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Effect of integrated nutrient management on the physico-chemical properties of Nagpur mandarin orchard under Vertisols

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Abstract
The experiment was conducted in the orchard at the Regional Fruit Research Station, Katol, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, during the years 2021–22 and 2022–23. The study was initiated in an eleven-year-old Nagpur mandarin orchard under normal planting density (6 m x 6 m). The experiment was laid out in a Randomized Block Design (RBD) with nine treatments comprising various combinations of FYM, biofertilizers, RDF and foliar sprays of micronutrients with three replications. Experimental findings revealed that integrated use of organic manures, biofertilizers and chemical fertilizers increased the fertility status of soil, influencing parameters like available nitrogen, phosphorus, Potassium, Sulphur, in the soil compared to individual applications of both organic and inorganic fertilizers or imbalanced fertilizer applications. However, the physical properties of soil have not been much affected by integrated nutrient management in a short period of time. The physical and chemical properties of soil that are not much affected are bulk density, hydraulic conductivity, maximum water holding capacity and chemical properties like pH, EC and $CaCO_3$.

Keywords: INM, FYM, bulk density, organic carbon, biofertilizers, Nagpur mandarin

Introduction
Citrus, is the third-largest fruit crop grown in India, next to banana and mango. It is often regarded as the queen of fruits, stands as a vital subtropical crop and the world's largest fruit. Mandarins, securing a 40.66 percent share of total citrus production, rank second in importance within the citrus group after sweet oranges (Anonymous, 2018) [2]. Nagpur mandarin (*Citrus reticulata* Blanco) is a significant citrus crop in India, with an annual production of 100.9 lakh tonnes, covering 310.42 lakh ha (12.4%) of the total fruit crop area. However, it has an average yield of 9.7 t ha^{-1}, which is lower compared to other citrus varieties (Shirgure *et al.*, 2012) [37]. In Maharashtra, the area dedicated to this crop is 1.48 lakh ha, with a production of 8.75 lakh tonnes and the average yield varies between 10-14 t ha^{-1}. In the Vidarbha region of Maharashtra, Nagpur mandarin covers an area of 1,46,040 ha and produces 5,97,758 MT (Anonymous, 2018) [2].

The various implications of commercial fertilizer decreasing soil productivity are due to its huge and continuous use. In modern agriculture, the ever-increasing use of fertilizer without adequate organic recycling has not only aggravated multi-nutrient deficiency in soil plant systems but also degraded soil productivity and created environmental pollution. The nutrient-responsive nature of citrus has been well proven since the commercial cultivation of citrus came into being. There are absolutely no two opinions that a balanced nutrition programme is mandatory to maintain a sustained productive life of orchards in addition to quality production (Ghosh, 1990) [12]. The concept of integrated nutrient management is gaining importance; hence, the integrated use of chemical fertilizer along with biofertilizer and organic manure is essential.

Integrated nutrient management involves the judicious blend of organic and inorganic fertilizers along with biofertilizer, which maintains soil fertility and productivity and ultimately causes a significant reduction in chemical fertilizer, which is cost-effective. The aim is ecological safety through the exploitation of local resources that can produce the desired yield and maintain soil health on a long-term basis under integrated nutrient management (Bodkhe, 2017) [08]. Independent use of neither the chemical fertilizer nor an organic source can sustain the fertility of the soil and productivity of crops in a high-input production system, whereas integrated nutrient management maintains soil and plant health increases fertilizer use efficiency and ensures high crop production. This may cause a significant reduction in the use of fertilizers. The inorganic fertilizer could supply only one, two or three nutrients, but integrated use of organic and inorganic fertilizers would provide macro- and micronutrients to plants and soil and resist the occurrence of multiple deficiencies. In the presence of organic manures, chemical fertilizers play a better role with the slow release of nutrients after decomposition. Organic manures have a favorable influence on soil physiochemical properties, which enhance crop growth (Thawale *et al.*, 2021) [42]. The use of organic manure and biofertilizers can have greater importance in increasing the availability of nutrients, fertilizer use efficiency and microbial biomass. Organic manure and biofertilizers are less expensive, easily available and eco-friendly and are expected to improve soil fertility, crop yield and quality. The introduction of efficient strains of biofertilizers in soils may help boost production through an increased microbial population and consequently, the fixation of more atmospheric nitrogen and more solubilization of insoluble phosphorus in the soil. Hence, the present study was undertaken to know the effect of integrated nutrient management on the physico-chemical properties of Nagpur mandarin orchard under Vertisol.

