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Assessment of integrated nutrient management strategies on soil health parameters in apple (*Malus × domestica* Borkh.) cv. Red delicious

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Abstract

The present investigation entitled “Studies on Integrated Nutrient Management in Apple (*Malus × domestica* Borkh.) cv. Red Delicious” was conducted at the Regional Horticultural Research Sub Station, Bhaderwah during the years 2024 and 2025. The experiment was laid out in a randomized block design with fifteen treatments replicated thrice to evaluate the effect of different integrated nutrient management (INM) combinations on soil properties. The treatment details include: T₁-Azotobacter + PSB (Phosphorus Solubilizing Bacteria), T₂-Azotobacter + PSB + FYM 100 kg + 100% recommended NPK (700:350:700 g/plant), T₃-Azotobacter + PSB + FYM 100 kg + 75% recommended NPK (525:262.5:525 g/plant), T₄-Azotobacter + PSB + FYM 100 kg + 50% recommended NPK (350:175:350 g/plant), T₅-Azotobacter + PSB + Vermicompost 10 kg + 100% recommended NPK (700:350:700 g/plant), T₆-Azotobacter + PSB + Vermicompost 10 kg + 75% recommended NPK (525:262.5:525 g/plant), T₇-Azotobacter + PSB + Vermicompost 10 kg + 50% recommended NPK (350:175:350 g/plant), T₈-Azotobacter + PSB + 100% recommended NPK (700:350:700 g/plant), T₉-Azotobacter + PSB + 75% recommended NPK (525:262.5:525 g/plant), T₁₀-Azotobacter + PSB + 50% recommended NPK (350:175:350 g/plant), T₁₁-FYM 100 kg + 75% recommended NPK (525:262.5:525 g/plant), T₁₂-FYM 100 kg + 50% recommended NPK (350:175:350 g/plant), T₁₃-Vermicompost 10 kg + 75% recommended NPK (525:262.5:525 g/plant), T₁₄-Vermicompost 10 kg + 50% recommended NPK (350:175:350 g/plant) and T₁₅-Recommended dose of NPK (700:350:700 g/plant)-Control. The results revealed that INM treatments did not produce any statistically significant variation in soil pH during both years of investigation. However, comparatively higher pH values (6.90) were recorded under T₁₂-FYM 100 kg + 50% recommended NPK (350:175:350 g/plant), whereas the lowest values (6.12) were observed under T₁₅-Recommended dose of NPK (700:350:700 g/plant). Similarly, soil electrical conductivity (EC) was not significantly influenced by different treatments. Nevertheless, relatively higher EC values (0.66 ds m⁻¹) were observed under T₁₄: Vermicompost 10 kg + 50% recommended NPK (350:175:350 g/plant), while lower EC values (0.19 ds m⁻¹) were recorded under T₁₃ (Vermicompost 10 kg + 75% recommended NPK (525:262.5:525 g/plant)). In contrast, soil organic carbon content was significantly affected by the INM treatments during both years. The highest organic carbon content (1.43 %) was recorded under T₅: Azotobacter + PSB + vermicompost @ 10 kg + 100% recommended NPK, while the lowest values (1.01 %) were observed under T₁: Azotobacter + PSB alone. The study indicates that integration of biofertilizers with organic manures and balanced fertilizer application improves soil organic carbon without adversely affecting soil pH and electrical conductivity in apple orchards.

Keywords: Integrated nutrient management, randomized block design, soil organic carbon, biofertilizers, vermicompost

1. Introduction

Apple (*Malus × domestica* Borkh.) is one of the most important temperate fruit crops cultivated in the north-western Himalayan region of India. Belonging to the family Rosaceae, apple holds a prominent position among temperate fruits grown worldwide. Major apple-producing countries include China, Russia, India, the United States, Poland, Turkey, Italy, and Chile (FAOSTAT, 2023) [5]. In India, apple cultivation is largely concentrated in the north-western Himalayan states of Himachal Pradesh, Jammu and Kashmir, and Uttarakhand, along with selected areas of the north-eastern region such as Arunachal Pradesh, Sikkim, Meghalaya, Mizoram, Nagaland, and Manipur.

