/plant) + KSB (20 g/plant)

T₄ - 100 % RDF through organic sources, 50 % through vermicompost (6.6 kg/plant) + 50 % through neem cake (2 kg/plant) + *P. pinophilum* (20 g/plant) + VAM (50 g/plant) + PSB (20 g/plant) + KSB (20 g/plant)

T₅ - T₁ + Micronutrients 100 g through soil application (Zinc sulphate @ 25 g + Boric acid 25 g + Manganese Sulphate 25 g + Iron sulphate 25 g per plant)

T₆ - T₂ + Micronutrients 100 g through soil application (Zinc sulphate @ 25 g + Boric acid 25 g + Manganese Sulphate 25 g + Iron sulphate 25 g per plant)

T₇ - T₃ + Micronutrients 100 g through soil application (Zinc sulphate @ 25 g + Boric acid 25 g + Manganese Sulphate 25 g + Iron sulphate 25 g per plant)

maturation. The application of vermicompost improves soil biological activity and nutrient availability through humic substances and beneficial microbes which promotes assimilation and metabolic processes in pomegranate plants that Favor sugar accumulation and thus lower titratable acidity (Andreu-Coll *et al.*, 2023).

Among the treatments, the maximum amount anthocyanin (8.92 mg/100 g FW) was observed in T₇, which involved 50 % RDF along with organic sources such as vermicompost, FYM, neem cake and biofertilizers. In contrast, the lowest value (7.47 mg/100 g FW) was recorded under the control T₁ (Table 3). The combined application of organic manures, inorganic fertilizers and biofertilizers improves nutrient uptake and

Table 3 : Total soluble solids, titratable acidity, TSS to acid ratio, anthocyanin content and shelf life as influenced by INM module in pomegranate cv. Bhagwa.

Treatment	TSS (°Brix)	Titratable acidity (%)	TSS to acid ratio	Anthocyanin content (mg/100 g FW)	Shelf life (days)
T ₁	14.57	0.55	26.49	7.47	20.45
T ₂	14.85	0.47	31.59	7.86	21.40
T ₃	15.12	0.53	28.50	7.93	22.64
T ₄	15.33	0.51	30.05	8.24	23.22
T ₅	15.08	0.46	32.78	8.02	22.98
T ₆	15.45	0.45	34.33	8.36	24.21
T ₇	15.75	0.42	37.50	8.92	25.18
S. Em±	0.19	0.01	0.47	0.21	0.40
CD at 5 %	0.57	0.03	1.45	0.63	1.22

T₁ - 100% RDF (400:200:200 g NPK/plant)

T₂ - 75% RDF (300:150:150 g NPK/plant) + 25 % through organic source i.e., vermicompost (3.3 kg/plant) + Trichokawach (100 g/plant) + *Penicillium pinophilum* (20 g/plant) + VAM (50 g/plant) + PSB (20 g/plant) + KSB (20 g/plant)

T₃ - 50% RDF (200:100:100 g NPK/plant) + 25 % through neem cake (1 kg/plant) + 25 % through vermicompost (3.3 kg/plant) + *P. pinophilum* (20 g/plant) + VAM (50 g/plant) + PSB (20 g/plant) + KSB (20 g/plant)

T₄ - 100% RDF through organic sources, 50 % through vermicompost (6.6 kg/plant) + 50 % through neem cake (2 kg/plant) + *P. pinophilum* (20 g/plant) + VAM (50 g/plant) + PSB (20 g/plant) + KSB (20 g/plant)

T₅ - T₁ + Micronutrients 100 g through soil application (Zinc sulphate @ 25 g+ Boric acid 25 g+ Manganese Sulphate 25 g + Iron sulphate 25 g per plant)

T₆ - T₂ + Micronutrients 100 g through soil application (Zinc sulphate @ 25 g + Boric acid 25 g + Manganese Sulphate 25 g + Iron sulphate 25 g per plant)

T₇ - T₃ + Micronutrients 100 g through soil application (Zinc sulphate @ 25 g + Boric acid 25 g+ Manganese Sulphate 25 g + Iron sulphate 25 g per plant).

soil health, which in turn stimulates secondary metabolism linked with pigment biosynthesis. Organic sources like vermicompost and neem cake provide a steady nutrient supply along with growth-promoting substances, while biofertilizers enhance microbial activity and nutrient availability, leading to increased synthesis of flavonoids and phenolics the precursors of anthocyanins. In addition, the inclusion of micronutrients such as zinc and boron under INM modules further strengthens enzymatic activity and carbohydrate metabolism, which directly favour anthocyanin accumulation and better fruit coloration (Hasani *et al.*, 2012). The highest shelf life (25.18 days) was recorded in T₇ and lowest shelf life (20.45 days) was recorded in T₁.

Several physiological factors contribute to this improvement, particularly better water absorption by plant cells, maintenance of turgor pressure and reduced moisture loss through transpiration. These factors help the fruit retain water, thereby enhancing its firmness and overall longevity. The experiment clearly indicates that integrated nutrient management practices maximize fruit firmness. In addition, biofertilizers support longer shelf life by improving nutrient availability, boosting plant vigour and increasing resistance to diseases, which lowers the

chances of post-harvest decay. Neem cake also plays a role, as it supplies calcium a crucial component of cell walls that strengthens fruit structure and contributes to improved storage life. Similar results reported by Ghosh *et al.* (2012).

Conclusion

The findings of the study revealed that different combinations of organic, inorganic and micronutrient applications had a notable effect on the growth and quality traits of pomegranate cv. Bhagwa. Among the treatments, the most effective results were obtained with the application of 50% RDF (200:100:100 g NPK/plant) + 25% through neem cake (1 kg/plant) + 25% through vermicompost (3.3 kg/plant) + *P. pinophilum* (20 g/plant) + VAM (50 g/plant) + PSB (20 g/plant) + KSB (20 g/plant), along with soil application of (Zinc sulphate @ 25 g + Boric acid 25 g+ Manganese Sulphate 25 g + Iron sulphate 25 g per plant).

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