

Substitution response of nutrient sources on fruit yield, quality and soil fertility changes in Nagpur mandarin (*Citrus reticulata*)

Ommala D. Kuchanawar, Kajal D. Bhoyar, R.M. Ghodpage, Padmaja H. Kausadikar and Nishigandha R. Mairan

College of Agriculture, Dr Panjabrao Krishi Vidyapeeth (Akola), Nagpur 440 033, Maharashtra, India

ABSTRACT

Studies were carried out to find out the substitution response of chemical fertilizers with organic manures and biofertilizers in different proportions on quality production and soil fertility on black clay soils-growing Nagpur mandarin (*Citrus reticulata* Blanco), at Dr Panjabrao Krishi Vidyapeeth, during 2021-23. There was maximum fruit yield through balanced nutrition. The highest fruit yield was observed with the application of 100 % NPK + FYM (50 kg/tree) + biofertilizers + S + Zn + Fe + B as one combination of integrated nutrient management. Additionally, all other integrated nutrient management treatments showed promising results, with regard to fruit quality, juice recovery percentage, total soluble solids and TSS: acid ratio, compared to only chemical fertilizers. The integrated use of organic manures, biofertilizers and chemical fertilizers improved fertility status of soil, represented by available nitrogen, phosphorus, potassium and sulphur compared to individual application of organic and inorganic fertilizers. These studies showed the role of integrated nutrient use for quality production of Nagpur mandarin grown on black clay soils of central India.

Key words: Nutrient, Yield, Quality, Soil fertility status, Organic manure, Biofertilizers

Nagpur mandarin (*Citrus reticulata* Blanco) is an important citrus crop grown in India, covering 12.4 % of the total area under fruit crops. In Maharashtra, it is grown in 1.48 lakh ha with a production of 8.75 lakh tonnes and average productivity of 10-14 tonnes/ha, which is low compared to other citrus cultivars (Srivastava, 2013). Citrus crops are relatively nutrient-demanding (Srivastava and Hu, 2019; Srivastava, 2023) and highly responsive to applied nutrients in the form of fertilizers, particularly nitrogen, which is a critical input, involved in plant metabolism and growth, and in different biochemical processes (Srivastava *et al.*, 2015; Asthir *et al.*, 2017). Enhanced yields with improved fruit quality are often obtained with integrated application of fertilizers, in right combinations of different nutrient source such as chemical fertilizers, organic manures and biofertilizers (Srivastava *et al.*, 2019), but such responses are highly fluctuating depending upon nature and properties of soil facing the kind of soil fertility constraints (Srivastava and Sharma, 2025). The deficiency or excess of any nutrient under such conditions can lead to a reduction in crop yield coupled with inferior fruit quality (Srivastava and Malhotra, 2017), thus, judicious application of fertilizers including macronutrients, micronutrients and organic sources is essential for increasing the productivity as well as quality of mandarin (Srivastava and Singh, 2001; 2009). Therefore, studies were carried out to find out the right combination of chemical fertilizers, organic manure

and biofertilizers to get high fruit yield, quality and soil fertility changes in Nagpur mandarin.

MATERIALS AND METHODS

The experiment was conducted at Regional Fruit Research Station, Katol, Dr Panjabrao Deshmukh Krishi Vidyapeeth, Nagpur (Maharashtra) during 2021–23. Eleven-year-old Nagpur mandarin trees grafted on rough lemon rootstock (*Citrus jambhiri* Lush) spaced at 6 m x 6 m raised on black clay soil were employed. The experiment was designed in a randomized block design, with nine treatments, each replicated three times. The treatments comprised: T₁ - only FYM (50 kg/tree) + biofertilizers, T₂ - 100% recommended dose of NPK, T₃ - 100% recommended dose of N only + FYM (50 kg/tree) + biofertilizers, T₄ - 100% recommended dose of N and P + FYM (50 kg/tree) + biofertilizers, T₅ - 100% NPK + FYM (50 kg/tree) + biofertilizers, T₆ - 100% NPK + FYM (50 kg/tree) + biofertilizers + S, T₇ - 100% NPK + FYM @ 50 kg/tree + biofertilizers + S + Zn, T₈ - 100% NPK + FYM (50 kg/tree) + biofertilizers + S + Zn + Fe and T₉ - 100% NPK + FYM (50 kg/tree) + biofertilizers + S + Zn + Fe + B.