The crop occupies nearly 3.13 lakh hectares with an annual production of about 24.37 lakh metric tonnes (Anonymous, 2023a) ^[1]. Apple is widely consumed as a fresh fruit and in processed forms due to its nutritional richness. It provides carbohydrates, essential minerals such as calcium, phosphorus, iron, magnesium, and potassium, and vitamins including thiamine and vitamin B6 (Bal, 2014; Skinner *et al.*, 2018) ^[3]. In addition to its nutritional value, apple is recognized for health-promoting properties, including cholesterol-lowering effects and digestive benefits.

Apple cultivation is generally practiced at elevations ranging from 1200 to 3500 m above mean sea level (Deodhar *et al.*, 2007) ^[4]. The crop performs best in deep, well-drained soils with slightly acidic reaction (pH 5.5-6.5) and adequate organic matter content. Soil physico-chemical properties such as soil pH, electrical conductivity (EC), and organic carbon (OC) play a decisive role in orchard productivity. Soil pH governs nutrient solubility and availability, thereby influencing uptake efficiency and overall tree performance. Electrical conductivity indicates the salinity status of soils; elevated EC levels may restrict root activity and reduce nutrient absorption (Patel *et al.*, 2020) ^[10]. Soil organic carbon, a key indicator of soil health, enhances soil aggregation, moisture retention, microbial activity, and nutrient buffering capacity, all of which are critical for sustainable apple production in fragile Himalayan ecosystems (Rana *et al.*, 2021) ^[11]. Therefore, systematic assessment of pH, EC, and OC is essential for understanding soil fertility status and devising appropriate nutrient management strategies in apple orchards.

In Jammu and Kashmir, 'Red Delicious' is the most extensively cultivated and commercially significant cultivar due to its attractive fruit colour, distinct shape, and high market demand. However, despite expansion in area and production, apple productivity in India remains comparatively low. Contributing factors include sloping terrain, shallow and less fertile soils, inadequate irrigation, imbalanced fertilization, and suboptimal orchard management practices.

Among these constraints, nutrient management is particularly critical. Apple is considered a nutrient-exhaustive crop with substantial annual removal of nitrogen (N), phosphorus (P), and potassium (K) through harvested fruits and vegetative growth. Even minor fluctuations in tissue nutrient concentration can significantly influence vegetative growth, flowering, fruit set, and yield. Hence, balanced and timely nutrient supply is essential to sustain productivity and maintain fruit quality. Nutrient management practices in fruit crops broadly include inorganic fertilizers, organic manures, and integrated approaches. Integrated Nutrient Management (INM), also referred to as the Integrated Plant Nutrient Supply System (IPNS), emphasizes the combined and judicious use of chemical fertilizers, organic manures, and biofertilizers to maintain soil fertility and enhance nutrient use efficiency (Zhang *et al.*, 2012) ^[18]. INM not only improves immediate crop response but also sustains long-term soil productivity by minimizing nutrient losses through leaching, volatilization, and runoff.

Organic inputs such as farmyard manure (FYM) and vermicompost contribute significantly to improving soil structure, enhancing microbial activity, and increasing soil organic carbon content. Vermicompost, in particular, is rich in plant-available nutrients and growth-promoting substances that support root development and nutrient uptake (Arancon *et al.*, 2004) ^[2]. Biofertilizers such as *Azotobacter* and phosphate-solubilizing bacteria (PSB) further enhance nutrient availability by fixing atmospheric nitrogen and mobilizing insoluble phosphorus fractions in the soil. The integrated use of these nutrient sources strengthens soil physico-chemical properties, including pH stabilization, improved EC balance, and enrichment of organic carbon pools, thereby supporting sustainable apple production systems in temperate Himalayan regions. Keeping in view the importance of soil physico-chemical properties, nutrient management, and their influence on apple productivity in the Himalayan region, the present investigation was undertaken to evaluate soil pH, electrical conductivity, and organic carbon status in apple orchards and to assess their implications for sustainable nutrient management and improved crop performance.

