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Enhancing Fruit Growth of Daisy Mandarin (Citrus Reticulata) Through Foliar Application of Manganese and Iron

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Abstract

The study titled "Impact of Micronutrients (Mn and Fe) on Vegetative Growth of Daisy Mandarin (*Citrus reticulata*)" was carried out during 2024–25 at Guru Kashi University, Talwandi Sabo, Punjab. The research aimed to assess the effects of foliar applications of manganese (Mn) and iron (Fe) on the vegetative growth, fruit physical attributes, chemical composition, and overall quality of Daisy mandarin. Manganese sulphate ($MnSO_4$) and ferrous sulphate ($FeSO_4$) were applied at concentrations of 0.1%, 0.2%, and 0.3%, both individually and in combination. The experiment followed a Randomized Block Design, comprising sixteen treatments with four replications, resulting in sixty-four treatment combinations. It was conducted in a six-year-old Daisy mandarin orchard budded on Jatti Khatti (Citrus jambhiri Lush) rootstock. Key parameters measured included scion girth, rootstock girth, and canopy volume. The treatment combining 0.3% $MnSO_4$ and 0.2% $FeSO_4$ yielded the most significant improvements in vegetative parameters, with a scion girth of 10.20 cm, rootstock girth of 9.8 cm, and canopy volumes of 134.0 m^3 (north-south) and 115.0 m^3 (east-west), compared to the control. These findings demonstrate that foliar application of $MnSO_4$ and $FeSO_4$,

across various combinations, markedly enhanced the vegetative growth of Daisy mandarin under subtropical conditions. The study underscores the importance of micronutrient supplementation in improving orchard productivity and provides valuable insights for subtropical horticulture practices.

Keywords: Daisy mandarin, Citrus reticulata, manganese sulphate, ferrous sulphate, foliar application, micronutrients, vegetative growth, subtropical horticulture, Randomized Block Design, Jatti Khatti rootstock

Introduction

Citrus crops are pivotal to global horticulture, contributing significantly to agricultural production, nutritional health, and economic trade. Annually, over 150 million metric tons of citrus fruits, including oranges, mandarins, lemons, limes, and grapefruits, are produced across 10.2 million hectares worldwide, with China, Brazil, India, and Mexico leading as top producers (Alonso *et al.,* 2023; Tariq *et al.,* 2024; FAO, 2023). China dominates with nearly 30% of global output, followed closely by Brazil and India, which rank third, contributing 7–8% of the global supply (Jiang *et al.,* 2023; NHB, 2022). In India, citrus cultivation spans 1.086 million hectares, yielding 14.26 million tons, with mandarins alone accounting for 6.35 million tons in 2023 (Keelery, 2023). Punjab, a key citrus-producing region, cultivates 52,836 hectares, primarily of Kinnow mandarins, with an annual production of 1.05 million tons and an exceptional productivity of 42.4 tons/ha (PAU Ludhiana, 2023; Anonymous, 2021).

Citrus fruits are prized for their nutritional profile, which is rich in vitamin C, dietary fibre, and bioactive compounds such as flavonoids and carotenoids, offering antioxidant, cardioprotective, and anti-inflammatory benefits (Sharma *et al.,* 2024; Kaur *et al.,* 2024a). The Daisy mandarin (*Citrus reticulata*), a hybrid of Fortune and Fremont mandarins, is particularly valued for its vibrant deep orange rind, early maturity, and balanced sweetness-acidity profile, making it a premium cultivar in domestic and international markets (Gill *et al.,* 2017; Kaur *et al.,* 2024a).

Iron supports chlorophyll synthesis and photosynthesis, and its deficiency leads to chlorosis, reducing photosynthetic efficiency and fruit size (Tariq *et al.,* 2024). Manganese aids enzymatic processes, magnesium is central to chlorophyll structure, (Sharma *et al.,* 2024; Anwar *et al.,* 2022). Foliar application of micronutrients, particularly Fe and Mn, has shown promise in enhancing fruit weight, sugar accumulation, and overall quality in citrus (Kaur *et al.,* 2024a).

This study aims to evaluate the effects of foliar-applied manganese and iron on the vegetative growth of Daisy mandarin in Punjab, India, hypothesizing that optimized micronutrient combinations will significantly enhance these parameters. Limited research on Daisy prompted this study to evaluate the impact of foliar Mn and Fe sprays on vegetative parameters (canopy, scion/rootstock girth) of Citrus reticulata, aiming to enhance productivity and quality.