The recommended doses of fertilizers for Nagpur mandarin was observed as N 800 g- P₂O₅ 300 g- K₂O 600 g- S 100 g/ tree. biofertilizers 500g VAM (*Glomus mosseae*) + 100 g phosphate solubilizing bacteria (*Bacillus megaterium*) + 100 g *Azospirillum* (*Azospirillum lipoferum*) + 100 g *Trichoderma* (*Trichoderma viride*) tree⁻¹ mixed with FYM at 50 kg tree⁻¹ were applied 15 days

Corresponding author: ommalakuchanwar@yahoo.com

before imposition of all the treatments flowering and fruit setting stages in two equal splits. Micronutrients (Zn 0.50%, Fe 0.50% and B 0.10%)/ tree were applied in two foliar sprays in July, August and September. Nutrients (organic, inorganic and biofertilizers) were applied in a ring that covered an area of 90- cm away from periphery of tree trunk and later covered periphery of the trees with soil to facilitate easy distribution of applied fertilizers inputs.

The weight of five fruits was recorded on electronic balance and the results were expressed as weight in grams per fruit. Fruit size in terms of length (from calyx end to tip of styler end) and breadth of fruits was measured with the help of digital Vernier Calliper and the average values for length and breadth of fruits were expressed in centimeter (cm). The fruit juice was extracted by hand operated extractor. The juice per cent was calculated from juice content and total weight of fruit. The total soluble solids content in fruits was determined by Erma Hand Refractometer (0 -32 °Brix). The titratable acidity was calculated in terms of acidity on basis of one ml of 0.1 N NaOH equivalent to 0.0067 g of anhydrous ascorbic acid by using the formula of Ranganna (1987). Ascorbic acid content of fruits was also determined as per the method suggested by Ranganna (1987).

The soil samples from the zone of maximum feeder root concentration at a depth of 0–20 cm and at a distance of 110–125 cm from trunk were collected by using a soil auger during the initial phase (December 2020) and further soil samples were collected treatment-wise after harvesting of fruits. The soil samples were dried in shade, gently ground with a mortar and pestle and sieved through a 2- mm sieve to obtain a homogeneous sample. For determination of organic carbon, soil samples were passed through a 0.5- mm sieve. These samples were stored in polythene bags and were subsequently analyzed. Soil pH and EC were determined as per the methods of Jackson (1973). Calcium carbonate was estimated using the rapid titration method and soil organic carbon were determined according to the wet oxidation method (Jackson, 1973). Available N and P were estimated using the alkaline K permanganate method and Olsen's method (Jackson, 1973). Available K was extracted in 1 N neutral normal ammonium acetate using a flame photometer (Jackson, 1973) and available S was determined by turbidity developed by barium chloride and measured spectrophotometrically at 420 nm wavelength (Chesnin and Yein, 1951).

The results were statistically analyzed and appropriately interpreted as per the methods of Gomez and Gomez (1984). Appropriate standard error and critical differences at 5% level were worked out.

RESULTS AND DISCUSSION

The row treated with 100 % NPK + FYM (50 kg/tree) + biofertilizers + S + Zn + Fe + B (T_9) produced the highest number of fruits (561 fruits/tree), followed by treatment 100 % NPK + FYM (50 kg/tree) + biofertilizers + S + Zn + Fe (T_8) recording 531 fruits/tree and 540 fruits/tree with treatment involving 100 % NPK + FYM (50 kg/tree) + biofertilizers + S + Zn (T_7) (Table 1). These treatments were found on a par with each other but significantly superior to rest of the other treatments. In contrast, lowest number of fruits was observed with treatment carrying only FYM (50 kg/tree) + biofertilizers (T_1) (315). Our results align with earlier observations made by Nurbhane *et al.* (2016), demonstrating more fruits due to inorganic fertilizers alone, and in combination with organic sources further facilitated sustained nutrient supply and nutrient-use of applied nutrients through improved microbial activity involved in nutrient transformation and fixation.

