Annals of Plant and Soil Research 27(1): 24-31 (2025)
https://doi.org/10.47815/apsr.2025.10432

Integrated nutrient management of Nagpur mandarin: Leaf nutrient composition-mediated fruit yield response

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Received: January, 2025; Revised accepted: Febuary, 2025

ABSTRACT

Balanced fertilization via integrated nutrient management (INM) is one of the holistic plant nutrient supply systems for ensured yield and fruit quality of citrus fruits amid occurrence of multiple nutrients constraints. A one-year field experiment (2022-2023) was conducted at the Regional Fruit Research Station, Dr PDKV Nagpur to investigate the effects of INM on leaf nutrient content and fruit yield of 11-year-old Nagpur mandarin orchard. The results showed that INM associated improvements in leaf nutrients composition that significantly improved fruit yield compared to exclusive use of chemical fertilizers. The maximum fruit yield was achieved with the application of 100% NPK + FYM @ 50 kg tree^{-1} + Biofertilizers + S + Zn + Fe + B compared to rest of the other NM-based treatments including chemical fertilizers. These responses on fruit yield were mediated through increase in leaf macronutrients (N, P, K and S) and micronutrients (Zn, Fe and B) concentration, significantly higher than simple recommended doses of fertilizers (RDF) alone. The present study aided in developing an INM strategy using three divergent nutrient sources viz., inorganic chemical fertilizers, organic manures and biofertilizers , thereby providing valuable insights about sustainable citrus production through INM strategy.

Key Words: *Nagpur mandarin, Fruit yield, Leaf nutrients, INM, Black soil* and *Central India*

INTRODUCTION

Nagpur mandarin (*Citrus reticulata* Blanco) is an important citrus crop grown in India, cultivated on 310.42 lakh ha. (12.4% of the total area under fruit crops), with an annual production of 100.9 lakh tonnes and an average productivity of 9.7 t ha^{-1} (Srivastav aand Singh , 2008) . In Maharashtra, the area is 1.48 lakh ha (the bearing area is 86,200 ha), with a production of 8.75 lakh tonnes. The average productivity is 10-14 t ha^{-1}, which is low, compared to other citrus cultivars (Shirgure *et al.,* 2012; Srivastava, 2023a). In the Vidarbha region of Maharashtra, Nagpur mandarin is grown over a 1, 46,040 ha area with a production of 5, 97,758 million tonnes (Anonymous, 2018). Imbalanced plant nutrition is one of the triggering factors responsible for citrus decline (Srivastava, 2023b) followed unprecedented reduction in productive life of orchards (Srivastava, 2024). Citrus crops are relatively nutrient-demanding and highly responsive to applied nutrients in the form of fertilizers (Srivastava and Malhotra, 2017) a critical input, involved in plant metabolism and growth and in different biochemical processes (Asthir *et al.,* 2017). Enhanced yields with improved fruit quality are commonly obtained with the application of proper and adequate fertilizers (Srivastava *et al.,* 2019). The deficiency or excess of any nutrient can lead to a reduction in crop yield coupled with inferior fruit quality; thus, judicious application of fertilizers including macronutrients (Srivastava *et al.,* 2017), micronutrients and organic sources (Srivastava *et al.,* 2019), is essential for increasing the productivity as well as quality of mandarin (Srivastava *et al.,* 2017). On the other hand , foliar application of mineral nutrients is a method for quick supply of the elements for higher plants (Srivastav and Singh , 2003) due to nutrients being consumed much faster , thereby their uptake from the soil by their roots (Srivastav and Malhotra, 2014) . Despite some shortcomings, it is regarded as the best method under certain conditions (Marschner and Marschner, 2011). The micronutrients are required in small amounts but play a great role in plant metabolism (Katyal and Datta, 2004; Kazi *et al.,* 2012). The knowledge of the precise macronutrients and

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micronutrients requirements of different citrus cultivars is a prerequisite for improved fertilizer use efficiency and avoiding the unnecessary use of excess fertilizers (Srivastava and Mousavi, 2024). For proper nutrient management, plant leaf analysis plays an important role in assessing the nutritional needs of trees (Srivastava and Hota, 2020). It was observed that nutrients applied without organic matter were less effective in improving citrus fruit production even at higher doses and more effective when applied with organic matter. Hence the concept of integrated nutrient management comes into play, which places emphasis on continuous improvement in soil productivity on a long-term basis through the appropriate use of fertilizers, bio-fertilizers and green manures and their scientific management for optimum growth, yield and quality of crop in a specific agro-ecological situation (Bora *et al.,* 2013 Srivastava *et al.,* 2015).