Materials and Methods

The study was conducted in 2024 at Guru Kashi University, Talwandi Sabo, Punjab, India, characterized by a subtropical climate. Sixty-four healthy, six-year-old Daisy mandarin (*Citrus reticulata*) trees, budded on Jatti Khatti (*Citrus jambhiri Lush*) rootstock, were selected for their uniformity.The experiment employed a Randomized Block Design (RBD) with 16 treatments, including a control, replicated four times, yielding 64 treatment combinations. Treatments comprised a water-spray control (T_0), solo applications of manganese sulphate at 0.1% (T_1), 0.2% (T_2), and 0.3% (T_3), and ferrous sulphate at 0.1% (T_4), 0.2% (T_5), and 0.3% (T_6), alongside combinations: 0.1% $MnSO_4$ + 0.1% $FeSO_4$ (T_7), 0.1% $MnSO_4$ + 0.2% $FeSO_4$ (T_8), 0.1% $MnSO_4$ + 0.3% $FeSO_4$ (T_9), 0.2% $MnSO_4$ + 0.1% $FeSO_4$ (T_{10}), 0.2% $MnSO_4$ + 0.2% $FeSO_4$ (T_{11}), 0.2% $MnSO_4$ + 0.3% $FeSO_4$ (T_{12}), 0.3% $MnSO_4$ + 0.1% $FeSO_4$ (T_{13}), 0.3% $MnSO_4$ + 0.2% $FeSO_4$ (T_{14}), and 0.3% $MnSO_4$ + 0.3% $FeSO_4$ (T_{15}). Foliar sprays were administered twice during the growing season using a high-pressure sprayer to ensure complete canopy coverage. Fruit diameter was measured at the equatorial plane using a digital Vernier calliper (accuracy: 0.01 mm), ensuring perpendicular alignment without fruit compression (Tariq, M., *et al.,* 2024). Juice content (%) was determined by weighing fruits and extracted juice on an electronic balance (accuracy: 0.01 g), calculated as: (Weight of Juice Extracted / Total Fruit Weight) × 100 (Kaur, N., *et al.*, 2024a). Vitamin C content (mg/100 g) was quantified via the 2,6-dichlorophenolindophenol (DCPIP) titration method, mixing 5 ml of juice with 5 ml of 5–6% metaphosphoric acid, titrating with 0.1% DCPIP to a faint pink endpoint, and calculated as: (Vf / Vs × Ms × 100 / Wf), where Vf is DCPIP volume used, Vs is sample volume, Ms is DCPIP molarity, and Wf is sample weight (Gullo, G., *et al.,* 2023). Fruit firmness (kg/cm^2) was evaluated using a penetrometer with a 5–8 mm probe inserted into peeled flesh perpendicularly, recording the maximum force (Lado, J., *et al.,*2024*).* Total soluble solids (TSS, °Brix) were measured with a digital refractometer using 2–3 drops of juice (Sharma, R., *et al.,* 2024). Titratable acidity (%) was assessed by titrating 5–10 ml of juice with 0.1 M NaOH and phenolphthalein indicator to a persistent pink endpoint (pH 8.2), calculated as: (ml of NaOH × N of NaOH × Equivalent Weight of Acid) / ml of Sample (Kaur, N., *et al.,* 2024a). The TSS: Acid ratio was derived by dividing TSS (°Brix) by titratable acidity (%). Individual fruit weight (g) was recorded using an electronic balance (accuracy: 0.01 g) (Alonso, J., *et al.,* 2023). The number of fruits per plant and yield per plant (kg) were determined by harvesting all fruits at full maturity in a single picking, counting fruits, and weighing the total yield per tree. Statistical analysis was performed using Analysis of Variance (ANOVA) with OPSTAT software (Gomez, K. A., & Gomez, A. A., 1983).

