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Integrated organic-mineral nutrition improves growth and stress resilience in high density avocado cv. TKD-1

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Abstract
An experiment was conducted to assess the effect of integrated organic-mineral nutrient management on vegetative growth and physiological responses of avocado (*Persea americana* Mill.) cv. TKD-1 under high-density planting conditions. The study was carried out on 12-year-old trees at Pandrimalai, Tamil Nadu, using a Randomized Block Design with ten treatments comprising combinations of recommended dose of fertilizers (RDF), compost, potassium supplied through polyhalite and phosphorus through phosphate-rich organic manure (PROM). Integrated nutrient treatments significantly influenced canopy development and physiological attributes, while tree height and trunk girth showed non-significant variation. Among the treatments, T_9 (25 kg compost + 50% K through polyhalite + 50% P through PROM) recorded the maximum canopy spread (5.37 m), canopy volume (178.51 m^3), leaf area (254.99 cm^2), chlorophyll content (61.28 SPAD) and relative water content (96.39%). Physiological stress indicators were markedly reduced under integrated nutrient application, with T_9 registering the lowest PAL activity (18.13 µmol g^{-1} FW) and proline content (3.25 µmol g^{-1} FW), compared to the control. The results demonstrate that integration of organic amendments with mineral nutrient sources is an effective and sustainable strategy for improving canopy development and physiological efficiency in avocado orchards under high-density planting systems.

Keywords: Avocado, polyhalite, PROM, proline and PAL activity

Introduction
Avocado growth is influenced by complex physiological, morphological and environmental interactions, particularly due to its monopodial growth habit, shallow rooting nature and rhythmic flush pattern. In avocado, vegetative growth typically occurs in distinct flushes, often coinciding or competing with reproductive development, which creates strong competition for assimilates between shoots, roots and developing fruits (Whiley *et al.*, 2013) [22]. Shoot growth generally precedes root growth, but root growth is markedly suppressed during periods of high fruit load (Arpaia *et al.*, 1995) [1]. Avocado exhibits both proleptic and sylleptic shoot types, forming characteristic growth modules which determine canopy structure, leaf area development and resource partitioning (Thorp *et al.*, 1994) [21]. The shallow root system, concentrated at 30-40 cm depth, increases tree sensitivity to soil moisture imbalance, aeration stress and nutrient limitations (Scora *et al.*, 2002) [19]. Therefore, balanced nutrient supply, favourable soil environment and optimized canopy growth regulation are critical to ensure continuous vegetative renewal and improved reproductive success in avocado orchards.

Materials and Methods
The field experiment was conducted at Pandrimalai, Dindigul district, Tamil Nadu (10°33' N, 77°73' E; 1251 m MSL), located in the Western Agro-Climatic Zone of Tamil Nadu. The region experiences a subtropical climate with an annual rainfall of ~800 mm, predominantly received during the North-East Monsoon (October-December), with mean temperatures ranging from 15-29 °C. Meteorological data recorded during the study period were obtained from the Office of the Assistant Director of Statistics, Dindigul. The experiment was carried out on 12-year-old avocado trees (var. TKD-1) planted at 5 × 5 m spacing under high-density planting. The study was laid out in a Randomized Block Design (RBD) consisting of 10 treatments replicated thrice, with 10 trees per replication, comprising a total of 300 plants.

Results and Discussion

The data pertaining to the effect of organic mineral nutrient treatments on tree height of avocado cv. TKD-1 are presented in Table 1. The results indicated that the application of organic mineral nutrients resulted in a marginal increase in tree height compared to the control; however, the differences among treatments were statistically non-significant (NS). Among the treatments, T_9 (25 kg compost + 50% K through polyhalite + 50% P through PROM) recorded the maximum tree height (7.98 m), which was statistically on par with T_8 (50% RDF + 50% K through polyhalite + 50% P through PROM) registering 7.93 m. The minimum tree height (7.38 m) was observed in T_{10} (control). The increase in tree height under polyhalite nutrition appears to result from its balanced release of K, Ca, Mg and S, which collectively sustain metabolic activity and vegetative growth. Potassium acts as a major enzymatic activator for photosynthesis, assimilate transport and protein synthesis (Ng Kee Kwong, 2001) [12], while sulphur supports oxidative processes and ferredoxin-mediated electron transfer during photosynthesis. This coordinated nutrient supply enhances carbohydrate accumulation and nitrogen metabolism, contributing to vigorous stem elongation, as similarly noted in sugarcane by Raghunath *et al.* (2021) [15]. Calcium-driven regulation of cell division and elongation further promotes vertical growth (Monshausen, 2012) [11]. Organic manures also increased plant height by improving nutrient mineralization, soil structure and releasing growth-promoting compounds. Their phosphorus content enhances meristematic activity and stem elongation (Noor *et al.*, 2021) [13] and combined organic-inorganic applications have been shown to raise plant height in several crops (Zafar *et al.*, 2011; Raiger, 2004; Khangarot, 2022) [23, 16, 7].

