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Optimizing mango production through integrated nutrient management under high density planting

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Abstract

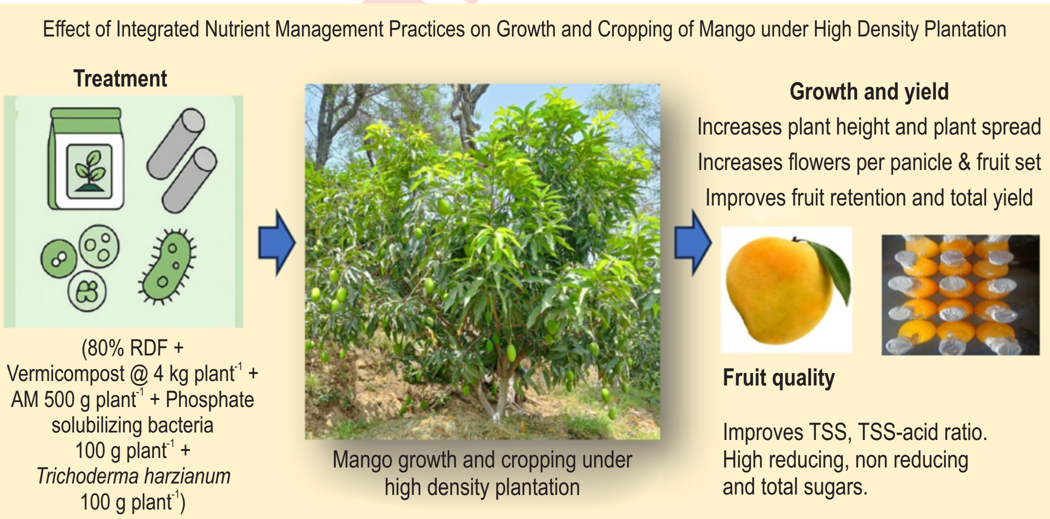
Aim: To evaluate the effect of integrated nutrient management practices on the growth, flowering, fruiting and quality of mango cv. Dashehari under high density planting system.

Methodology: A field experiment was conducted in 2021-22 on six-year-old mango trees using five different treatments. These treatments included combinations of RDF, vermicompost, AM fungi, PSB and Trichoderma harzianum. Observations on growth, flowering, yield and fruit quality were recorded and the data were analyzed using ANOVA under a randomized block design.

Results: The treatment with 80% RDF + vermicompost (4 kg/plant) + AM (500 g/plant) + PSB and Trichoderma harzianum @ 100 g/plant significantly improved plant height (26.08%), canopy spread (10.65%), shoot growth (5.08%)compared to control treatment. It also recorded higher flowering, fruit set, yield (5.03 kg/plant; 10.06 t/ha), better fruit quality (TSS 19.75°B and total sugars 13.62 %)and improved soil fertility (organic carbon and NPK availability).

Interpretation: The findings suggest that integrating 80% RDFwithvermicompost and biofertilizers enhances growth, yield, fruit qualityand soil fertility in mango under high-density planting.

Key words: Dashehari, High density plantation, Integrated nutrient management, Magnifera indica, *Trichoderma harzianum*



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Introduction

Mango (*Mangifera indica* L.) is one of the most popular fruit crop in India, belonging to the family Anacardiaceae and subfamily Anacardioideae. It is one of the oldest cultivated fruits, indigenous to South-east Asia having been grown for more than 4000 years, and exhibits the capacity to thrive in the subtropical regions across the globe (Litz, 2009; Yadav and Singh, 2017). Mango cultivation under high-density planting (HDP) systems has gained importance for enhancing productivity per unit area; however, sustaining tree vigour, soil fertility and long-term productivity under such intensive systems remains a major challenge. Higher planting density often leads to increased competition for nutrients, poor canopy management and rapid depletion of soil nutrients, ultimately affecting yield and fruit quality (Zonayet *et al.,* 2020). Integrated Nutrient Management (INM), involves the combined use of inorganic fertilizers, organic manures and biofertilizers, has been reported to improve the nutrient use efficiency, soil health and crop productivity in fruit crops (Bura *et al.,* 2026; Kumar *et al.,* 2025). In mango, the integration of organic and inorganic nutrient sources has been shown to significantly improve the growth, yield and fruit quality parameters (Vala *et al.,* 2020; Zonayet *et al.,* 2020). Recent studies have also highlighted the role of INM in enhancing the soil microbial activity, enzymatic functions and nutrient cycling, which are critical for sustainable orchard management (Bhardwaj *et al.,* 2014; Bibi *et al.,* 2023).