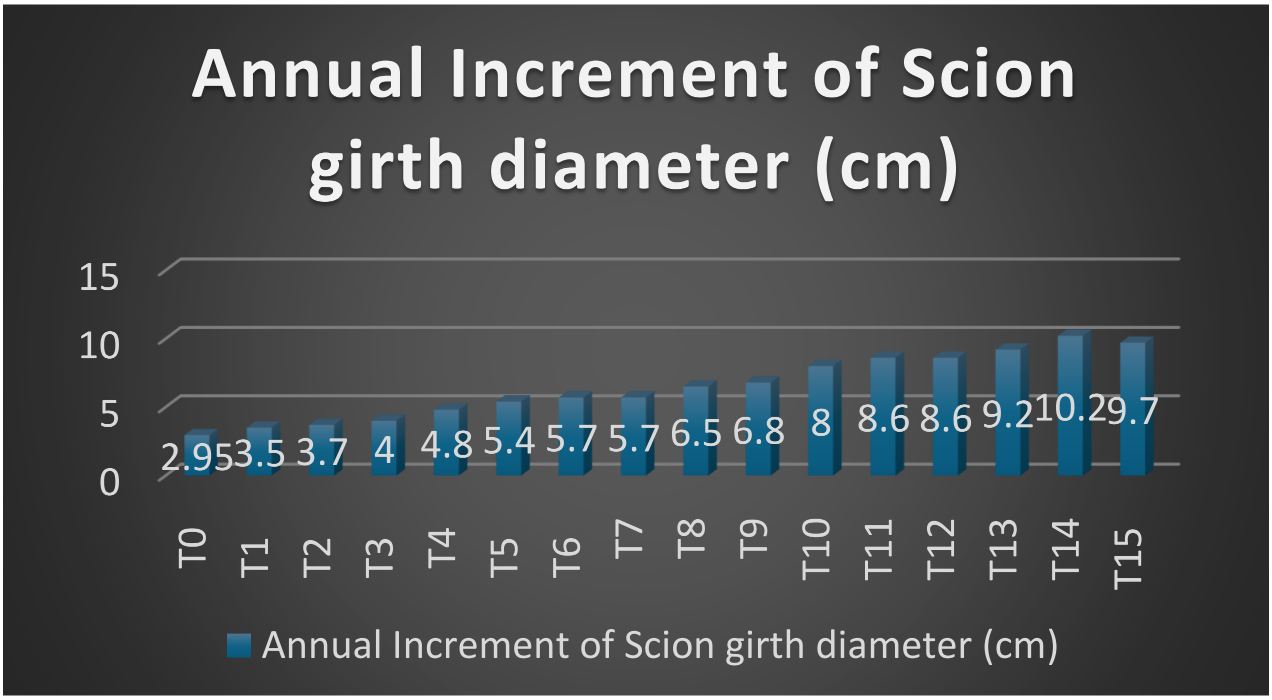
Results and Discussion

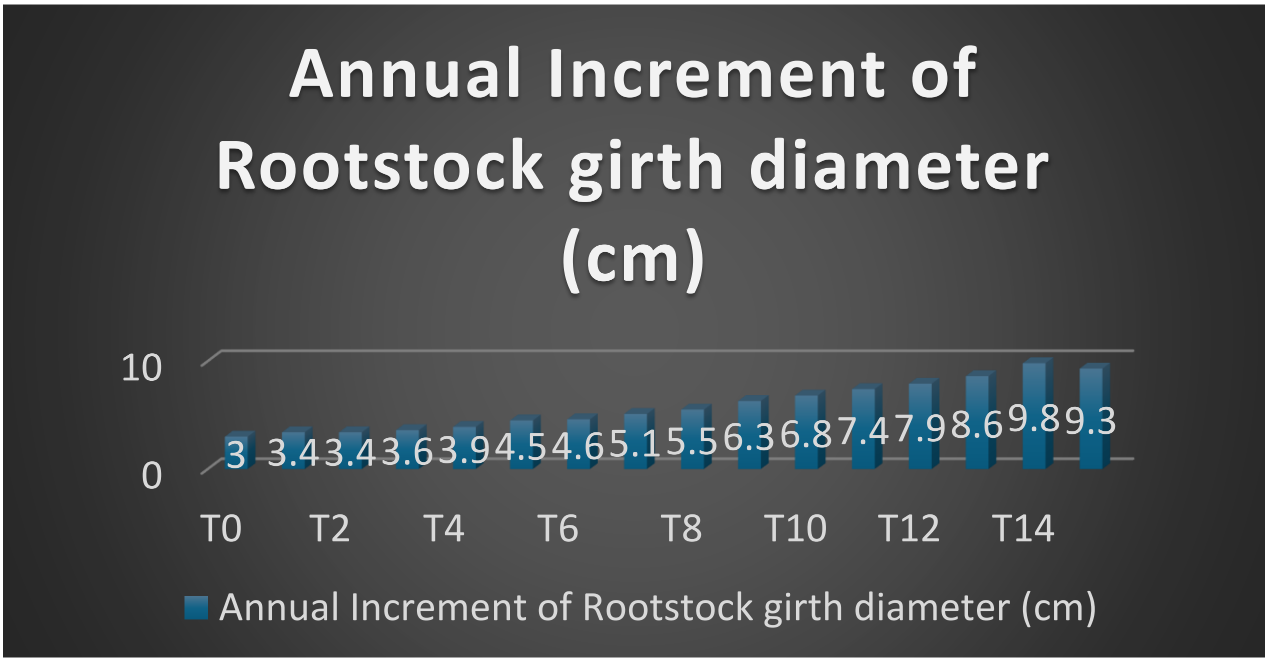
Scion and Rootstock Girth (cm): The Daisy mandarin trees treated with T14 (0.3% $MnSO_4$ + 0.2% $FeSO_4$) exhibited maximum scion girth (10.20 cm) and rootstock girth (9.8 cm), compared to the control (T0) at 2.95 cm and 3.0 cm, respectively. Higher concentrations of $MnSO_4$ and $FeSO_4$ increased girth, with T13 and T15 showing similar results, highlighting the role of balanced nutrients in enhancing tree growth and vigor.