Integrated nutrient management (INM) with emphasis on the use of bio-organics is a comparatively recent concept which needs to be vigorously pursued to achieve the sustainability in citrus production trend spaced over the years. Additionally crop nutrition, therefore, must respect the prescriptions of INM (Srivastava and Ngullie, 2009). The merits of INM based practices also takes into account the mobilization of unavailable nutrients could also be effected by speeding up the rate of mineralization of various organic substrates. This practice seeks to mitigate reliance on chemical fertilizers, promoting cost-effectiveness (Bodkhe, 2017). Continuous and imbalanced fertilizer use poses a threat to soil quality and yield sustainability. Thus, emphasizing adequate fertilization, regular nutrient application and alternative nutrient use enriched with organic manures and biofertilizers becomes crucial in ensuring quality citrus production (Srivastava and Singh, 2009). Hence, keeping all these point in view, the present investigation is planned to study the suitable combination of organic, inorganic manures and biofertilizers for obtaining higher yield and improved leaf nutrition status in Nagpur mandarin.

MATERIALS AND METHODS

Experimental details

The field experiment was carried out using a 11-year-old Nagpur mandarin orchard in Ambiabahar at the Regional Fruit Research Station, Katol, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, during the year, 2022–23. The experiment was laid out in a Randomized Block Design comprising thirteen treatments, each replicated three times. The treatments comprised of : T_1- Only FYM @ 50 kg tree^{-1} + Biofertilizers, T_2- 100% Recommended dose of NPK, T_3-100% Recommended dose of N only + FYM @ 50 kg tree^{-1} + Biofertilizers, T_4-100% Recommended dose of N and P + FYM @ 50 kg tree^{-1} + Biofertilizers, T_5- 100% NPK+ FYM @ 50 kg tree^{-1} + Biofertilizers, T_6- 100% NPK+ FYM @ 50 kg tree^{-1} + Biofertilizers + S, T_7-100% NPK+ FYM @ 50 kg tree^{-1} + Biofertilizers + S + Zn, T_8- 100% NPK + FYM @ 50 kg tree^{-1} + Biofertilizers + S + Zn + Fe, T_9- 100% NPK + FYM @ 50 kg tree^{-1} + Biofertilizers + S + Zn + Fe + B. The N, P, K and S were applied in the form of urea, DAP, muriate of potash (MOP) and elemental sulphur, respectively. In sulphur-free treatments, DAP was used instead of SSP to avoid the addition of sulphur. The calculated doses of these fertilizers (N 800g, P_2O_5 300g, K_2O 600g and S 100g as recommended doses) were applied at the time of bahar treatment with a spray of B @ 0.10%. The entire dose of P, K and S were given in the month of January; while nitrogen was given in two split doses, half with all fertilizers and the remaining half when fruits were of pea size. Biofertilizers consisting of 500g VAM (*Glomus mosseae*) + 100g PSB (*Bacillus megaterium*) + 100g *Azospirillum* (*Azospirillum lipoferum*) + 100g *Trichoderma* (*Trichoderma viride*) tree^{-1} were mixed with FYM @ 50 kg tree^{-1} and applied 15 days prior to fertilizer treatments. It was thoroughly mixed with the soil by hand-operating implements and covered with soil, ensuring good moisture. Micronutrients viz., Zn @ 0.5%, Fe @ 0.5% and B @ 0.10% were given as two foliar sprays, each in the month of July, August and September. Inorganic nutrients (organic, inorganic and biofertilizers) were applied in a ring that covered an area of 90 cm away from the periphery of the tree trunk.

Leaf sampling and analysis

Leaf samples were collected from 6-7 month-old Ambia flush at the start of the investigation in October 2020. About 40–50 middle leaf samples from the 2nd, 3rd or 4th leaf from non-fruiting terminals facing all four directions were collected at a height of 1.5–1.8 m from the ground (Srivastava and Kohli, 1997). Further, leaf samples were also collected from each treatment at the fruit development stage of the crop. The leaf samples were washed first with distilled water, then with 0.1 N 1 ml HCl in 1 liter of water. Then washings of distilled water were given to the leaf sample (Chapman, 1964). The extra moisture was wiped out; the samples were placed in a paper bag and dried in an oven at 70 °C. Treatment-wise, plant samples were finely ground in a grinding machine to obtain homogeneous samples.