Despite its importance, mango productivity remains below its potential due to factors such as poor orchard management, wider spacing with dense canopies and inadequate nutrient and water management practices (Kumar, 2018). These limitations result in poor light interception, reduced productivity and higher incidence of pests and diseases. Therefore, adoption of improved production technologies and efficient management practices is necessary to enhance yield and fruit quality in mango. High-density planting (HDP) is an important method to increase the productivity per unit area in fruit crops and helps in better use of land and resources (Ahmed and Kaur, 2022). In mango and other fruit crops, HDP involves closer spacing along with practices like training, pruning and canopy management to improve light use and maintain productivity (Usha *et al.,* 2015; Menzel and Lagadec, 2014).

HDP increases the yield and returns per unit area and also reduces the gestation period compared to traditional planting systems (Ahmed and Kaur, 2022). However, its success depends on proper orchard management, especially canopy, irrigation and nutrient management. In mango, poor management of HDP can lead to overcrowding, poor light penetration and higher pest and disease incidence, which reduces the productivity (Kumar, 2018). Therefore, proper nutrient management is important to maintain growth, yield and fruit quality under high-density planting systems. In this context, balanced nutrient supply becomes a key factor for sustaining productivity under HDP conditions. Integrated nutrient management (INM), involving the combined use of organic, inorganic and biofertilizer inputs, is widely recognized for maintaining soil fertility and sustaining crop productivity. By thoughtfully blending organic inputs like farmyard manure, compost and biofertilizers with inorganic fertilizers, INM provides a balanced nutrient supply that promotes healthy tree growth and better fruit quality. The impact of INM strategies under high-density mango systems is multifaceted. These practices influence vegetative growth, flowering and fruit development while improving soil fertility and boosting the plant's natural resistance to diseases, ultimately leading to higher yields and better fruit quality. However, response to INM can vary depending on soil type, climate conditions and mango cultivar, highlighting the need for site-specific nutrient management strategies.

In view of the limited information on nutrient management under high-density planting, the present study was undertaken to evaluate the effect of integrated nutrient management (INM) on growth, flowering, yield and fruit quality of mango. The study aims to identify suitable nutrient management practices for improving productivity and sustainability in high-density planting systems.

Materials and Methods

The present study was conducted during 2021-2022 at the experimental farm of the Department of Fruit Science, College of Horticulture and Forestry, Neri, Hamirpur, Himachal Pradesh. The area falls under a sub-tropical climate with a hilly terrain and is located at an altitude of about 650 m above mean sea level (31°41'47.6" N latitude and 76°28'6.3" E longitude). The experiment was laid out in a randomized block design (RBD) with five treatments and four replications. Each replication consisted of two plants. The experiment was conducted on six-year-old mango cv. Dashehari plants planted at a spacing of 2.5 × 2.0 m. The plants selected were uniform in growth and vigour. These selected plants were then subjected to a series of five distinct treatments, which included the application of 80 % Recommended Dose of Fertilizer (RDF) in conjunction with vermicompost @ 4 kg/plant along with the incorporation of NBF (T_1), as well as 60 % RDF combined with vermicompost @ 8 kg/plant + NBF(T_2), followed by 40 % RDF paired with vermicompost at 12 kg/plant + NBF (T_3) and finally, 20 % RDF along with vermicompost at 15 kg/plant + NBF (T_4), all of which were compared against a control treatment involving soil application of 100 % RDF combined with 60 kg of Farmyard Manure (FYM) (T5). NBF (Neri Biofertilizer) included mycorrhizal fungi (MF @ 500 g/plant), phosphate-solubilizing bacteria (PSB @ 100 g/plant) and *Trichoderma harzianum* @ 100 g/plant. The recommended fertilizer dose for six-year-old plants was 60 kg FYM along with 300 g nitrogen, 150 g phosphorus and 225 g potassium, applied through urea, SSP (single super phosphate) and MOP (muriate of potash), respectively.

A pre-irrigation was applied before fertilizer application to maintain adequate soil moisture. The full dose of phosphorus (P), potassium (K), vermicompost, MF, PSB and *Trichoderma harzianum* was applied as a basal dose. Nitrogen (N) was applied in three equal splits. The first split was applied with the basal dose, the second at flowering to fruit set stage and the third during fruit development.