Table 4.1. Effect of different treatments and their combinations on the Scion girth and Rootstock girth

Treatments	Annual Increment of Scion girth diameter (cm)	Annual Increment of Rootstock girth diameter (cm)
T0 Control	2.95	3.00
T1 (0.10% Manganese sulphate)	3.50	3.40
T2 (0.20% Manganese sulphate)	3.70	3.40
T3 (0.30% Manganese sulphate)	4.00	3.60
T4 (0.10% Ferrous sulphate)	4.80	3.90
T5 (0.20% Ferrous sulphate)	5.40	4.50
T6 (0.30% Ferrous sulphate)	5.70	4.60
T7 (0.1% Manganese sulphate + 0.1% Ferrous sulphate)	5.70	5.10
T8 (0.1% Manganese sulphate + 0.2% Ferrous sulphate)	6.50	5.50
T9 (0.1% Manganese sulphate + 0.3% Ferrous sulphate)	6.80	6.30
T10 (0.2% Manganese sulphate + 0.1% Ferrous sulphate)	8.00	6.80
T11 (0.2% Manganese sulphate+ 0.2% Ferrous sulphate)	8.60	7.40
T12 (0.2% Manganese sulphate + 0.3% Ferrous sulphate)	8.60	7.90

T13 (0.3% Manganese sulphate + 0.1% Ferrous sulphate)	9.20	8.60
T14 (0.3% Manganese sulphate +0.2% Ferrous sulphate)	10.20	9.80
T15 (0.3% Manganese sulphate +0.3% Ferrous sulphate)	9.70	9.30
C.D. at 5%	3.351	2.61