2. Materials and Methods

The present study entitled "Studies on Integrated Nutrient Management in Apple (*Malus × domestica* Borkh.) cv. Red Delicious" was conducted during 2024-2025 at the Experimental Farm of the Regional Horticulture Research Sub-Station (RHRSS), Bhaderwah. The experimental site is characterized by an average annual rainfall of approximately 1000 mm. Nearly sixty percent of the total precipitation is received during the southwest monsoon period (July-September), while additional moisture is supplemented through winter snowfall, particularly from late December to February.

The soils of the study area vary from silty loam to clay loam in texture, possess comparatively high organic matter content, and exhibit a slightly acidic to near-neutral reaction, with pH ranging between 6.2 and 6.8. These soil characteristics are generally considered favorable for apple cultivation under temperate conditions.

Application of inorganic fertilizers was carried out in accordance with the recommended package of practices. Nitrogen was supplied in two equal splits, with half applied during February and the remaining half at the time of fruit set. Phosphorus and potassium were applied as a basal dose in February during both years of experimentation. The experiment consisted of fifteen treatment combinations involving organic sources (farmyard manure and vermicompost), inorganic fertilizers (urea, diammonium phosphate, and muriate of potash), and biofertilizers (*Azotobacter* and phosphate-solubilizing bacteria), applied either individually or in different integrated combinations (Table 1). A control treatment comprising the recommended dose of NPK served as the reference. The trial was laid out in a Randomized Block Design (RBD) to minimize experimental variability and ensure reliable comparison among treatments.

Table 1: Treatment Details:

S. No.	Treatment combination
T ₁	<i>Azotobacter</i> + PSB (Phosphorus Solubilizing Bacteria)
T ₂	<i>Azotobacter</i> + PSB + FYM 100 kg + 100% recommended NPK (700:350:700 g/plant)
T ₃	<i>Azotobacter</i> + PSB + FYM 100 kg + 75% recommended NPK (525:262.5:525 g/plant)
T ₄	<i>Azotobacter</i> + PSB + FYM 100 kg + 50% recommended NPK (350:175:350 g/plant)
T ₅	<i>Azotobacter</i> + PSB + Vermicompost 10 kg + 100% recommended NPK (700:350:700 g/plant)
T ₆	<i>Azotobacter</i> + PSB + Vermicompost 10 kg + 75% recommended NPK (525:262.5:525 g/plant)
T ₇	<i>Azotobacter</i> + PSB + Vermicompost 10 kg + 50% recommended NPK (350:175:350 g/plant)
T ₈	<i>Azotobacter</i> + PSB + 100% recommended NPK (700:350:700 g/plant)
T ₉	<i>Azotobacter</i> + PSB + 75% recommended NPK (525:262.5:525 g/plant)
T ₁₀	<i>Azotobacter</i> + PSB + 50% recommended NPK (350:175:350 g/plant)
T ₁₁	FYM 100 kg + 75% recommended NPK (525:262.5:525 g/plant)
T ₁₂	FYM 100 kg + 50% recommended NPK (350:175:350 g/plant)
T ₁₃	Vermicompost 10 kg + 75% recommended NPK (525:262.5:525 g/plant)
T ₁₄	Vermicompost 10 kg + 50% recommended NPK (350:175:350 g/plant)
T ₁₅	Recommended dose of NPK (700:350:700 g/plant)-Control

Soil pH was determined in a 1:2.5 soil-to-water suspension using a digital glass electrode pH meter. The procedure adopted for pH estimation was in accordance with the standard method proposed by Jackson (1967) [6]. The electrical conductivity of the soil extract was measured in the soil-water suspension with the help of a conductivity meter. The estimation was carried out following the standard protocol described by Jackson (1973) [7]. The organic carbon content of the soil samples was quantified by the rapid titration method of Walkley and Black (1934) [17]. For this purpose, one gram of air-dried soil was treated with 10 ml of potassium dichromate solution and 20 ml of concentrated sulphuric acid to facilitate oxidation of organic matter. The excess dichromate remaining after oxidation was back-titrated against a standard ferrous ammonium sulphate solution in the presence of orthophosphoric acid, using diphenylamine as an internal indicator to determine the end point.