Nitrogen was estimated through the micro-Kjeldhal method and total N was calculated using the expression given by (Piper, 1966). The leaf samples were digested with a di-acid (HNO_3: $HClO_4$) mixture. In this digest, total phosphorus was estimated by the Vanadomolybdo phosphoric acid yellow color method with a spectrophotometer as given by Jackson (1973), potassium was determined by a flame photometer as described by Jackson (1973), total sulphur using was determined with a double beam spectrophotometer by the turbidimetric method as described by Chesnin and Yein (1951). The estimation of micronutrients (Zn, Fe, Cu and Mn) was done through an atomic absorption spectrophotometer (Issac and Kerber, 1971). Total Boron was determined by the calorimetry method (Azomethine-H), as described by John *et al.* (1975).

Fruit sampling and analysis

Harvesting was carried out at once. Yield in respects of number of fruit per tree, weight of fruit (kg tree^{-1}) and yield (kg ha^{-1}) was recorded.

RESULT AND DISCUSSION

Changes in leaf nutrients composition

The effect of various treatments on leaf nutrients composition (Table 1 and 2) was observed significantly influenced. The highest total nitrogen (2.61%), as observed with the treatment carrying 100% NPK + FYM @ 50 kg tree^{-1} + Biofertilizers + S + Zn + Fe + B (T_9) . While, the highest leaf phosphorus (0.19%) and leaf potassium (1.62%) content were observed with the treatments involving 100% NPK + FYM @ 50 kg tree^{-1} + Biofertilizers + S + Zn (T_8) (0.19%) and 100% NPK + FYM @ 50 kg tree^{-1} + Biofertilizers + S + Zn + Fe + B (T_9) , respectively, along with highest sulphur content (0.21%).

Table 1: Impact of nutrient management on leaf macronutrient content in Nagpur mandarin grown on black soil

Treatments	Total nitrogen (%)	Total phosphorus (%)	Total potassium (%)	Total sulphur (%)
T_1	2.32	0.12	1.39	0.13
T_2	2.38	0.14	1.46	0.12
T_3	2.42	0.13	1.42	0.14
T_4	2.47	0.15	1.48	0.15
T_5	2.52	0.17	1.57	0.15
T_6	2.53	0.18	1.57	0.17
T_7	2.52	0.18	1.61	0.19
T_8	2.59	0.19	1.62	0.20
T_9	2.61	0.17	1.58	0.21
SE m (±)	0.03	0.02	0.04	0.02
CD at 5%	0.10	0.05	0.12	0.05

T_1 -Only FYM @ 50 kg tree^{-1}+ Biofertilizers, T_2 -100% Recommended dose of NPK, T_3 -100% Recommended dose of N only + FYM @ 50 kg tree^{-1}+ Biofertilizers, T_4 -100% Recommended dose of N and P + FYM @ 50 kg tree^{-1} + Biofertilizers, T_5 -T_2 + FYM @ 50 kg tree^{-1}+ Biofertilizers, T_6 -T_2 + FYM @ 50 kg tree^{-1}+ Biofertilizers + S, T_7 -T_2 + FYM @ 50 kg tree^{-1}+ Biofertilizers + S + Zn, T_8 -T_2 + FYM @ 50 kg tree^{-1}+ Biofertilizers + S + Zn + Fe, T_9-T_2 + FYM @ 50 kg tree^{-1}+ Biofertilizers + S + Zn + Fe @ 50 kg tree^{-1} + Biofertilizers (T_1)

But, significantly higher values of these nutrients were recorded with the treatment carrying 100% NPK + FYM @ 50 kg tree^{-1} + Biofertilizers (T_5). While, minimum total nitrogen, phosphorus and potassium contents were recorded with the treatment at 100% NPK (T_2) carrying completely inorganic fertilizers. In the case of total sulphur, the lowest was observed in treatment with only FYM.

Conjoint use of organic and inorganic sources showed the highest leaf nutrients concentration due to greater availability and uptake of secondary nutrients (S) and thereby efficient utilization via effective plant metabolism (Srivastava *et al.,* 2015). Similar outcomes were earlier reported by previous studies in different cultivars (Srivastava *et al.,* 2002; Baviskar and Patil, 2004). Additionally, Mundhe *et al.* (2018) reported that an increase in S content of index leaves was observed with the application of inorganic fertilizers, coupled with the addition of S through single super-phosphate and organic manure,. These responses were attributed to solubilization of native S, the enhancement of the efficiency of applied S through the decomposition process and the contribution of S via organic manure (Srivastava and Bora, 2023).

The data on micronutrients, including Zn, Fe and B contents of index leaves (Table 2), showed significant variations due to different treatments. However, Mn and Cu content varied non-significantly during year of the study. The data revealed the highest content of total zinc (26.12 mg kg^{-1}) was observed with the treatment involving 100% NPK + FYM @ 50 kg tree^{-1} + Biofertilizers + S + Zn (T_7).

