Plant Archives Vol. 26, Supplement 1, 2026 pp. 111-116 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.supplement-1.016

INTEGRATED NUTRIENT MANAGEMENT: A SUSTAINABLE APPROACH TO IMPROVE GROWTH AND QUALITY OF SWEET ORANGE CV. SATHGUDI

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(Date of Receiving : 10-08-2025; Date of Acceptance : 20-10-2025)

ABSTRACT

The present study evaluated the impact of Integrated Nutrient Management (INM) on the growth performance and fruit quality of sweet orange (*Citrus sinensis* cv. Sathgudi) during the Hasta Bahar season of 2024–25 at the Main Horticultural Research and Extension Centre (MHREC), Bagalkot. The experiment was conducted using a Randomized Complete Block Design (RCBD) comprising seven treatment combinations on four-year-old trees. The treatments consisted of varying proportions of the recommended fertilizer dose (RDF) integrated with organic manures, biofertilizers and micronutrient spray. Results revealed that INM practices significantly enhanced vegetative growth, flowering, yield and fruit quality compared to the application of RDF alone. Among the treatments, the combination of 100% RDF (400:180:270 g NPK/plant) along with 50% organic supplementation (comprising 25% vermicompost + 25% neem cake + VAM + KSB + PSB) exhibited the best performance. This treatment recorded the highest plant height (3.21 m), canopy volume (4.77 m^3), leaf area (35.13 cm^2), fruit set (67.14%), fruit yield (58.54 kg/plant or 23.42 t/ha), total soluble solids (13.14 °Brix) and shelf life (34.14 days), along with reduced acidity (0.63%).
***Keywords* :** Sweet orange, Sathgudi, Integrated nutrient management, growth, quality

Introduction

Citrus is one of the important fruit crops worldwide, belonging to the family Rutaceae. The major commercial species of the genus Citrus include sweet orange, mandarin, lemon, lime, grapefruit and pummelo. Among these, sweet orange (*Citrus sinensis* L. Osbeck) occupies a significant place due to its pleasant flavour, attractive colour, refreshing aroma and high nutritional as well as medicinal value. Citrus fruits are rich sources of fibre, vitamin C, B-complex vitamins and various phytochemicals. Regular consumption of citrus fruits helps in lowering the risk of several chronic diseases such as cancer, cardiovascular disorders, anaemia and cataracts. They are consumed both fresh and in processed forms such as juices, marmalades, squashes, syrups and cordials. Additionally, citrus peel contains essential oils that are extensively used in the food flavouring and baking industries.

India ranks third in global citrus production after China and Brazil, contributing around 7–8% to the world's output. During 2022–23, sweet orange was cultivated over 2.26 lakh hectares, producing about 37.20 lakh tonnes, with Andhra Pradesh being the leading producer, followed by Maharashtra, Telangana and Karnataka (PJTSAU, 2023). Among the different cultivars, Sathgudi holds prime commercial importance in South India owing to its adaptability, high yield potential and consumer preference (Mounika, 2021).

Sweet orange, though adaptable to various agro-climatic conditions, relies heavily on proper nutrient supply and soil fertility to sustain yield and fruit quality. Overuse of chemical fertilizers can harm soil health and reduce fruit quality, making balanced nutrient management essential. Integrated Nutrient Management (INM), which combines chemical fertilizers with organic manures, biofertilizers and micronutrients such as zinc, iron, boron and copper, improves soil fertility, nutrient uptake, yield and fruit quality. Therefore, INM is crucial for sustaining soil health and enhancing the productivity of Sathgudi sweet orange, particularly during the Hasta Bahar season.

Material and Methods

The present study was conducted during the Hasta Bahar season of 2024–25 at the Main Horticultural Research and Extension Centre (MHREC), University of Horticultural Sciences, Bagalkot, Karnataka, using a four-year-old sweet orange orchard with trees spaced at 5 m × 5 m. The experiment included 105 trees arranged in a Randomized Complete Block Design (RCBD) with seven treatments, each replicated three times. The treatments were: T_1–100% RDF (400:180:270 g NPK/plant), T_2 – 125% RDF (500:225:337.5 g NPK/plant), T_3 – 150% RDF (600:270:405 g NPK/plant), T_4 – 50% RDF + 50% organic [25% vermicompost (3.3 kg/plant) + 25% neem cake (2 kg/plant)] + VAM (50 g/plant) + KSB (20 g/plant) + PSB (20 g/plant), T_5 – 75% RDF + 50% organic + VAM (50 g/plant) + KSB (20 g/plant) + PSB (20 g/plant), T_6 – 100% RDF + 50% organic + VAM (50 g/plant) + KSB (20 g/plant) + PSB (20 g/plant) and T_7 – 100% RDF entirely through organic manures (50% vermicompost + 50% neem cake) + VAM (50 g/plant) + KSB (20 g/plant) + PSB (20 g/plant). Organic manures and biofertilizers were applied at the initiation of Hasta Bahar, with biofertilizers mixed into farmyard manure 15 days prior and kept under shade. Micronutrients were applied as foliar sprays at pre-flowering, flowering and fruit development stages, alongside basal NPK doses. Inorganic fertilizers were applied in three splits during growth stages in the ratio of 3:2:1 (pre-flowering), 1:3:2 (flowering) and 2:1:3 (fruit development) for NPK, respectively.