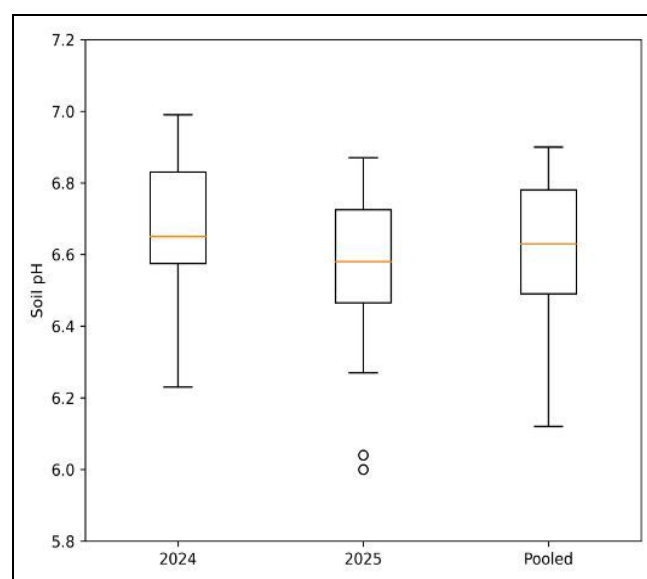
3. Results and Discussion

3.1 Soil pH

The data pertaining to soil pH presented in table 2 and fig. 1 revealed that the various integrated nutrient management (INM) treatments did not bring about any statistically significant variation in soil pH during either year of investigation. Although the differences were non-significant, comparatively higher pH values of 6.99 in 2024 and 6.87 in 2025 were observed under treatment T₃ (*Azotobacter* + PSB + FYM @ 100 kg + 75% recommended NPK). In contrast, the lowest pH value during 2024 (6.31) was recorded under treatment T₄ (*Azotobacter* + PSB + FYM @ 100 kg + 50% recommended NPK), whereas during 2025 the minimum pH (6.00) was noted under treatment T₁₅ (recommended dose of NPK-control). The pooled analysis of both years also indicated a non-significant influence of INM treatments on soil pH. However, numerically the highest pooled pH value (6.90) was recorded under treatment T₁₂ (FYM @ 100 kg + 50% recommended NPK), while the lowest value (6.12) was associated with treatment T₁₅ (recommended dose of NPK-control).

Further, the results revealed that the integrated nutrient management (INM) treatments did not significantly alter soil pH. The pooled analysis showed that the highest pH value (6.90) was observed under treatment T₁₂ (FYM @ 100 kg + 50% recommended NPK), whereas the lowest value (6.12) was recorded under treatment T₁₅ (recommended dose

of NPK-control). The non-significant variation in soil reaction across treatments could be attributed to the inherent buffering capacity of the soil, which resists abrupt changes in pH. Furthermore, the nutrient inputs were applied in moderate and balanced proportions, thereby preventing marked shifts in soil acidity or alkalinity. Organic amendments such as farmyard manure and vermicompost are known to improve soil organic matter content and enhance cation exchange capacity, enabling the soil to regulate fluctuations in hydrogen ion concentration (Kumari *et al.*, 2024) [8]. The combined use of organic, inorganic, and biological sources of nutrients likely contributed to maintaining a stable soil reaction throughout the experimental period.

**Fig 1:** Effect of INM on soil pH of apple cv. Red Delicious

3.2 Electrical Conductivity (dS m⁻¹)

The effect of different INM treatments on soil electrical conductivity (EC) during 2024 and 2025 is presented in table 1 and fig. 2. The analysis showed that none of the treatments significantly influenced soil EC in the apple orchard of cv. Red Delicious. Despite the non-significant differences, the highest EC values of 0.67 and 0.66 dS m⁻¹ during 2024 and 2025, respectively, were recorded under treatment T₁₄ (Vermicompost @ 10 kg + 50% recommended NPK). The lowest EC value during 2024 (0.11 dS m⁻¹) was observed under treatment T₈ (*Azotobacter* + PSB + 100%