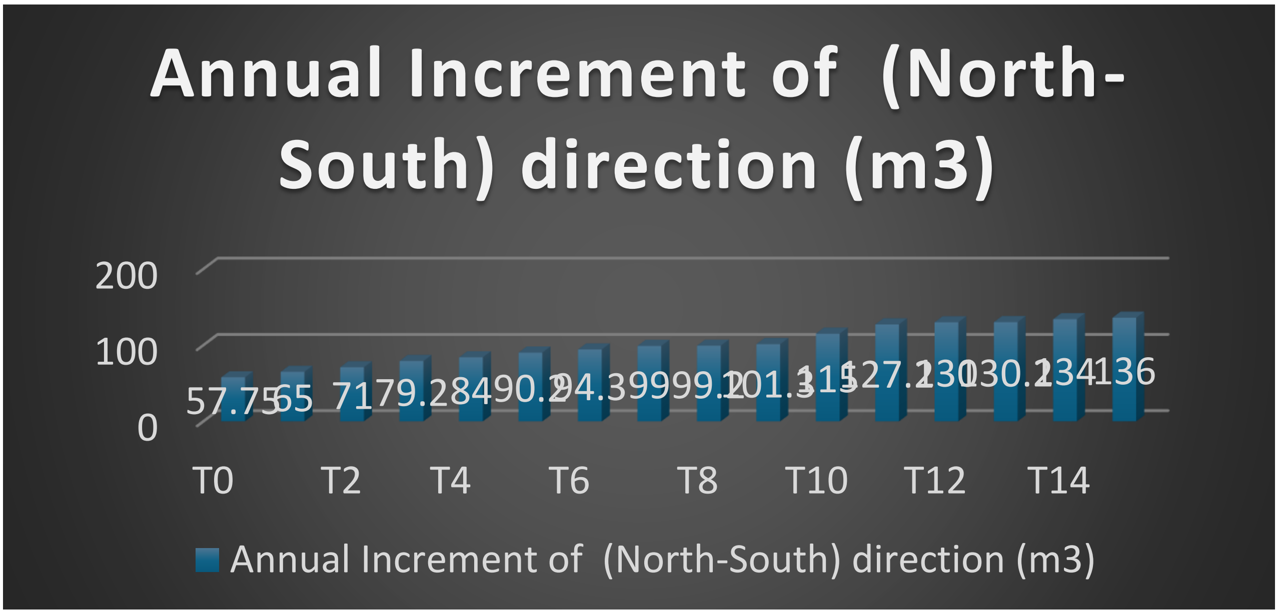


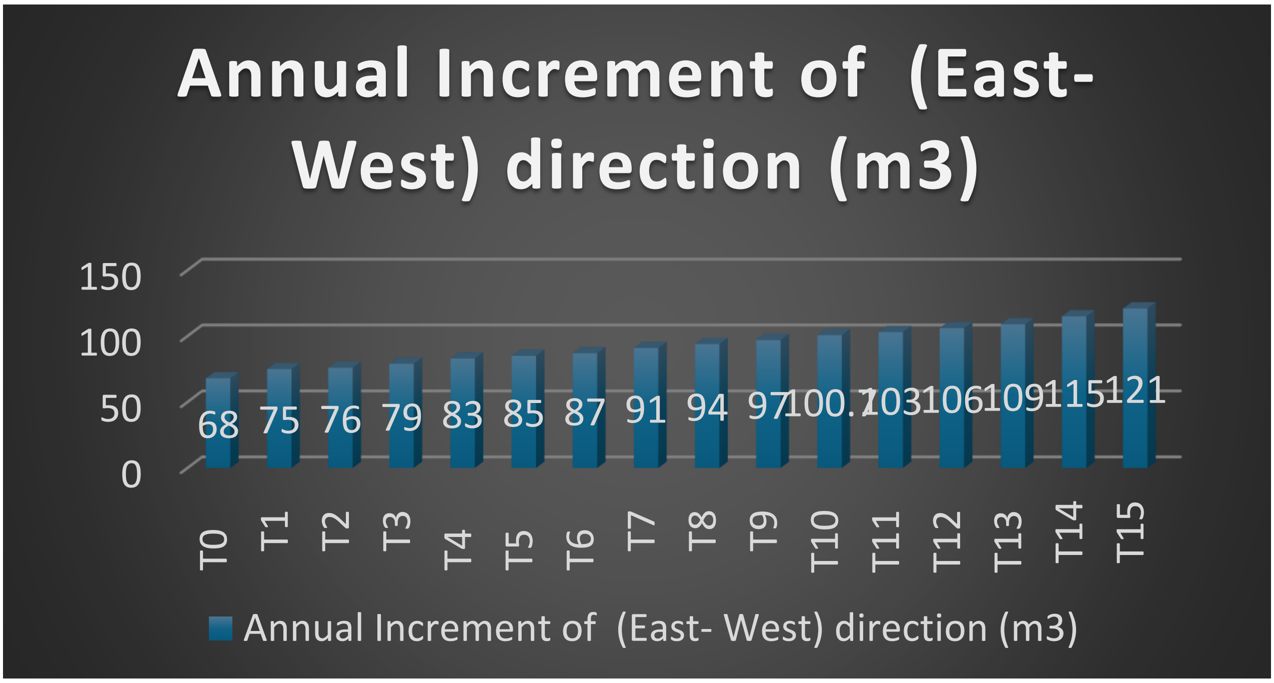


Tree Canopy Volume (m^3): Foliar application of 0.3% $MnSO_4$ + 0.3% $FeSO_4$ (T15) maximized Daisy mandarin canopy volume at 136.0 m^3 (N-S) and 121.0 m^3 (E-W), with T14, T13, and T12 showing comparable results, while the control (T0) recorded the lowest at 57.75 m^3 and 68.0 m^3. Combined Mn and Fe treatments outperformed individual applications, significantly enhancing canopy growth.