The average fruit weight was significantly higher with treatment 100 % NPK + FYM (50 kg/tree) + biofertilizers + S + Zn + Fe + B (T_9) with 113.74 g as pooled mean. This was followed by all other treatments using integrated supply of nutrients, excluding the inorganic nutrient source, superior to other treatments of integrated nutrients-supply. Conversely, a significantly lower average fruit weight was observed with the treatment with only FYM (50 kg/tree) + biofertilizers (T_1) registering fruit weight of 106.59 g. Application of inorganic NPK along with biofertilizers resulted in a higher rate of photosynthesis conditioned by optimum soil fertility, eventually led to higher carbohydrate accumulation in fruits, and thereby causing improvements in fruit size and weight (Srivastava *et al.*, 2021). Regarding yield, significantly higher yields in terms of tree/kg and tonnes/ha were obtained with combined application of 100 % NPK + FYM (50 kg/tree) + biofertilizers + S + Zn + Fe + B (T_9) as 63.93 kg/tree and 17.71 tonnes/ha, respectively.

These treatments were on par with each other and significantly superior to individual application of either organics (33.53 kg/tree and 9.29 tonnes/ha) or inorganic fertilizers (55.76 kg/tree and 15.44 tonnes/ha), also significantly superior to remaining treatments. The integrated use of chemical fertilizers with organic materials added a significant quantity of organic matter to the soil, resulting in higher fruit yield. Similar results were earlier reported (Srivastava, 2023; Srivastava *et al.*, 2015), advocating maximized fruit yields with chemical fertilizers in combination with farmyard manure and biofertilizers (Srivastava and Sharma, 2025).

Fruit quality parameters, including juice recovery, total soluble solids (TSS) and TSS: acid ratio, were

Table 1: Response of different integrated nutrient management treatments on fruit yield-attributing parameters of Nagpur mandarin (pooled data: Two seasons)

	Treatment	Number of fruits /tree	Average fruit weight (g)	Fruit yield (kg/ tree)	Fruit yield (tonnes/ ha)
T ₁	FYM (50 kg/ tree) + biofertilizers	315	106.59	33.53	9.29
T ₂	100 % recommended dose of NPK	501	111.10	55.76	15.44
T ₃	100 % recommended dose of N only + FYM (50 kg/tree) + biofertilizers	384	108.78	41.72	11.56
T ₄	100 % recommended dose of N and P + FYM (50 kg/ tree) + biofertilizers	461	111.02	51.24	14.19
T ₅	T ₂ + FYM @ 50 kg/ tree + Biofertilizers	523	112.17	58.78	16.28
T ₆	T ₂ + FYM (50 kg/tree) + biofertilizers + S	528	112.09	59.07	16.36
T ₇	T ₂ + FYM (50 kg/tree) + biofertilizers + S + Zn	540	113.62	61.47	17.03
T ₈	T ₂ + FYM (50 kg/ tree) + biofertilizers + S + Zn + Fe	551	113.65	62.57	17.33
T ₉	T ₂ + FYM (50 kg/ tree) + biofertilizers + S + Zn + Fe + B	561	113.74	63.93	17.71
	SE m (±)	13.08	2.13	1.83	0.51
	CD at 5 %	39.21	NS	5.48	1.52

significantly influenced by different nutrient management treatments (Table 2). However, influence of different treatments on fruit height, width, volume, peel thickness, acidity and ascorbic acid content showed non-significant response. The highest fruit height (5.92 cm), width (6.56 cm) and volume (171.15 cm³) were observed with treatment carrying combination of 100 % NPK + FYM (50 kg /tree) + biofertilizers + S + Zn + Fe + B (T₉). While, lowest was recorded with treatment involving only organic inputs (T₁), though a slight improvement in fruit height was observed with treatment involving combined application of organic manure, biofertilizers and inorganic fertilizers along with foliar sprays of micronutrients, specifically in 100 % NPK + FYM (50 kg/tree) + biofertilizers + S + Zn + Fe + B. Previously, Hazarika and Aheibam (2019) reported an increase in fruit height due to the integration of organic and inorganic sources. Additional findings from Bakshi *et al.* (2018) indicated that application of organic, inorganic and biofertilizers significantly improved fruit width.