recommended NPK), whereas in 2025 the minimum value (0.10 dS m⁻¹) was recorded under treatment T₂ (Azotobacter + PSB + FYM @ 100 kg + 100% recommended NPK). The pooled data further confirmed the absence of any significant effect of INM treatments on soil EC. However, numerically the maximum pooled EC (0.66 dS m⁻¹) was found under treatment T₁₄ (Vermicompost @ 10 kg + 50% recommended NPK), while the minimum pooled EC (0.19 dS m⁻¹) was recorded under treatment T₁₃ (Vermicompost @ 10 kg + 75% recommended NPK). The absence of significant variation in EC among treatments may be explained by the judicious and balanced application of nutrient sources, which likely prevented the excessive build-up of soluble salts in the soil profile (Shahid *et al.*, 2013) ^[14]. Organic inputs such as vermicompost and FYM are known to enhance soil physical properties, including aggregation, porosity, and water infiltration, thereby facilitating the movement and leaching of soluble salts beyond the root zone (Moharana *et al.*, 2017) ^[9]. In addition, partial replacement of chemical fertilizers with organic and biofertilizer components might have minimized the potential

risk of salt accumulation, maintaining EC within a safe range for crop growth.

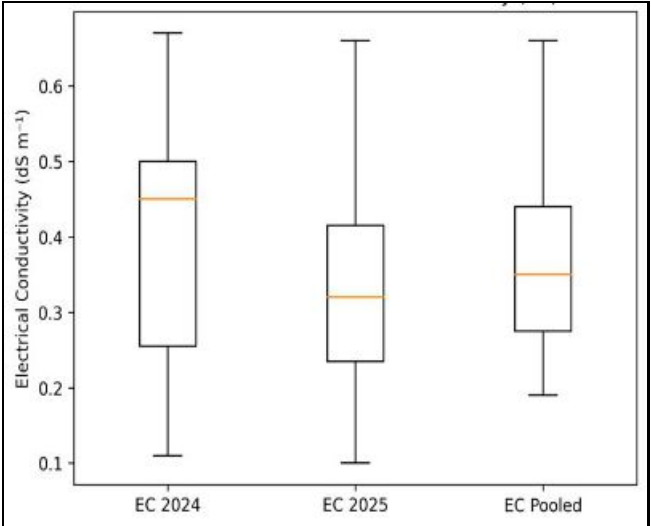


Fig 2: Effect of INM on soil pH of apple cv. Red Delicious

Table 2: Effect of integrated nutrient management on soil pH and electrical conductivity (dSm⁻¹) of apple cv. Red Delicious

Treatments	pH			Electrical Conductivity(dSm ⁻¹)		
	2024	2025	Pooled	2024	2025	Pooled
T ₁ -Azotobacter + PSB (Phosphorus Solubilizing Bacteria)	6.61	6.58	6.60	0.54	0.16	0.35
T ₂ -Azotobacter + PSB + FYM 100 kg + 100% recommended NPK (700:350:700 g/plant)	6.78	6.75	6.77	0.49	0.10	0.29
T ₃ -Azotobacter + PSB + FYM 100 kg + 75% recommended NPK (525:262.5:525 g/plant)	6.99	6.58	6.79	0.45	0.11	0.28
T ₄ -Azotobacter + PSB + FYM 100 kg + 50% recommended NPK (350:175:350 g/plant)	6.31	6.27	6.29	0.29	0.29	0.29
T ₅ -Azotobacter + PSB + Vermicompost 10 kg + 100% recommended NPK (700:350:700 g/plant)	6.72	6.70	6.71	0.30	0.42	0.36
T ₆ -Azotobacter + PSB + Vermicompost 10 kg + 75% recommended NPK (525:262.5:525 g/plant)	6.56	6.51	6.54	0.51	0.35	0.43
T ₇ -Azotobacter + PSB + Vermicompost 10 kg + 50% recommended NPK (350:175:350 g/plant)	6.61	6.04	6.32	0.22	0.32	0.27
T ₈ -Azotobacter + PSB + 100% recommended NPK (700:350:700 g/plant)	6.68	6.65	6.67	0.11	0.31	0.21
T ₉ -Azotobacter + PSB + 75% recommended NPK (525:262.5:525 g/plant)	6.46	6.42	6.44	0.14	0.40	0.27
T ₁₀ -Azotobacter + PSB + 50% recommended NPK (350:175:350 g/plant)	6.59	6.53	6.56	0.49	0.41	0.45
T ₁₁ -FYM 100 kg + 75% recommended NPK (525:262.5:525 g/plant)	6.65	6.61	6.63	0.54	0.45	0.50
T ₁₂ -FYM 100 kg + 50% recommended NPK (350:175:350 g/plant)	6.92	6.87	6.90	0.48	0.52	0.50
T ₁₃ -Vermicompost 10 kg + 75% recommended NPK (525:262.5:525 g/plant)	6.88	6.84	6.86	0.20	0.18	0.19
T ₁₄ -Vermicompost 10 kg + 50% recommended NPK (350:175:350 g/plant)	6.89	6.85	6.87	0.67	0.66	0.66
T ₁₅ -Recommended dose of NPK (700:350:700 g/plant)-Control	6.23	6.00	6.12	0.44	0.32	0.38
SE(m) ±	0.26	0.36	0.23	0.12	0.13	0.08
C.D. (≤0.05)	NS	NS	NS	NS	NS	NS