Materials and Methods

The research was conducted in the orchard at the Regional Fruit Research Station, Katol, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, during the years 2021–22 and 2022–23. Eleven-year-old Nagpur mandarin trees, spaced at 6 m x 6 m intervals, were employed for this experiment. The experiment was designed following the principles of a Randomized Block Design, with nine treatments, each replicated three times. The treatments comprise 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 recommended doses of fertilizers for Nagpur mandarin are N 800 g, P_2O_5 300 g, K_2O 600 g, and S 100 g tree^{-1}. Biofertilizers 500g VAM (*Glomus mosseae*) + 100 g PSB *(Bacillus megaterium)* + 100 g Azospirillum (*Azospirillum lipoferum*) + 100 g Trichoderma (*Trichoderma viride*) tree^{-1} mixed with FYM @ 50 kg tree^{-1} were applied 15 days before all treatments. Micronutrients (Zn 0.5%, Fe 0.5% and B 0.1%) tree^{-1} had two foliar sprays in each of the months of July, August and September. 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 and covered the periphery of the trees. Soils should be hoed to a depth of 25–30 cm and sources of nutrients should be properly mixed in the soil.

The representative 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 the trunk were collected by using a soil auger during the initial phase (December 2020) and further soil samples were collected treatment-wise after the harvesting of fruits. The soil samples were dried in the shade, gently grind with a mortar and pestle and sieved through a 2 mm sieve. For the determination of organic carbon, the soil samples were passed through a 0.5 mm sieve. These samples were stored in polythene bags and were subsequently analyzed.

The soil bulk density was determined by the clod coating method (Blake and Hartge, 1986) [07]. The saturated hydraulic conductivity was measured using the constant head method of Richards (1954) [33]. Maximum water holding capacity was determined by using the Keen-Rocrko-Waske-Box on a wet and dry basis of water content, as described by Shankaran (1966) [36]. For the pH and EC methods given by Jackson (1973) [15]. Calcium carbonate was estimated using the rapid titration method using the phenolphthalein indicator as described by Piper (1966) [31]. Soil organic carbon was determined according to the wet oxidation method (Walkley and Black, 1934) [44]. Available N was estimated using the alkaline K permanganate method (Subbiah and Asija, 1956) [39], available P was estimated by Olsen’s method (Olsen *et al*., 1954) [29], available K was extracted in 1 N neutral normal ammonium acetate using a flame photometer (Jackson, 1973) [15] and available S was determined by turbidity developed by barium chloride and measured spectrophotometrically at 420 nm wavelength (Chesnin and Yein, 1951) [09].

Statistical analysis

The results obtained were statistically analyzed and appropriately interpreted as per the methods in “Statistical Methods for Agricultural Workers” by Gomez and Gomez (1984) [13]. Appropriate standard error (S.E.) and critical differences (C.D.) at 5% level were worked out as and when necessary.

Results and Discussion

Soil physico-chemical properties

Bulk density of soil (Mg m^{-3})

The data on bulk density of soil influenced by integrated nutrient management under Nagpur mandarin is presented in Table 1. The bulk density of the soil ranged between 1.35 to 1.38 Mg m^{-3} and 1.34 to 1.38 Mg m^{-3} during the years 2021–22 and 2022–23, respectively. The bulk density was significantly lowest in all the treatments with a combination of 100% NPK + FYM @ 50 kg tree^{-1} + Biofertilizers (1.35 and 1.34 Mg m^{-3}) while it showed the highest value in treatment 100% NPK (T_2) (1.38 Mg m^{-3}) during both years of study. However, the results indicated non-significant differences in treatments, but there was a slight decrease in soil bulk density values in the treatments where organic manure was applied singly or in combination with inorganic fertilizers. These treatments favorably improved the organic carbon status of the soil. When organic manures are decomposed, the humified fraction of soil helps improve the soil structure and tilth, thereby increasing aeration and aggregation, which in turn reduces the bulk density of the soil (Rudrappa *et al.*, 2006) [34]. Surekha and Rao (2009) [40] reported that the organic sources applied for a long period enhanced the soil physical parameters, i.e., bulk density, penetration resistance and soil fertility parameters, over inorganic sources alone.