Trunk girth showed significant variation among the treatments (Table 1). Although slight variations were observed among treatments, the differences were statistically non-significant (NS). The highest trunk girth was recorded in T_9 (98.34 cm), which was statistically on par with T_8 (98.22 cm) and followed by T_5 (98.08 cm). The lowest trunk girth (97.05 cm) was observed in the control (T_{10}). Polyhalite improved trunk girth through complementary functions of its constituent nutrients. Calcium strengthened cell walls and supported xylem formation, while Mg and S maintained higher photosynthetic efficiency and protein synthesis, promoting sustained secondary thickening and greater deposition of structural carbohydrates. Similar benefits of polyhalite on stem thickening have been reported in the rice-wheat system (Kumar *et al.*, 2025) [8], tomato (Sacks *et al.*, 2017) [17], sugarcane (Bhatt *et al.*, 2021) [3] and sunflower. PROM enhanced radial growth by supplying slow-release phosphorus and organic matter, supporting root expansion, nutrient uptake, ATP production and cambial activation. This steady P availability facilitates auxin-mediated secondary growth and increased translocation of assimilates to woody tissues. Vermicompost and PSB further strengthened trunk girth by improving P solubilization, nitrogen mineralization and microbial activity, collectively enhancing cambial activity. Similar responses in custard apple cv. Arka Sahan were documented by Bhatnagar and Singh (2015) [2].

Significant differences were observed in canopy spread among the treatments (Table 1). The maximum canopy spread was recorded in T_9 (5.37 m), which was statistically on par with T_8 (5.33 m) and T_6 (5.14 m). The minimum canopy spread (4.34 m) was observed in the control (T_{10}). The enhanced canopy spread under integrated nutrient treatments indicates improved vegetative growth due to balanced nutrient availability. The canopy volume of avocado trees was significantly influenced by organic mineral nutrient treatments (Table 1). Treatment T_9 recorded the highest canopy volume (178.51 m^3), which was statistically on par with T_8 (176.55 m^3) and T_5 (167.91 m^3).

Table 1: Effect of organic mineral nutrients on vegetative characteristics of avocado cv. TKD 1

Treatment Details	Tree height (m)	Trunk girth (cm)	Canopy spread (m)	Canopy volume (m^3)	Leaf area (cm^2)	Chlorophyll content (SPAD)	RWC (%)	PAL activity (μmol g^{-1} FW)	Proline content (μmol g^{-1} FW)
T_1-100% RDF	7.51	97.32	4.57	135.78	239.03	56.52	88.02	28.65	8.81
T_2-50% RDF + 25kg Compost	7.59	97.49	4.75	145.44	242.64	57.60	89.91	26.27	7.56
T_3-50% RDF + 50% K through Polyhalite	7.73	97.80	4.97	157.07	246.98	58.89	92.19	23.41	6.04
T_4-50% RDF + 50% P through PROM	7.64	97.60	4.78	147.17	243.28	57.79	90.25	25.85	7.33
T_5-50% K through Polyhalite + 50% P through PROM	7.86	98.08	5.17	167.91	251.03	60.10	94.31	20.74	4.63
T_6-25kg Compost + 50% K through Polyhalite	7.81	97.97	5.14	166.10	250.35	59.90	93.96	21.19	4.87
T_7-25kg Compost + 50% P through PROM	7.71	97.75	4.95	156.21	246.66	58.80	92.02	23.62	6.15
T_8-50% RDF + 50% K through Polyhalite + 50% P through PROM	7.93	98.22	5.33	176.55	254.26	61.06	96.01	18.61	3.51
T_9-25kg Compost + 50% K through Polyhalite + 50% P through PROM	7.98	98.34	5.37	178.51	254.99	61.28	96.39	18.13	3.25
T_{10}-Control	7.38	97.05	4.34	123.53	234.45	55.16	85.62	31.67	10.41
S.ED.	NS	NS	0.07	7.37	1.37	0.41	0.72	0.90	0.48
C.D. @ 5%	NS	NS	0.14	15.48	2.88	0.86	1.51	1.90	1.00

The lowest canopy volume (123.53 m^3) was recorded in the control (T_{10}). The increase in canopy volume under combined organic and mineral nutrient treatments reflects better canopy development and plant vigour.

The substantial increase in canopy spread and volume under integrated nutrient treatments reflects enhanced vegetative growth and plant vigour. The combined supply of macro- and secondary nutrients through polyhalite and PROM likely improved nutrient availability and uptake efficiency, resulting in improved shoot proliferation and canopy expansion. The sustained release of potassium, calcium, magnesium and sulphur from polyhalite may have promoted active cell division and elongation, leading to improved canopy architecture. Similar improvements in canopy development under balanced nutrient supply have been reported cabbage and cauliflower (Satisha and Ganeshamurthy, 2016) [18].