Growth parameters, including plant height, canopy volume, plant spread, leaf area and chlorophyll content, were recorded. Plant height and canopy volume were measured using a measuring tape and a long stick. Leaf area was determined using the linear (LBK) method by randomly selecting ten leaves per plant, calculating their average and applying the formula.

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

where L represents the maximum leaf length, B is the maximum leaf breadth and K is a correction factor.

Chlorophyll content in fully mature leaves was measured with a SPAD-502 chlorophyll meter. Yield-related traits, fruit set (%) and fruit yield per tree, were recorded. For biochemical analysis, five healthy fruits per tree at full maturity were randomly collected. Total soluble solids (TSS) were measured using a hand refractometer, while titratable acidity, ascorbic acid content and pH were estimated following standard procedures (Ranganna, 1986). Shelf life was determined by noting the number of days the fruits remained in acceptable condition under ambient storage.

Result and Discussion

The INM modules had a significant impact on the growth parameters the maximum plant height (3.21 m), Canopy volume (4.77 m^3), leaf area (35.13 cm^2) and chlorophyll content (43.46 SPAD values) were recorded in T_6 (Table 1).

Integrated nutrient management (INM) significantly enhanced both plant height and canopy volume compared to the sole application of chemical fertilizers. The improvement may be attributed to the synergistic effect of organic manures, inorganic fertilizers and biofertilizers, which ensured balanced nutrient supply, improved soil health and enhanced microbial activity. Organic amendments such as vermicompost and neem cake promoted root growth and nutrient uptake, leading to greater cell elongation and canopy expansion. The increase in canopy volume reflects improved photosynthetic efficiency and nutrient utilization due to a well-developed foliage structure. Similar findings were reported by Dudi *et al.* (2003), Kaul and Bhatnagar (2006) and Tarai and Ghosh (2016) in citrus, confirming that integrated nutrient sources effectively improve vegetative growth and overall plant vigour in sweet orange.

In sweet orange, treatment T_6, which combined inorganic fertilizers, organic manures, and biofertilizers, recorded the highest leaf area and chlorophyll content. The improvement in leaf area can be attributed to the synergistic effects of balanced nutrient supply, enhanced soil physical and biological properties and increased microbial activity from organic and biofertilizers (Kumar *et al.*, 2017). Organic manures such as vermicompost improve soil moisture retention and nutrient availability, promoting vegetative growth and leaf expansion (Mounika, 2021).

Larger leaf area increases photosynthetic surface area, resulting in higher light interception, CO_2 assimilation and carbohydrate accumulation. Nitrogen, abundantly available in T_6, stimulates protein synthesis and chlorophyll formation, which are essential for photosynthetic efficiency (Lovatt *et al.,* 1988). The enhanced chlorophyll content also reflects improved nitrogen uptake, better root growth and higher synthesis of growth regulators like IAA, GA_3 and cytokinin, supporting leaf development. Magnesium, supplied through organic amendments, forms the central atom of chlorophyll, further enhancing photosynthetic efficiency.

These results are consistent with previous studies reporting improved leaf area and chlorophyll content in sweet orange under integrated nutrient management practices (Kumar *et al*., 2017). Overall, the combination of organic, inorganic and biofertilizers in T_6 promoted leaf expansion and chlorophyll accumulation, which directly contributed to better plant growth and productivity.

The highest fruit set (67.14%) and fruit yield (58.54 kg/plant and 23.42 t/ha) were recorded in treatment T_6, whereas the lowest values for fruit set percentage and fruit yield were observed in treatment T_1, as presented in Table 2.