4.2. Table 2. Effect of different treatments and their combinations on the Tree canopy (North-South) and (East-West)

Treatments	Annual Increment of (North-South) direction (m^3)	Annual Increment of (East-West) direction (m^3)
T0 Control	57.75	68.00
T1 (0.1% Manganese sulphate)	65.00	75.00
T2 (0.2% Manganese sulphate)	71.00	76.00
T3 (0.3% Manganese sulphate)	79.20	79.00
T4 (0.1% Ferrous sulphate)	84.00	83.00
T5 (0.2% Ferrous sulphate)	90.20	85.00
T6 (0.3% Ferrous sulphate)	94.30	87.00
T7 (0.1% Manganese sulphate + 0.1% Ferrous sulphate)	99.00	91.00
T8 (0.1% Manganese sulphate + 0.2% Ferrous sulphate)	99.20	94.00
T9 (0.1% Manganese sulphate + 0.3% Ferrous sulphate)	101.30	97.00
T10 (0.2% Manganese sulphate + 0.1% Ferrous sulphate)	115.00	100.70
T11 (0.2% Manganese sulphate+ 0.2% Ferrous sulphate)	127.20	103.00
T12 (0.2% Manganese sulphate + 0.3% Ferrous sulphate)	130.00	106.00
T13 (0.3% Manganese sulphate + 0.1% Ferrous sulphate)	130.20	109.00
T14 (0.3% Manganese sulphate +0.2% Ferrous sulphate)	134.00	115.00
T15 (0.3% Manganese sulphate +0.3% Ferrous sulphate)	136.00	121.00
C.D. at 5%	13.107	4.857





This study highlights the significant impact of foliar manganese (Mn) and iron (Fe) applications on the vegetative growth of Daisy mandarin (Citrus reticulata) trees in subtropical conditions. Treatment T_{14} (0.3% $MnSO_4$ + 0.2% $FeSO_4$) markedly increased scion and rootstock girth to 10.20 cm and 9.8 cm, respectively, supporting Sidhu's (1988) findings on the importance of balanced nutrient supply for tree vigor. The enhanced girth likely results from Mn's role in enzymatic processes and Fe's contribution to chlorophyll synthesis, which boosts photosynthesis and carbohydrate allocation for structural growth (Mongi Zekri et al., 2024; Obreza et al., 2024). This synergy fosters robust stem development, improving nutrient and water transport critical for tree health.

Treatment T_{15} (0.3% $MnSO_4$ + 0.3% $FeSO_4$) yielded the largest canopy volume at 136.0 m^3 (north-south) and 121.0 m^3 (east-west), indicating enhanced photosynthetic efficiency due to Mn's support for photosystem II and Fe's role in electron transport (Dhillon et al., 2023–24). Treatments T_{14}, T_{13}, and T_{12} showed similar canopy expansion, suggesting that higher Mn and Fe combinations outperform individual applications. Conversely, the control (T_0) exhibited minimal growth, with scion and rootstock girth at 2.95 cm and 3.0 cm, and canopy volumes of 57.75 m^3 and 68.0 m^3, reflecting soil micronutrient deficiencies (pH 7.86, loamy texture) that limited development (Obreza et al., 2024). These results advocate for targeted Mn and Fe foliar applications to optimize Daisy mandarin growth and orchard productivity in subtropical regions.

Conclusion

Foliar applications of manganese (Mn) and iron (Fe) significantly enhanced Daisy mandarin tree growth, with T_{14} (0.3% $MnSO_4$ + 0.2% $FeSO_4$) increasing scion and rootstock girth to 10.20 cm and 9.8 cm, and T_{15} (0.3% $MnSO_4$ + 0.3% $FeSO_4$) maximizing canopy volume at 136.0 m^3 (N-S) and 121.0 m^3 (E-W). These improvements, driven by Mn's enzymatic activation and Fe's role in chlorophyll synthesis, outperformed the control (T_0), which showed limited growth due to soil micronutrient deficiencies, highlighting the efficacy of combined Mn and Fe sprays for optimizing tree vigor in subtropical conditions.

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