Improved fruit quality was observed, as indicated by a decrease in fruit juice acidity and ascorbic acid content, as well as peel thickness. The lowest fruit juice acidity (0.72 %) and ascorbic acid content (34.89 mg 100 /mL) were recorded with the treatment combining organic manure, biofertilizers and foliar sprays of micronutrients, specifically with treatment, 100 % NPK + FYM (50 kg / tree) + biofertilizers + S + Zn + Fe + B (T₉), compared to treatments using only inorganic fertilization. The lowest peel thickness (3.28 mm) was observed with the treatment with carrying FYM (50 kg/ tree) + biofertilizers (T₁). These results are in agreement with the finding of Kumar *et al.* (2017). Fruit juice recovery significantly increased with different nutrient management practices. The highest juice recovery of 46.77% was observed with

treatment carrying 100 % NPK + FYM (50 kg /tree) + biofertilizers + S + Zn + Fe + B (T₉), followed by 46.33% with 100 % NPK + FYM (50 kg/ tree) + biofertilizers + S + Zn + Fe (T₈) and 46.07% with 100 % NPK + FYM (50 kg/ tree) + biofertilizers + S + Zn (T₇). However, lowest juice recovery of 43.82% was observed with the treatment with carrying FYM (50 kg/tree) + biofertilizers (T₁). Ennab (2016) observed the highest juice recovery (48.14 %) with combined use of farmyard manure and biofertilizers with a dose of NPK . A similar finding was also reported by Srivastava *et al.* (2019) highlighting significant increase in juice content of mandarin fruits with combination of 75 % RDF (recommended doses of fertilizers) and 25 % RDF-equivalent vermicompost and microbial consortium, which significantly improved different fruit quality parameters over 100 % RDF alone.

The highest total soluble solids of 9.53% in fruit juice was recorded with the treatment with 100 % NPK + FYM (50 kg /tree) + biofertilizers + S + Zn + Fe + B (T₉), followed by 9.36% with 100 % NPK + FYM (50 kg/tree) + biofertilizers + S + Zn + Fe (T₈) (9.36), at par with 9.33% with 100 % NPK + FYM (50 kg/tree) + biofertilizers + S + Zn (T₇). These treatments were on par with each other, but significantly superior to other treatments. The lowest fruit TSS of 8.72% was observed with only FYM (50 kg/ tree) + biofertilizers (T₁), aligning these results with previously reported by Kumar *et al.* (2017).

The maximum soil pH was recorded with treatment carrying 100 % NPK (T₂) (Table 3). Such treatment response of FYM is accountable to acidifying effect of urea and organic acids produced during the course of the decomposition of organic amendments, a well-known fact established through a large number of experiments . While, electrical conductivity indicating total soluble salts

Table 2 : Response of different integrated nutrients-supply treatments on fruit quality of Nagpur mandarin (pooled data: two seasons)