Leaf area differed significantly among the nutrient management treatments (Table 1). The highest leaf area was recorded in T_9 (25 kg compost + 50% K through polyhalite + 50% P through PROM), with a value of 254.99 cm^2, which was statistically on par with T_8 (254.26 cm^2). This was followed by T_5 (50% K through polyhalite + 50% P through PROM), which recorded a leaf area of 251.03 cm^2. In contrast, the control (T_{10}) exhibited the minimum leaf area (234.45 cm^2). Increased leaf area under integrated nutrient management may be attributed to improved nutrient uptake and enhanced photosynthetic efficiency. Enhanced leaf area under integrated nutrient management may be attributed to improved nutrient uptake and greater photosynthetic surface development. The synergistic interaction between nitrogen and sulphur plays a critical role in leaf expansion by promoting protein synthesis and chloroplast development, as reported by Bologna-Campbell *et al.* (2013) [5]. Adequate potassium supplied through polyhalite, owing to its high mobility, likely contributed to improved turgor regulation, stomatal functioning and assimilate translocation, thereby supporting vigorous leaf growth. The balanced supply of Ca, Mg, K and S may have further facilitated cell wall formation, laminar tissue strength and leaf enlargement, culminating in increased total leaf area and canopy spread.

Chlorophyll content (SPAD value) differed significantly among the treatments (Table 1). The highest chlorophyll content was recorded in T_9 (61.28 SPAD), followed closely by T_8 (61.06 SPAD) and followed by T_5 (60.10 SPAD). The lowest chlorophyll content (55.16 SPAD) was observed in the control (T_{10}). Higher chlorophyll content under polyhalite and PROM-based treatments indicates improved nitrogen assimilation and photosynthetic capacity. Higher chlorophyll content under polyhalite-and PROM-based treatments indicates improved nitrogen assimilation and enhanced photosynthetic capacity. The availability of magnesium from polyhalite is particularly important, as Mg constitutes the central atom of the chlorophyll molecule and is essential for chlorophyll synthesis and stability. In addition, sulfur plays a vital role in the formation of amino acids and enzymes involved in chlorophyll biosynthesis. Organic amendments such as PROM and vermicompost further enhance soil microbial activity and nutrient mineralization, increasing the availability of nitrogen, iron and other micronutrients required for chlorophyll formation. These findings are consistent with earlier reports highlighting the role of organic matter and balanced nutrient supply in improving leaf greenness and photosynthetic efficiency (Mir *et al.*, 2013; Shahi *et al.*, 2018; Bo Yan and Ying Hou, 2018) [10, 20, 4].