Table 2: Impact of nutrient management on leaf micronutrient content in Nagpur mandarin grown on black soil

Treatments	Total zinc (mg kg^{-1})	Total iron (mg kg^{-1})	Total manganese (mg kg^{-1})	Total copper (mg kg^{-1})	Total boron (mg kg^{-1})
T_1	23.43	105.18	57.79	9.97	20.75
T_2	22.73	101.48	57.26	9.95	20.49
T_3	23.67	107.55	57.78	10.06	20.97
T_4	23.82	108.07	57.87	10.09	21.22
T_5	24.14	109.74	57.93	10.16	21.51
T_6	24.24	111.87	57.86	10.11	21.68
T_7	26.12	116.62	58.02	10.07	21.83
T_8	25.80	119.91	57.77	9.99	22.06
T_9	25.58	118.15	58.08	10.18	23.73
SE m (±)	0.40	3.18	1.31	0.23	0.43
CD at 5%	1.20	9.52	NS	NS	1.29

T_1 -Only FYM @ 50 kg tree^{-1}+ Biofertilizers, T_2 -100% Recommended dose of NPK, T_3 -100% Recommended dose of N only + FYM @ 50 kg tree^{-1}+ Biofertilizers, T_4-100% Recommended dose of N and P + FYM @ 50 kg tree^{-1} + Biofertilizers, T_5 -T_2 + FYM @ 50 kg tree^{-1}+ Biofertilizers, T_6 -T_2 + FYM @ 50 kg tree^{-1}+ Biofertilizers + S, T_7 -T_2 + FYM @ 50 kg tree^{-1}+ Biofertilizers + S + Zn, T_8 -T_2 + FYM @ 50 kg tree^{-1}+ Biofertilizers + S + Zn + Fe, T_9-T_2 + FYM @ 50 kg tree^{-1}+ Biofertilizers + S + Zn + Fe+ B

Similarly, the highest total iron content in leaves was found in treatment 100% NPK + FYM @ 50 kg tree^{-1} + Biofertilizers + S + Zn + Fe (T_8) (119.91 mg kg^{-1}) and boron content in Nagpur mandarin leaves was noticed in treatment 100% NPK + FYM @ 50 kg tree^{-1} + Biofertilizers + S + Zn + Fe + B (T_9) (23.73 mg kg^{-1}), while the lowest Zn, Fe and B content was observed in treatment 100% NPK (T_2) (22.73 mg kg^{-1}), (101.48 mg kg^{-1}) and (20.49 mg kg^{-1}), respectively. Regarding the micronutrients, nutrients like Mn and Cu concentration showed non-significant differences. The highest Mn and Cu levels were found in treatments with 100% NPK + FYM @ 50 kg tree^{-1} + Biofertilizers (Mn: 58.08 mg kg^{-1}, Cu: 10.18 mg kg^{-1}); whereas the lowest levels were noted with the treatment 100% NPK (T_2) (Mn: 57.26 mg kg^{-1} and Cu: 9.95 mg kg^{-1}). Application of micronutrients through foliar spraying, when combined with FYM, biofertilizers and inorganic fertilizers, led to an increase in leaf zinc, iron and boron content. These results corroborated with the results earlier reported studies of Meshram (2014), who observed the significantly higher response of 100% NPK + FYM, @ 5 Mg ha^{-1} with respect to higher Fe concentration as compared to treatment with 100% NPK. Such results were accountable to enhancement in enzymatic activity by the supply of FYM with NPK, which stimulated the translocation of assimilates from roots to vegetative and reproductive plant parts, thereby reflecting in increased nutrient concentration in eventual terms (Srivastava *et al.,* 2008).