3.3 Organic Carbon (%)

The data presented in table 3 and fig. 3 demonstrated that INM treatments significantly influenced soil organic carbon content during both years of study. The highest organic carbon content was recorded under treatment T₅ (Azotobacter + PSB + Vermicompost @ 10 kg + 100% recommended NPK), with values of 1.35% in 2024 and 1.53% in 2025. This treatment was statistically at par with treatment T₂ (Azotobacter + PSB + FYM @ 100 kg + 100% recommended NPK) during 2024. The lowest organic carbon content was observed under treatment T₁ (Azotobacter + PSB), registering 0.80% in 2024 and 1.21% in 2025. The pooled analysis of the two years also revealed a significant effect of INM treatments on soil organic carbon. The highest pooled organic carbon content (1.43%) was recorded under treatment T₅, whereas the lowest pooled value (1.00%) was observed under treatment T₁. The enhanced organic carbon levels under treatments receiving vermicompost and FYM may be attributed to the direct

incorporation of organic residues into the soil, which enriches the carbon pool and stimulates microbial activity. The addition of organic materials promotes humification processes and improves soil aggregation, thereby reducing carbon losses through rapid mineralization. Integration of organic manures with recommended fertilizer doses likely created favorable conditions for microbial proliferation and efficient nutrient cycling, leading to improved stabilization of soil organic carbon fractions. These observations are consistent with earlier findings. For instance, Shukla *et al.* (2022) ^[15] reported significant increases in soil organic carbon under integrated nutrient management systems. Similarly, Ravikiran *et al.* (2018) ^[12] documented improvements in soil fertility attributes, including organic carbon, following combined application of organic and inorganic nutrient sources. Comparable results were also noted by Sahu *et al.* (2014) ^[13], who highlighted the superiority of integrated nutrient management over sole chemical fertilization in enhancing soil organic carbon status.

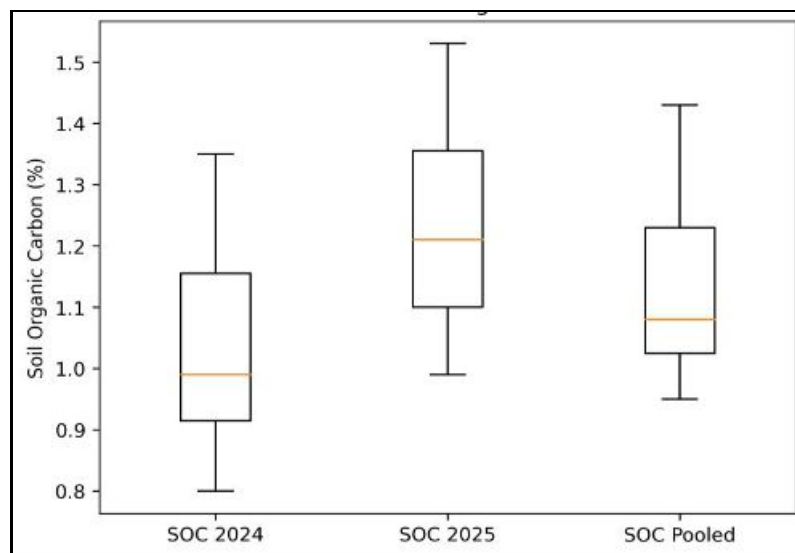


Fig 3: Effect of INM on soil organic carbon (%) of apple cv. Red Delicious

Table 3: Effect of integrated nutrient management on soil organic carbon (%) of apple cv. Red Delicious.