	Treatment	Fruit height (cm)	Fruit width (cm)	Fruit volume (cm ³)	Peel thickness (mm)	Juice recovery (%)	Ascorbic acid (mg 100/ mL)	TSS (°Brix)	Acidity (%)
T ₁	FYM (50 kg/ tree) + biofertilizers	5.65	6.40	168.39	3.28	43.82	35.26	8.72	0.75
T ₂	100 % recommended dose of NPK	5.68	6.42	170.07	3.44	44.90	35.33	8.77	0.76
T ₃	100 % recommended dose of N only + FYM (50 kg/tree) + biofertilizers	5.73	6.37	168.59	3.36	44.14	35.21	8.78	0.75
T ₄	100 % recommended dose of N and P + FYM (50 kg/ tree) + biofertilizers	5.72	6.44	170.19	3.36	44.61	35.22	8.94	0.74
T ₅	T ₂ + FYM (50 kg/ tree) + biofertilizers	5.78	6.50	170.41	3.35	45.58	35.31	9.14	0.74
T ₆	T ₂ + FYM (50 kg/ tree) + biofertilizers + S	5.75	6.52	170.10	3.37	45.66	35.23	9.18	0.75
T ₇	T ₂ + FYM (50 kg/ tree) + biofertilizers + S + Zn	5.83	6.53	171.86	3.34	46.07	34.96	9.33	0.74
T ₈	T ₂ + FYM (50 kg/ tree) + biofertilizers + S + Zn + Fe	5.87	6.59	171.05	3.34	46.37	35.00	9.36	0.73
T ₉	T ₂ + FYM (50 kg/ tree) + biofertilizers + S + Zn + Fe + B	5.92	6.56	171.15	3.31	46.77	34.89	9.53	0.72
	SE m (±)	0.22	0.31	1.86	0.02	0.53	0.16	0.16	0.01
	CD at 5 %	NS	NS	NS	NS	1.59	NS	0.48	NS

in the soil did not change much due to various treatments, it ranged narrowly between 0.25 to 0.28 dS/m. The minimum CaCO₃ in soil was observed in organic manure-incorporated treatments and maximum was recorded in treatment 100 % NPK (T₂). The organic acids released during decomposition of organic manures reacted with CaCO₃ to release CO₂, thereby reducing the concentration of CaCO₃ in the soil.

Significantly highest available nitrogen of 312.2 kg/ha in soil was recorded with treatment receiving 100 % NPK + FYM (50 kg/tree) + biofertilizers + S + Zn (T₇), on par with treatments, viz. 100 % NPK + FYM (50 kg/tree) + biofertilizers + S + Zn + Fe (T₈), 100 % NPK + FYM (50 kg/tree) + biofertilizers + S (T₆), 100 % NPK + FYM (50 kg/tree) + biofertilizers + S + Zn + Fe + B (T₉) and 100 % NPK + FYM (50 kg/ tree) + biofertilizers (T₅), but significantly superior over treatment 100 % recommended dose of N only + FYM (50 kg/tree) + biofertilizers (T₃) (298.5 kg/ha) and 100 % NPK + FYM (50 kg/tree) + biofertilizers (T₂) (294.8 kg/ha). The availability of organically bound nitrogen through transformation in soil to plant mainly depended on the population of microorganisms, influenced by application of inorganic fertilizers and organic manure, as reported (Srivastava *et al.*, 2021).

The available phosphorus in soil after harvest of Nagpur mandarin was noticed highest (20.80 kg/ha) with treatment. 100 % NPK + FYM (50 kg/tree) + biofertilizers + S (T₆), on par with treatments like 100 % NPK + FYM (50 kg/tree) + biofertilizers (T₅), 100 % NPK + FYM (50

kg/tree) + biofertilizers + S + Zn + Fe + B (T₉), 100 % NPK + FYM (50 kg/tree) + biofertilizers + S + Zn (T₇), 100 % NPK + FYM (50 kg/tree) + biofertilizers + S + Zn + Fe (T₈) and 100 % recommended dose of N and P + FYM (50 kg/tree) + biofertilizers (T₄) and 100 % NPK (T₂), but significantly superior over treatment 100 % recommended dose of N only + FYM (50 kg/tree) + biofertilizers (T₃). Considerable improvement in available P status was observed due to residual effect of applied fertilizers and mineralization of organic sources coupled with solubilization of nutrients from the native sources during the process of decomposition (Srivastava, 2023).

Several other studies reported an increase in soil available P content with the application of FYM + inorganic fertilizers (Thakur *et al.*, 2009) and vermicompost + biofertilizers + inorganic fertilizers (Nakade *et al.*, 2021). The available potassium in soil after the harvest of Nagpur mandarin was noticed to be the highest (364.0 kg/ha), with treatment involving 100 % NPK + FYM (50 kg/tree) + biofertilizers + S + Zn + Fe + B (T₉) and significantly superior (344.6 kg/ha) over treatment 100 % NPK (T₂) or 100 % recommended dose of N and P + FYM (50 kg/tree) + biofertilizers (T₄) and 100 % Recommended dose of N only + FYM (50 kg/tree) + biofertilizers (T₃) (341.7 kg/ha).