Effect of INM on yield related parameters

The significant improvements in leaf nutrients composition was associated with consequent improvements in fruit of Nagpur mandarin (Table 3) . The highest number of fruits (595 tree^{-1}), fruit weight (116.17 g), and fruit yield (69.16 kg tree^{-1} or yield (19.16 t ha^{-1}) were recorded with combined application of 100% NPK + FYM @ 50 kg tree^{-1} + Biofertilizers + S + Zn + Fe + B (T_9) and followed by the treatments 100% NPK + FYM @ 50 kg tree^{-1} + Biofertilizers + S + Zn + Fe (T_8) and 100% NPK + FYM @ 50 kg tree^{-1} + Biofertilizers + S + Zn (T_7) as two most effective treatments. These treatments were however, at par with each other and significantly superior over individual application of either organics (9.02 t ha^{-1} with T_1) or inorganic fertilizers (16.18 t ha^{-1} with T_2) , significantly superior over rest of all other treatments. The significant percentage increase in yield per hectare was observed with treatment involving 100% NPK + FYM @ 50 kg tree^{-1} + Biofertilizers + S + Zn + Fe + B (T_9), which showed a 18.42 per cent increase over treatment 100% NPK (T_2) and a 112.42 per cent increase over treatment with FYM @ 50 kg tree^{-1} + Biofertilizers (T_1). Additionally, treatment 100% NPK + FYM @ 50 kg ha^{-1} + Biofertilizers (T_5) increased the fruit yield by 5.38 per cent over the 100% NPK (T_2) treatment and by 89.02 per cent over the treatment with only FYM @ 50 kg tree^{-1} + Biofertilizers (T_1) during the year of study. These observations suggested the superiority of combined application of INM-based treatments compared sole application of either organic manures or chemical fertilizers alone.The combined application of FYM, biofertilizers and inorganic fertilizers, complemented by three oliar sprays of micronutrients, substantially increased the number of fruits tree^{-1}. This

Table 3: Effect of nutrient management on yield attributes of Nagpur mandarin grown on black soil

Treatments	Number of fruits tree^{-1}	Average fruit weight (g)	Fruit yield (kg tree^{-1})	Fruit yield (t ha^{-1})
T_1	304	106.67	32.56	9.02
T_2	516	113.01	58.40	16.18
T_3	399	111.61	44.49	12.32
T_4	476	112.48	53.60	14.85
T_5	542	113.56	61.55	17.05
T_6	550	113.33	62.31	17.26
T_7	585	115.95	67.97	18.83
T_8	589	115.50	68.15	18.88
T_9	595	116.17	69.16	19.16
SE m (±)	16.86	0.91	2.30	0.62
CD at 5%	50.54	2.71	6.91	1.86

T_1 *-Only FYM @ 50 kg tree^{-1}+ Biofertilizers,* ***T_2*** *-100% Recommended dose of NPK,* ***T_3*** *-100% Recommended dose of N only + FYM @ 50 kg tree^{-1}+ Biofertilizers,* ***T_4*** *-100% Recommended dose of N and P + FYM @ 50 kg tree^{-1} + Biofertilizers,* ***T_5*** *-T_2 + FYM @ 50 kg tree^{-1}+ Biofertilizers,* ***T_6*** *-T_2 + FYM @ 50 kg tree^{-1}+ Biofertilizers + S,* ***T_7*** *-T_2 + FYM @ 50 kg tree^{-1}+ Biofertilizers + S + Zn,* ***T_8*** *-T_2 + FYM @ 50 kg tree^{-1}+ Biofertilizers + S + Zn + Fe,* ***T_9*** *-T_2 + FYM @ 50 kg tree^{-1}+ Biofertilizers + S + Zn + Fe + B*

This comprehensive INM -based nutrient management strategy enhanced the flower development, fruit set and overall plant health, resulting in a higher fruit-bearing capacity (Sharma *et al.,* 2017). Similar results were also reported previously by Srivastava *et al.* (2015) FYM-based treatments registered a much lower fruit yield than VAM-based treatments. Inclusion of VAM (*Arbuscular mycorrhiza* 500 g tree^{-1}) + PSB (phosphate solubilizing bacteria 100 g tree^{-1}) + Az (*Azospirillum* 100 g tree^{-1}) + Th (*Trichoderma viride* 100 g tree^{-1}) to 75 % RDF plus 25% organic manure improved the fruit yield of

Kinnow mandarin. Earlier Jugnake *et al.* (2017) reported an increase in fruit yield due to beneficial effects of FYM and biofertilizers on nutrient availability. These observed results were consistent with the findings of Kumari*et al.* (2022) in sweet orange and Srivastava *et al.* (2021) where foliar application of micronutrients proved to be a better choice for enhancing productivity and improving fruit quality of citrus fruits. Inclusion of bio fertilizers, especially VAM and *Trichoderma* are so well known for imparting plant health resilience (Bora and Bora, 2020; Bora *et al.,* 2019), besides growth promoting ability in such treatments

CONCLUSION

This study conclusively demonstrated that a balanced fertilizer treatment, consisting of three dynamic nutrient sources viz., inorganic fertilizers as immediate nutrient supply source , organic manures having slow nutrient release pattern and biofertilizers mobilising native stock of nutrients in soil significantly improved the leaf nutrient contents, thereby improving the yield of Nagpur mandarin trees. However, other fertilizer combinations also showed promising results. These findings have important implications for citrus farmers and fertilizer management practices, highlighting the need for optimized fertilizer application to improve crop productivity and sustainability.

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