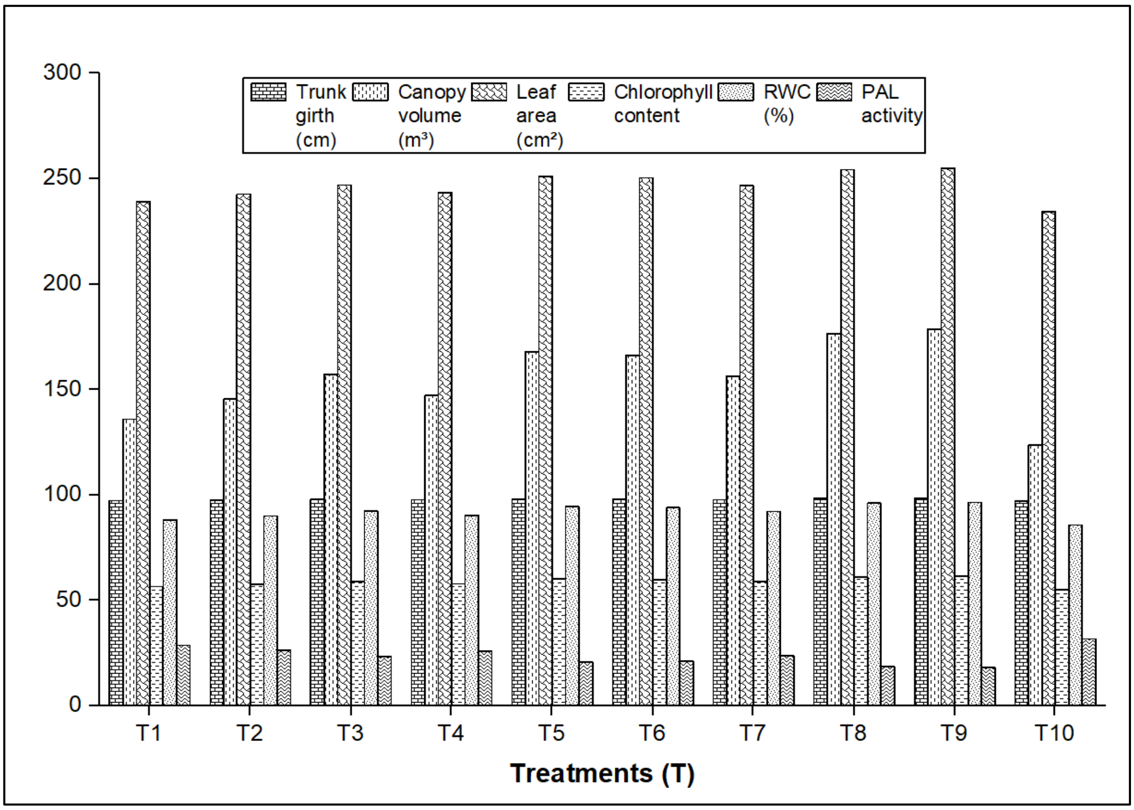

Fig 1: Organic-mineral nutrient integration in avocado cv. TKD-1

Relative water content was significantly influenced by organic mineral nutrient treatments (Table 1). Treatment T_9 recorded the maximum RWC (96.39%), which was statistically on par with T_8 (96.01%) and followed by (94.31%). The minimum RWC (85.62%) was observed in the control (T_{10}). Higher RWC under integrated nutrient treatments suggests improved plant water status and stress tolerance. Polyhalite enhanced relative water content (RWC) by improving osmotic adjustment, stabilizing stomatal activity and maintaining cell turgor. Calcium strengthened membranes, reducing water loss and magnesium sustained photosynthetic efficiency, indirectly supporting hydration. These outcomes align with improvements reported in tomato (Sacks *et al.*, 2017) [17].

Compost further improved RWC by enhancing soil water-holding capacity, nutrient retention and root-zone aeration. When combined with phosphorus, it improved ion balance, reduced sodium uptake and promoted antioxidant activity, lowering oxidative stress. Ding *et al.* (2021) [6] similarly found that PROM and compost enhanced stomatal conductance and RWC while reducing proline under stress; comparable outcomes were reported by Omara *et al.* (2022) [14] and Masjedi *et al.* (2025) [9]. The improved hydration and nutrient balance reduced PAL activity and proline accumulation, indicating lower stress signalling and more stable physiological functioning under integrated nutrient management.

PAL activity showed significant variation among treatments (Table 1). The lowest PAL activity, which is physiologically desirable, was recorded in T_9 (18.13 units g^{-1} FW), which was statistically on par with T_8 (18.61 units g^{-1} FW) and followed by T_5 (20.74 units g^{-1} FW). In contrast, the highest PAL activity was observed in the control (31.67 units g^{-1} FW). Proline content also differed significantly among treatments (Table 1). The lowest proline content, which is considered favourable, was recorded in T_9 (3.25 µmol g^{-1} FW), followed by T_8 (3.51 µmol g^{-1} FW) and T_5 (4.63 µmol g^{-1} FW). The highest proline accumulation occurred in the control (10.41 µmol g^{-1} FW). Lower PAL activity indicates reduced stress-induced activation of the phenylpropanoid pathway and reflects improved metabolic stability. PAL is commonly upregulated under nutrient deficiency or environmental stress; therefore, its reduced activity under integrated organic-mineral nutrient treatments suggest enhanced nutrient availability and lower oxidative stress. The balanced supply of K, Ca, Mg and S from polyhalite, along with phosphorus from PROM, likely minimized stress signals and suppressed excessive PAL induction. Proline accumulation, a well-established indicator of physiological stress, was also lower under integrated nutrient treatments, indicating improved cellular hydration, membrane stability and osmotic balance. Adequate potassium-mediated stomatal regulation and sulfur-supported amino acid metabolism collectively contributed to reduced proline synthesis.

Conclusion

Integrated organic-mineral nutrient management significantly enhanced vegetative growth of avocado cv. TKD-1 compared to conventional fertilization. The combined application of compost with potassium through polyhalite and phosphorus through PROM (T_9) improved canopy development, leaf area, chlorophyll content and plant water status, while significantly reducing PAL activity and proline accumulation, indicating lower physiological stress. The balanced, slow-release supply of macro-and secondary nutrients from polyhalite, together with organic phosphorus sources, improved nutrient uptake efficiency and photosynthetic performance. Tree height and trunk girth showed minimal variation, suggesting that integrated nutrition primarily promoted canopy expansion and physiological efficiency rather than vertical growth. Overall, integrated organic-mineral nutrient application represents a sustainable and effective nutrient management strategy for avocado under high-density planting systems.

Authors Contribution

Work assessment, execution, lab work, data gathering, statistical analysis and final correction.

Declaration

There are no competing interests for the writers.

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