Hydraulic conductivity of soil (cm hr^{-1})

The data pertaining to the hydraulic conductivity of soil is reflected in Table 1. Hydraulic conductivity values of soil ranged from 0.84 to 0.93 cm hr^{-1} and 0.84 to 0.93 cm hr^{-1} during the years 2021–22 and 2022–23, respectively. The hydraulic conductivity of soil was significantly highest in all the treatments with a combination of 100% NPK + FYM @ 50 kg $tree^{-1}$ + Biofertilizers (0.90 and 0.93 cm hr^{-1}), while it showed the lowest value in treatment 100% NPK (T_2) (0.85 and 0.84 cm hr^{-1}) during both years of study. The hydraulic conductivity of soil during both years of study showed non-significant differences among different treatments but a slight increase in hydraulic conductivity under the integrated use of NPK and FYM along with biofertilizers. Similar findings were reported by Bellakki and Badanur *et al.* (1997) [4], the increase in hydraulic conductivity under the integrated use of organic and inorganic fertilization was mainly attributed to a decrease in bulk density and an increase in effective pore volume because of the better aggregation in these treatments. Nagar *et al.* (2016) [27] found that the combined use of organic manure, FYM + phosphocompost and pigeonpea stalk + phosphocompost resulted in improvements in the physical properties of the soil over the recommended dose of fertilizer (RDF) application.

Table 1: Effect of integrated nutrient management on physical properties of soil

Treatments		Bulk density (Mg m^{-3})		Hydraulic conductivity (cm hr^{-1})		Maximum water holding capacity (%)	
		2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
T_1	Only FYM @ 50 kg $tree^{-1}$ + Biofertilizers	1.37	1.36	0.86	0.88	48.19	48.33
T_2	100% Recommended dose of NPK	1.38	1.38	0.85	0.84	48.07	48.09
T_3	100% Recommended dose of N only + FYM @ 50 kg $tree^{-1}$ + Biofertilizers	1.37	1.35	0.87	0.90	48.18	48.31
T_4	100% Recommended dose of N and P + FYM @ 50 kg $tree^{-1}$ + Biofertilizers	1.36	1.34	0.90	0.90	48.11	48.36
T_5	T_2 + FYM @ 50 kg $tree^{-1}$ + Biofertilizers	1.35	1.35	0.89	0.91	48.14	48.38
T_6	T_2 + FYM @ 50 kg $tree^{-1}$ + Biofertilizers + S	1.35	1.34	0.90	0.91	48.16	48.36
T_7	T_2 + FYM @ 50 kg $tree^{-1}$ + Biofertilizers + S + Zn	1.36	1.35	0.88	0.90	48.04	48.41
T_8	T_2 + FYM @ 50 kg $tree^{-1}$ + Biofertilizers + S + Zn + Fe	1.35	1.34	0.90	0.93	48.07	48.29
T_9	T_2 + FYM @ 50 kg $tree^{-1}$ + Biofertilizers + S + Zn + Fe + B	1.36	1.35	0.86	0.89	48.14	48.31
SE m (±)		0.05	0.05	0.03	0.02	0.19	0.38
CD at 5%		NS	NS	NS	NS	NS	NS

Maximum water holding capacity (%)

The data with respect to the maximum water holding capacity of soil as influenced by various organic sources is presented in Table 1. The maximum water-holding capacity of soil ranged from 48.07 to 48.16 percent and 48.09 to 48.41 percent during the years 2021–22 and 2022–23, respectively. The maximum water holding capacity of soil was significantly highest in all the treatments with a combination of 100% NPK + FYM @ 50 kg $tree^{-1}$ + Biofertilizers (48.16 and 48.41 percent), while it showed the lowest value in treatment 100% NPK (T_2) (48.07 and 48.09 percent) during both years of study. The maximum water holding capacity of soil during both years of the study showed non-significant differences among different treatments but a slight increase in hydraulic conductivity under the integrated use of NPK and FYM along with biofertilizers. The increased WHC might be due to the increased organic matter status of the soil as well as improved soil structure. These results confirm with the findings of Masto *et al.* (2006) [24] and Kumar *et al.* (2012) [20]; they found a significant increase in the maximum water holding capacity with the application of organic materials along with fertilizers, which resulted in an improvement in the soil structure due to increased OC content and decreased soil BD.

Soil pH (soil reaction)

The results pertaining to the effect of integrated nutrient management on soil pH in Nagpur mandarin are narrated in Table 2. During the years 2021–22 and 2022–23, soil pH values were variable in the range of 7.56 to 7.63 and 7.54 to 7.61, respectively. There were no significant changes observed in the soil during both years, but a decrease in soil pH as compared to the initial and fertilized plots was noticed under treatments with a combination of 100% NPK + FYM @ 50 kg $tree^{-1}$ + Biofertilizers. Whereas, the maximum pH recorded in treatment was 100% NPK (T_2). This may be due to the 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 (Hati *et al.*, 2007) [14]. This was supported by the findings of Kharche *et al.* (2013) [17]. that the soil pH was maintained with the conjunctive use of organics and chemical fertilizers over a period of 2 years, which could be attributed to the buffering effect caused by organic matter and, secondly, the high buffering capacity of the clayey soil. However, it was significantly lowered under the treatments of integration, indicating the need for the addition of organics to maintain the pH of soils.