The increase in K- availability was attributed to direct addition of K through fertilizers to available pool of soil, in addition to K solubilized from K-bearing minerals by organic acids released from the organic manures

Table 3 : Soil fertility changes in response to different treatments of integrated nutrient management (pooled data: two seasons)

	Treatment	Soil pH	EC (dS m ⁻¹)	CaCO ₃ (%)	Available nitrogen (kg/ ha)	Available phosphorus (kg/ ha)	Available potassium (kg/ ha)	Available sulphur (mg/ kg)
T ₁	FYM (50 kg/ tree) + biofertilizers	7.61	0.27	3.72	291.7	18.49	339.7	14.30
T ₂	100 % recommended dose of NPK	7.63	0.28	3.74	294.8	19.17	344.6	14.01
T ₃	100 % recommended dose of N only + FYM (50 kg/ tree) + biofertilizers	7.60	0.25	3.70	298.5	18.81	341.7	14.42
T ₄	100 % recommended dose of N and P + FYM (50 kg/ tree) + biofertilizers	7.60	0.25	3.69	304.4	20.22	343.8	14.57
T ₅	T ₂ + FYM (50 kg/ tree) + biofertilizers	7.58	0.26	3.69	307.5	20.75	361.0	14.84
T ₆	T ₂ + FYM (50 kg/ tree) + biofertilizers + S	7.57	0.26	3.70	311.7	20.80	363.9	15.49
T ₇	T ₂ + FYM (50 kg/ tree) + biofertilizers + S + Zn	7.57	0.25	3.66	312.2	20.69	363.8	15.50
T ₈	T ₂ + FYM (50 kg/ tree) + biofertilizers + S + Zn + Fe	7.56	0.25	3.67	311.7	20.65	362.0	15.45
T ₉	T ₂ + FYM (50 kg/ tree) + biofertilizers + S + Zn + Fe + B	7.58	0.26	3.66	311.0	20.73	364.0	15.48
SE m (±)		0.03	0.02	0.05	2.53	0.55	4.16	0.29
CD at 5 %		NS	NS	NS	7.59	1.65	12.47	0.86

and reduction in K-fixation and release of K due to considerable improvement in soil interaction of organic available K under the influence of FYM + inorganic fertilizers. Considerable improvement in soil interaction of organic available K was also reported with clay with the incorporation of FYM + inorganic fertilizers (Zhang *et al.*, 2015).

The available sulphur in soil after harvesting of Nagpur mandarin was recorded displaying most significant gain (15.50 mg kg⁻¹) with the treatment involving 100 % NPK + FYM (50 kg/tree) + biofertilizers + S + Zn (T₇), closely followed by treatment 100 % NPK + FYM (50 kg/tree) + biofertilizers + S (T₆), 100 % NPK + FYM (50 kg/ tree) + biofertilizers + S + Zn + Fe + B (T₉), 100 % NPK + FYM (50 kg/tree) + biofertilizers + S + Zn + Fe (T₈) and 100 % NPK + FYM (50 kg/tree) + biofertilizers (T₅), but at par with each other and significantly superior over treatment 100 % recommended dose of N and P + FYM (50 kg/tree) + biofertilizers (T₄). However, significantly lowest S (14.01 mg/kg) was noted with treatment 100 % NPK (T₂). Increased sulphur availability in soil due to addition of organic manure was attributed to greater root proliferation and the increasing activity of sulphur-oxidizing bacteria. Our results are similar to those of Kumar *et al.* (2017).

CONCLUSION

The best results obtained by adoption of integrated nutrient management involving combined use of FYM, biofertilizers and inorganic fertilizers, along with foliar micronutrient spray to realise holistic soil-plant response

in terms of fruit yield, fruit quality and soil fertility status. Such concept is considered close to organic citrus.

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