The significant improvement in yield parameters under integrated nutrient management (INM) in sweet orange can be attributed to enhanced vegetative growth, higher chlorophyll content and increased photosynthetic activity, which supplied more assimilates to developing fruits. INM, combining inorganic fertilizers, organic manures and biofertilizers, promoted tree vigour, leaf area and canopy volume, thereby supporting better flowering, fruit set and retention (Ramana *et al.* 2014). Vermicompost improved soil structure, microbial activity and nutrient availability, while biofertilizers enhanced nitrogen fixation, phosphate solubilization and root development (Vadak *et al*., 2014). The continuous nutrient supply from organic and inorganic sources strengthened the source–sink relationship, leading to higher floral initiation and fruit development. Micronutrients like boron and zinc, supplied through foliar sprays and organic amendments, further enhanced reproductive growth and fertilization (Shilewant *et al*. 2023). These results align with previous findings in sweet orange by Pawar *et al*. (2016), and Bhattacharjee and Patel (2023), who reported improved vegetative growth, flowering and yield under INM practices.

The influence of INM on total soluble solids (TSS), titratable acidity, fruit pH and TSS-to-acid ratio in sweet orange is presented in Table 3. A significant variation was observed among treatments, with T_6 recording the highest TSS (13.14 °Brix), lowest acidity (0.63%) and maximum TSS to acid ratio (20.86), while T_1 showed the lowest TSS (11.86 °Brix), highest acidity (0.76%) and minimum TSS to acid ratio (15.61). The superior TSS observed in treatment T6 may be attributed to the combined application of the highest dose of nitrogen through inorganic and organic sources such as vermicompost and neem cake, integrated with biofertilizers and micronutrient sprays during the fruit development stage. This synergistic approach likely enhanced the synthesis and translocation of organic acids within the fruits, resulting in improved TSS accumulation (Kumar *et al*., 2017).

The increase in TSS was further supported by improved photosynthetic efficiency, carbohydrate accumulation, sugar translocation to fruits and metabolic activity, aided by micronutrient sprays containing zinc (enzyme activity and carbohydrate formation), boron (sugar transport) and manganese (photosynthesis). The lowest acidity in T_6 corresponded with the hydrolysis of starch and utilization of organic acids during fruit ripening, while balanced nutrient supply contributed to a favourable sugar–acid ratio (Marathe & Bharambe, 2007).

The highest TSS-to-acid ratio under T_6 reflects enhanced sugar accumulation, efficient assimilate partitioning and delayed acid degradation, highlighting the effectiveness of INM in improving fruit biochemical quality (Dalal *et al.,* 2009). These results are in agreement with previous studies in sweet orange and other citrus crops (Dutta *et al*., 2003, Maity *et al*., 2006, Savreet, 2014).

INM also significantly improved fruit shelf life, with T_6 showing the maximum duration (24.14 days) and T_1 the minimum (19.56 days) (Table 3). The extension in shelf life is linked to improved physiological and biochemical attributes, including higher fruit firmness, better water retention and enhanced turgor, which reduce shrivelling and postharvest losses Rajendra *et al*., 2013. Biofertilizers and neem cake contributed to nutrient enrichment and structural integrity through calcium supply, while organics and biofertilizers promoted antioxidant and phenolic compound accumulation, delaying oxidative damage and senescence. These findings align with reports in sweet orange and other citrus crops (Zamin *et al*., 2012, Bhandari *et al*., 2018, Li *et al.,* 2025, Pant, 2021, Zoremtluangi *et al*., 2019).

Conclusion

The study revealed that the combined application of organic, inorganic, and micronutrient sprays at three different growth stages significantly influenced the growth and quality traits of sweet orange cv. Sathgudi.

Among all treatments, the most effective results were observed with 100% RDF (400:180:270) supplemented with 50% organic sources [25% vermicompost (3.3 kg/plant) + 25% neem cake (2 kg/plant)], along with VAM (50 g/plant), KSB (20 g/plant), PSB (20 g/plant), and foliar sprays of micronutrients applied at three growth stages.

Acknowledgement

The authors sincerely acknowledge the Department of Fruit Science and the Main Horticultural Research and Extension Centre (MHREC), University of Horticultural Sciences, Bagalkot, for their invaluable support and for providing the necessary facilities and resources to conduct this experiment.