Observations recorded: Observations were recorded on vegetative growth, flowering, yield and physio-biochemical characteristics of mango fruits. Vegetative parameters such as plant height, canopy spread, trunk girth and shoot extension growth were measured before fertilizer application and after harvest. Floral and yield parameters were recorded by selecting four branches in each direction (north, south, east and west) of the plant. These branches were observed from flowering to harvest. Fruit retention was calculated at maturity by dividing the number of fruits retained on selected branches by the number of fruits at initial fruit set. Total fruit yield was recorded by weighing the fruits harvested from each plant using a weighing balance. For the purpose of conducting physical and biochemical analyses, a total of ten random fruits were selected from each individual experimental unit tree. The dimensions of the fruits, including length and breadth, were precisely measured using a vernier calliper and the average measurements were recorded in centimeters, while the weight of the fruits was accurately documented using a physical weight balance and expressed in grams. Reducing sugars, total sugars and non-reducing sugars were analyzed following the procedure given by Ranganna (1985).

Estimation of soil properties: Soil samples were collected at two stages: before application of treatments and after harvest. Before treatment application, composite soil samples were prepared for each treatment by mixing representative samples. After harvest, four individual soil samples per treatment (one from each replication) were collected and analyzed separately. The samples were air-dried, ground and passed through a sieve before analysis. Soil samples were analyzed for pH, electrical conductivity (EC), organic carbon (OC) and available nitrogen (N), phosphorus (P) and potassium (K) using standard methods. Soil pH was determined in a 1:2.5 soil-water suspension using a glass electrode pH meter (Jackson, 1967). EC was measured by conductimetric method (Jackson, 1973). OC was estimated by rapid titration method (Walkley and Black, 1934). Available N was determined by alkaline potassium permanganate method (Subbiah and Asija, 1956). Available P was estimated by Olsen's method (Olsen *et al.,* 1954) and available K was determined by ammonium acetate method (Jackson, 1973). The initial soil properties of the experimental field indicated a pH of 6.67, EC of 0.169 dS m^{-1} and organic carbon content of 0.98 %. The available N, P and K contents were 219.52, 17.92 and 110.20 kg ha^{-1}, respectively.

Statistical analysis: The data collected during the experiment were analyzed by applying ANOVA (Analysis of Variance) following the procedures described by Gomez and Gomez (1984) for a Randomized Block Design.

Results and Discussion

The growth parameters, including plant height, plant spread, leaf area, trunk girth and annual shoot growth, varied among the treatments (Table 1). Higher values for most of these parameters were observed under improved nutrient management conditions. Among the treatments, T_1 consistently recorded the highest values for all growth parameters compared to other treatments. The growth of the plant may be depicted in terms of annual increase in plant height, plant spread and trunk girth. The maximum plant height (2.03 m), along with a significantly greater canopy spread both in the east-west (1.53 m) and north-south (2.21 m) directions was obtained under treatment T_1, representing an increase of approximately 26.1% in plant height over the control (1.61 m), which was at par with treatment T_2. Similarly, this treatment produced the largest leaf area (83.98 cm^2), a critical determinant of photosynthetic efficiency and overall biomass accumulation. In terms of stem development, the trunk girth reached 44.80 cm, while annual shoot extension was recorded at 36.1 cm, indicating enhanced vegetative vigor and sustained growth potential. In contrast, the control treatment recorded the lowest values for all the measured growth traits, indicating that the application of RDF along with FYM was less effective compared to integrated use of vermicompost and biofertilizers in promoting vegetative growth.

The results of the present study clearly demonstrate that the integration of chemical fertilizers with vermicompost, mycorrhizal inoculants and beneficial microorganisms markedly enhanced vegetative growth attributes compared to conventional fertilization alone. Higher values of plant height, canopy spread, leaf area, trunk girth and shoot growth may be attributed to better

Table 1: Effect of integrated nutrient management on vegetative growth in mango

Treatments	Plant Height (m)	Plant Spread (N-S) (m)	Plant Spread (E-W) (m)	Leaf area (cm^2)	Trunk girth (cm)	Annual shoot growth (cm)
T_1	2.03	2.21	1.53	83.98	44.80	36.1
T_2	1.88	2.17	1.49	78.78	42.96	35.6
T_3	1.79	2.13	1.43	75.50	41.66	35.2
T_4	1.70	2.08	1.39	70.76	40.10	34.7
T_5	1.61	2.04	1.34	66.48	38.41	34.1
SEM	0.05	0.02	0.01	5.07	1.07	0.20
CD at 5 %	0.17	0.07	0.04	11.17	3.34	0.64