Treatments	Organic Carbon (%)		
	2024	2025	Pooled
T ₁ -Azotobacter + PSB (Phosphorus Solubilizing Bacteria)	0.80	1.21	1.00
T ₂ -Azotobacter + PSB + FYM 100 kg + 100% recommended NPK (700:350:700 g/plant)	1.33	1.47	1.38
T ₃ -Azotobacter + PSB + FYM 100 kg + 75% recommended NPK (525:262.5:525 g/plant)	1.22	1.38	1.30
T ₄ -Azotobacter + PSB + FYM 100 kg + 50% recommended NPK (350:175:350 g/plant)	0.99	1.33	1.16
T ₅ -Azotobacter + PSB + Vermicompost 10 kg + 100% recommended NPK (700:350:700 g/plant)	1.35	1.53	1.43
T ₆ -Azotobacter + PSB + Vermicompost 10 kg + 75% recommended NPK (525:262.5:525 g/plant)	1.27	1.39	1.33
T ₇ -Azotobacter + PSB + Vermicompost 10 kg + 50% recommended NPK (350:175:350 g/plant)	1.09	1.29	1.16
T ₈ -Azotobacter + PSB + 100% recommended NPK (700:350:700 g/plant)	1.03	1.20	1.12
T ₉ -Azotobacter + PSB + 75% recommended NPK (525:262.5:525 g/plant)	0.95	1.21	1.08
T ₁₀ -Azotobacter + PSB + 50% recommended NPK (350:175:350 g/plant)	0.88	1.24	1.06
T ₁₁ -FYM 100 kg + 75% recommended NPK (525:262.5:525 g/plant)	0.99	1.10	1.05
T ₁₂ -FYM 100 kg + 50% recommended NPK (350:175:350 g/plant)	0.87	1.06	0.97
T ₁₃ -Vermicompost 10 kg + 75% recommended NPK (525:262.5:525 g/plant)	1.01	1.10	1.06
T ₁₄ -Vermicompost 10 kg + 50% recommended NPK (350:175:350 g/plant)	0.97	0.99	0.98
T ₁₅ -Recommended dose of NPK (700:350:700 g/plant)-Control	0.85	1.06	0.95
SE(m) ±	0.02	0.01	0.01
C.D. (≤0.05)	0.06	0.03	0.01

4. Conclusion

The present investigation demonstrated that the adoption of integrated nutrient management practices ensured overall stability and improvement in soil chemical properties under apple cv. Red Delicious. Over the two years of study, the application of different combinations of organic manures, biofertilizers, and inorganic fertilizers did not produce significant alterations in soil pH and electrical conductivity. The soil reaction remained within a slightly acidic to near neutral range, reflecting the buffering capacity of the soil system and the balanced nature of nutrient inputs. Similarly, electrical conductivity values were maintained well within safe limits across treatments, indicating that the integrated use of nutrient sources did not lead to harmful salt accumulation in the root zone. The moderation of these parameters suggests that the combined nutrient approach preserved the chemical equilibrium of the soil environment. In contrast, soil organic carbon exhibited a positive and significant response to integrated nutrient application. Treatments supplemented with vermicompost and farmyard manure in conjunction with recommended fertilizer doses consistently recorded higher organic carbon content compared to treatments receiving biofertilizers alone. The enhancement in organic carbon levels may be ascribed to

the continuous addition of organic substrates, which stimulated microbial biomass, improved decomposition dynamics, and facilitated the formation of stable humic substances. The synergistic interaction between organic and inorganic nutrient sources likely promoted efficient nutrient turnover and improved carbon stabilization within the soil matrix. Collectively, the findings underline that integrated nutrient management serves as a sustainable nutrient strategy capable of maintaining soil chemical balance while enriching the organic carbon pool. The approach not only safeguards against undesirable shifts in soil reaction and salinity but also strengthens soil fertility through improved organic matter status. Therefore, the integration of organic amendments with balanced fertilizer application emerges as a practical and ecologically sound practice for sustaining soil health and long-term productivity in apple-based production systems.

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6. Declaration of competing interest

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

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