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

Treatment	Plant height (m)	Canopy volume (m^3)	Leaf area (cm^2)	Chlorophyll (SPAD values)
T_1	2.68	2.49	27.54	35.18
T_2	2.95	3.50	30.13	39.54
T_3	3.14	3.88	31.47	40.64
T_4	2.89	2.92	29.87	36.90
T_5	3.20	3.90	33.95	41.42
T_6	3.21	4.77	35.13	43.76
T_7	2.8	2.81	29.37	35.19
S. Em±	**0.04**	**0.05**	**0.53**	**0.74**
CD at 5 %	**0.13**	**0.15**	**1.64**	**2.24**

T_1 : 100 % RDF (400:180:270 g NPK/plant) (UHS, Bagalkot POP)
T_2 : 125 % RDF (500:225:337.5 g NPK/plant)
T_3 : 150 % RDF (600:270:405 g NPK/plant)
T_4 : 50 % RDF (200:90:135 g NPK/plant) + 50 % through organic [25 % through Vermicompost (3.3 kg/plant) + 25 % through neem cake (2 kg/plant)]+ VAM (50 g/plant) + KSB (20 g/ plant) + PSB (20 g/plant)
T_5 : 75 % RDF (300:135:202) + 50 % through organic [25 % Vermicompost 3.3kg/plant) + 25 % neem cake (2kg/plant)] + VAM (50g/plant) + KSB (20 g/ plants) + PSB (20 g/plant)
T_6 : 100 % RDF (400:180:270) + 50 % through organic [25 % Vermicompost (3.3 kg/plant) + 25 % neem cake (2 kg/plant)] + VAM (50g/plant) + KSB (20 g/ plant) + PSB (20 g/plant)
T_7 : 100 % RDF through organic (50 % Vermicompost + 50 % neem cake) + VAM (50g/plant) + KSB (20 g/ plant) + PSB (20 g/plant)

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

Treatment	Fruit set (%)	Fruit yield	
		Kg/plant	t/ha
T_1	46.89	37.37	14.95
T_2	57.45	47.01	18.80
T_3	60.21	54.40	21.76
T_4	53.52	42.92	17.17
T_5	65.28	57.81	23.12
T_6	67.14	58.54	23.42
T_7	48.31	41.05	16.42
S. Em±	**0.76**	**0.88**	**0.23**
CD at 5 %	**2.35**	**2.71**	**0.69**

T_1 : 100 % RDF (400:180:270 g NPK/plant) (UHS, Bagalkot POP)
T_2 : 125 % RDF (500:225:337.5 g NPK/plant)
T_3 : 150 % RDF (600:270:405 g NPK/plant)
T_4 : 50 % RDF (200:90:135 g NPK/plant) + 50 % through organic [25 % through Vermicompost (3.3 kg/plant) + 25 % through neem cake (2 kg/plant)]+ VAM (50 g/plant) + KSB (20 g/ plant) + PSB (20 g/plant)
T_5 : 75 % RDF (300:135:202) + 50 % through organic [25 % Vermicompost 3.3kg/plant) + 25 % neem cake (2kg/plant)] + VAM (50g/plant) + KSB (20 g/ plants) + PSB (20 g/plant)
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T_7 : 100 % RDF through organic (50 % Vermicompost + 50 % neem cake) + VAM (50g/plant) + KSB (20 g/ plant) + PSB (20 g/plant)

Table 3: Total soluble solids, titratable acidity, TSS to acid ratio and shelf life as influenced by INM module in sweet orange cv. Sathgudi

Treatment	TSS (°Brix)	Titratable acidity (%)	TSS to acid ratio	Shelf life (days)
T_1	11.86	0.76	15.61	19.56
T_2	12.21	0.75	16.28	22.62
T_3	12.74	0.69	18.46	23.26
T_4	12.45	0.75	16.60	20.93
T_5	13.02	0.64	20.34	23.83
T_6	13.14	0.63	20.86	24.14
T_7	12.58	0.72	17.47	22.71
S. Em±	**0.19**	**0.01**	**0.29**	**0.36**
CD at 5 %	**0.60**	**0.04**	**0.90**	**1.10**

T_1 : 100 % RDF (400:180:270 g NPK/plant) (UHS, Bagalkot POP)
T_2 : 125 % RDF (500:225:337.5 g NPK/plant)
T_3 : 150 % RDF (600:270:405 g NPK/plant)
T_4 : 50 % RDF (200:90:135 g NPK/plant) + 50 % through organic [25 % through Vermicompost (3.3 kg/plant) + 25 % through neem cake (2 kg/plant)]+ VAM (50 g/plant) + KSB (20 g/ plant) + PSB (20 g/plant)
T_5 : 75 % RDF (300:135:202) + 50 % through organic [25 % Vermicompost 3.3kg/plant) + 25 % neem cake (2kg/plant)] + VAM (50g/plant) + KSB (20 g/ plants) + PSB (20 g/plant)
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T_7 : 100 % RDF through organic (50 % Vermicompost + 50 % neem cake) + VAM (50g/plant) + KSB (20 g/ plant) + PSB (20 g/plant)

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