Table 2: Effect of integrated nutrient management on flowering and yield related characters in mango

Treatments	First flower to Full bloom (Days)	Number of flowers per panicle	Fruit set (%)	Fruit retention (%)	Total fruits per plant	Total yield (kg/plant)	Total yield (tonnes ha^{-1})
T_1	9.75	397.50	12.70	5.66	30.25	5.12	10.24
T_2	10.12	383.13	12.32	5.28	27.75	4.57	9.15
T_3	10.38	369.25	11.82	4.88	26.50	4.17	8.35
T_4	10.75	353.88	11.48	4.56	22.75	3.47	6.95
T_5	11.50	340.87	10.91	4.03	20.75	2.97	5.94
SEM	0.63	10.40	0.19	0.23	1.20	0.19	0.39
CD at 5 %	NS	32.41	0.60	0.72	3.74	0.61	1.23

Table 3: Effect of integrated nutrient management on physical quality characteristics of mango.

Treatments	Fruit weight (g)	Fruit length (cm)	Fruit breadth (cm)	Fruit volume (cm^3)
T_1	169.00	11.11	6.04	163.00
T_2	165.25	10.04	5.25	159.00
T_3	157.50	9.53	4.90	152.50
T_4	153.00	8.76	4.52	146.75
T_5	143.25	8.13	4.16	138.75
SEM	2.22	0.37	0.19	2.15
CD at 5 %	6.93	1.17	0.60	6.72

nutrient availability and uptake under integrated nutrient management. The addition of organic and microbial inputs likely enhanced nutrient mineralization, increased the root surface area and improved the absorption of nutrients. These observations are in close agreement with the findings of Sharma *et al.* (2016), who also reported superior vegetative performance under integrated nutrient application. Similarly, Singh *et al.* (2017) emphasized that the combined use of biofertilizers with organic and inorganic nutrient sources elevates the synthesis of growth-promoting hormones, thereby stimulating vegetative development. In addition, PSB improve phosphorus availability by producing organic acids such as gluconic and citric acids in the rhizosphere. These acids lower the soil pH and convert insoluble forms of phosphorus into soluble forms, making them available for plant uptake (Khan *et al.,* 2007).

Improved phosphorus availability under integrated nutrient management (INM) treatments may have contributed to better flowering and fruiting behaviour in mango. The results indicated that INM influenced flowering and fruiting parameters (Table 2). The number of days from first flowering to full bloom did not differ significantly among treatments. However, a gradual decrease in days to full bloom was observed with increasing levels of RDF combined with vermicompost and biofertilizers. The number of flowers per panicle, fruit set, fruit retention, number of fruits per plant and yield showed an increasing trend with higher levels of RDF integrated with vermicompost and biofertilizers. Higher values for these parameters were observed under T_1 treatment, which remained statistically at par with T_2 treatment. The control treatment recorded the lowest values. Differences among the treatments were significant for number of flowers per panicle, fruit set, fruit retention, total fruits per plant and yield, indicating the positive effect of integrated nutrient management on reproductive performance. The maximum number of flowers per panicle (397.50) was recorded under T_1 treatment whereas the control produced the lowest (340.87 flowers per panicle). Similarly, fruit retention was considerably enhanced, as reflected in the highest fruit set percentage (12.70%) in the integrated treatment, compared with a notably lower percentage under control conditions. These improvements translated into substantial gains in yield, with the integrated treatment achieving the maximum fruit yield of 5.12 kg plant-1, equivalent to 10.24 tonnes ha^{-1}, thereby demonstrating the superior efficiency of integrating organic and biofertilizer components with reduced levels of chemical fertilizers.

The yield recorded under T_1 treatment (5.12 kg plant-1) was substantially higher than the control (2.97 kg plant-1), representing an increase of approximately 72.40% over control, thereby indicating a marked improvement in productivity under this treatment. This was statistically at par with T_2 treatment, which also recorded a comparable increase (53.87%) over the control. The findings of this study are consistent with those reported by Gautam *et al.* (2012) in mango and Bhutani *et al.* (2012) in banana, where incorporation of vermicompost and biofertilizers alongside chemical fertilizers significantly enhanced fruit yield and quality. The beneficial effects of such integration can be attributed to multiple synergistic mechanisms. Vermicompost not only serves as a rich source of macro- and micronutrients but also improves the soil structure, water retention and microbial activity, thereby facilitating sustained nutrient release throughout the crop cycle (Arancon *et al.,* 2004).

Table 4: Effect of integrated nutrient management on biochemical quality characteristics of mango.

Treatments	TSS (°B)	Titratable acidity (%)	TSS: Acid ratio	Reducing sugar (%)	Non-reducing sugar (%)	Total sugar (%)
T_1	19.75	0.22	91.03	3.88	9.78	13.62
T_2	18.75	0.26	73.57	3.73	9.45	13.17
T_3	18.25	0.30	61.99	3.63	9.20	12.83
T_4	17.75	0.32	56.10	3.50	9.00	12.50
T_5	17.25	0.35	49.03	3.45	8.70	12.15
SEM	0.42	0.007	2.04	0.06	0.13	0.109
CD at 5 %	1.33	0.02	6.36	0.19	0.42	0.34

Table 5: Effect of integrated nutrient management on soil pH, EC and organic carbon content in mango

Treatments	pH	Electrical conductivity (dS/m)	Organic carbon (%)	Available nitrogen (kg ha^{-1})	Available phosphorus (kg ha^{-1})	Available potassium (kg ha^{-1})
T_1	6.94	0. 178	1.73	229.19	23.71	122.33
T_2	6.91	0. 176	1.71	227.26	22.63	120.2
T_3	6.87	0.173	1.69	225.23	21.70	118.37
T_4	6.80	0.170	1.67	224.20	20.75	116.25
T_5	6.75	0.168	1.41	222.82	19.06	114.38
SEM	0.04	0.003	0.01	0.95	0.50	0.62
CD at 5 %	NS	NS	0.04	2.97	1.55	1.95

T_1: 80 % RDF + Vermicompost @ 4 kg/plant +NBF (*Trichoderma harzianum* and Phosphate solubilizing bacteria100 g/plant + AM 500 g/plant); T_2: 60 % RDF + Vermicompost @ 8 kg/plant + NBF (*Trichoderma harzianum* and Phosphate solubilizing bacteria100 g/plant + AM 500 g/plant); T_3: 40 % RDF + Vermicompost @ 12 kg/plant +NBF (*Trichoderma harzianum* and Phosphate solubilizing bacteria100 g/plant + AM 500 g/plant); T_4: 20 % RDF + Vermicompost @ 15 kg/plant + NBF (*Trichoderma harzianum* and Phosphate solubilizing bacteria100 g/plant + AM 500 g/plant) and T_5: Control (100 % RDF 300 g N, 150 g P_2O_5, 225 g K_2O/plant + 60 kg FYM)

In addition, inoculation with AM and PSB enhances phosphorus availability and uptake. PSB solubilize insoluble phosphorus through the release of organic acids and phosphatases whereas AM improves the nutrient acquisition by extending their hyphal network beyond the root zone and transferring phosphorus to the plant (Wahid *et al.,* 2020). Additionally, *Trichoderma harzianum* is known to contribute to rhizosphere health by promoting root growth, enhancing nutrient uptake and exerting antagonistic effects on soil-borne pathogens (Harman *et al.,* 2004). The significant increase in flowering, fruit set and yield parameters under INM can therefore be explained by the combined effects of balanced nutrient supply, hormonal stimulation and microbial deposition in the rhizosphere, as also noted by Mishra *et al.* (2011). These results indicate that INM treatments performed better than the conventional nutrient application (RDF + FYM) under the present experimental conditions.

In addition to improvements in yield attributes, INM also influenced the physical and biochemical characteristics of mango fruits. Mango cv. Dashehari showed substantial variation in fruit weight, length, breadth, volume, total soluble solids (TSS), titratable acidity, total sugars and reducing and non-reducing sugars among treatments (Table 3 and 4). . Plants treated with T_1 treatment (Table 3) resulted in the highest fruit weight (169.00 g), length (11.11 cm), breadth (6.04 cm) and volume (163.00 cm^3), comparable to plants treated with T_2. However, the plant treated with T_5 produced the smallest fruit weight (143.25 g), length (8.13 cm), breadth (4.16 cm) and volume (138.75 cm^3). The effect of different integrated treatments on TSS, titratable acidity and TSS: acid ratio was found to be significant (Table 4). The maximum TSS (19.75 °B) and TSS: acid ratio (91.03) was recorded under T_1 treatment which was followed by T_2 treatment. The data obtained from the experiment with respect to reducing sugar, non-reducing sugar and total sugar revealed that maximum reducing sugar (3.88 %), non-reducing sugar (9.78 %) and total sugar (13.62 %) was also recorded with same treatments, which was statistically at par with plants treated with T_2 in terms of reducing and non-reducing sugars. The enhancement in fruit physical and biochemical parameters under INM can be attributed to improved nutrient availability and increased metabolic activity in plants.

A balanced supply of nutrients and growth-promoting substances promotes cell division and expansion, leading to higher fruit weight, length, breadth and volume (Singh *et al.,* 2017; Arancon *et al.,* 2004). Better nutrient uptake and root activity also support efficient translocation of water and assimilates, resulting in improved fruit development. The increase in total soluble solids (TSS), reducing sugars, non-reducing sugars and total sugars may be due to enhanced synthesis and accumulation of carbohydrates. Balanced nutrient supply further helps in reducing titratable acidity, thereby improving the TSS: acid ratio and overall fruit quality. These improvements may be associated with efficient movement of metabolites and better utilization of photosynthates under INM practices (Singh *et al.,* 2017).

In addition to improvements in fruit quality, nutrient management treatments also influenced the soil characteristics, including organic carbon (OC) and the availability of nitrogen, phosphorus and potassium, whereas soil pH and electrical conductivity (EC) were found to be non-significant (Table 5). Among the integrated treatments, plants treated with T_1 treatment consistently achieved the highest values across all major soil fertility indicators. After treatment application, soil properties showed variation among treatments. Under the T_1 treatment, soil pH (6.94) and EC remained non-significant, while OC content increased to 1.73% indicating improved soil fertility and better nutrient retention capacity. Increased organic carbon improves soil structure and water-holding capacity, which supports better root growth. It also helps in maintaining a steady supply of nutrients by reducing losses and enhancing nutrient availability to plants (Diacono and Montemurro, 2010). The availability of nutrients also improved, with nitrogen (229.19 kg ha^{-1}), phosphorus (23.71 kg ha^{-1}) and potassium (122.33 kg ha^{-1}) recorded higher compared to other treatments. This improvement in nutrient dynamics and organic carbon content suggests enhanced nutrient cycling due to the combined application of vermicompost and chemical fertilizers. In contrast, the control (T_5) treatment recorded comparatively lower values of OC (1.41%), available N (222.82 kg ha^{-1}), P (19.06 kg ha^{-1}) and K (114.38 kg ha^{-1}).

Overall, the results indicate that the integration of chemical fertilizers with vermicompost and biofertilizers enhanced soil organic carbon and nutrient availability compared to conventional fertilization practices. The increase in nutrient availability may be attributed to the addition of organic matter through vermicompost, which improves nutrient retention and gradual release, along with improved nutrient solubilization and mobilization processes in the soil (Sharma *et al.,* 2016; Singh *et al.,* 2017). These findings are in agreement with Sharma *et al.* (2016), who reported improved soil fertility under integrated nutrient management. Similarly, Singh *et al.* (2017) highlighted that the combined use of organic and biofertilizer inputs enhances nutrient availability and uptake, leading to improved crop performance.

The present study demonstrated that the combined application of vermicompost and biofertilizers with inorganic fertilizers improved the vegetative growth, flowering, fruiting, yield and fruit quality of mango compared to the control. Treatment comprising 80 % RDF + vermicompost @ 4 kg $plant^{-1}$ + *Trichoderma harzianum* and PSB100 g plant + AM 500 g $plant^{-1}$ recorded superior performance and enhanced soil nutrient availability. Overall, integrated nutrient management was found to be an effective approach for improving the productivity and nutrient status under the given experimental conditions.

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Authors' contribution: Each author played a meaningful role in the execution and preparation of this research and manuscript. **S.K. Banyal:** Conceptualization and supervision of the study; **U. Kumar:** Actively carried out the fieldwork, data collection and analysis. **N. Arya and A. Sharma:** Supported the work through literature review, drafting of the manuscript and assistance with formatting and finalization.

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Research content: The manuscript presents original research on integrated nutrient management in high-density mango plantations and has not been published or submitted elsewhere.

Ethical approval: The study did not involve any human or animal subjects; hence, ethical approval was not required.

Conflict of interest: The authors declare no conflict of interest related to this study.

Data availability: All data generated or analysed during this study are available with the Corresponding author and can be provided upon reasonable request.

Consent to publish: All authors agree to publish the paper in *Journal of Environmental Biology.*

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