Electrical conductivity (dS m^{-1})

Electrical conductivity indicates the total soluble salts in the soil solution (Table 2). The electrical conductivity of the soil did not change much due to various treatments. It ranged between 0.25 to 0.28 dS m^{-1} and 0.23 to 0.27 dS m^{-1} during the years 2021–22 and 2022–23, respectively. However, the results indicated non-significant differences during both years of study. The small increase in electrical conductivity might be due to the accumulation of soluble salts at the surface where fertilizers were applied alone. Thus, from the results, it was observed that soil EC was not influenced by two-year integrated nutrient management treatments.

Treatment receiving 100% NPK (T_2) recorded the highest EC as compared to other treatments. This might be due to the fact that the continuous use of inorganic fertilizers slightly increases the EC of soil due to the soluble salts present in chemical fertilizers. However, combined application of organic and inorganic fertilizer showed a lower increase in EC as compared to only inorganic fertilizer application over initial soil EC. The results indicated that the integration of fertilizers with organics is more beneficial and also does not cause salinity hazards to the soil. Similar observations were reported by Rathod *et al.* (2003) [32] that organic inputs in the form of FYM at 5 t ha^{-1} lower the electrical conductivity of the soil. Such observations were also recorded by Walia *et al.* (2010) [43], reported that the addition of FYM, WCS and GM along with fertilizers decreased the soil EC as compared to fertilizer alone, but the differences were non-significant.

Calcium carbonate (%)

The data pertaining to the effect of integrated nutrient management on the calcium carbonate concentration of the soil of Nagpur mandarin is presented in Table 2. During the years 2021–22 and 2022–23, calcium carbonate content in soil varied from 3.66 to 3.74 percent and 3.64 to 3.77 percent during the years 2021–22 and 2022–23, respectively. From the results, it was observed that, the calcium carbonate content in the soil was non-significant during both years of study. Whereas, minimum $CaCO_3$ in soil was observed in organic manure-incorporated plots and maximum was recorded in treatment 100% NPK (T_2). The application of integrated nutrient management on a long-term basis may help lower the calcium content of the soil. Similar findings were reported by Sleutel *et al.* (2006) [38] that long-term applications of animal manure increase SOM and decrease calcium carbonate content in two ways: by adding OM contained in the manure and by increasing OM in crop residues due to higher crop yields. Also, Kharche (2013) [17] reported that the significant reduction in free $CaCO_3$ could be attributed to the considerable amount of biomass added to the soil due to long-term cultivation and organic matter applied through conjunctive use treatments. The reduction in $CaCO_3$ might be due to organic acids released during the decomposition of organic materials, which react with $CaCO_3$ to release CO_2, thereby reducing the $CaCO_3$ content of the soil.

Soil organic carbon (g kg^{-1})

The data presented in Table 2 shows that the organic carbon content in the soil clearly indicates that there was a build-up of organic carbon in the soil of Nagpur mandarin due to integrated nutrient management practices. The soil organic carbon content ranged from 6.19 to 6.43 g kg^{-1} and 6.27 to 6.63 g kg^{-1} during the years 2021–22 and 2022–23, respectively. The highest build-up of soil organic carbon was recorded in treatments with 100% NPK + FYM @ 50 kg ha^{-1} + Biofertilizers + S (6.43 and 6.63 g kg^{-1}), while the lowest soil organic carbon was recorded in treatments with only 100% NPK (T_2) (6.19 and 6.27 g kg^{-1}) during both years. This increase can be attributed to the creation of favorable conditions for the growth of soil microorganisms, root biomass and other factors, leading to a more rapid decomposition of organic matter due to the increased microbial population. The highest increase in organic carbon is likely due to the additional carbon input from FYM and higher productivity in these treatments. The experimental results align with the findings of Meshram *et al.* (2016) [25] observed that the combined application of organic manure and inorganic fertilization in Vertisol led to an improvement in soil organic carbon. This improvement can be attributed to the use of both fertilizer and organic manure, which increased the contribution of biomass to the soil, including greater root biomass from crop stubbles and residues. The subsequent decomposition of these materials likely resulted in an enhanced organic carbon content in the soil. Similarly, Mundhe *et al.* (2018) [26] reported that the combined use of 100% NPK + FYM at 5 Mg ha^{-1} was beneficial for maintaining organic carbon content compared to the use of only chemical fertilizers. Marathe *et al.* (2009) [23] also found that organic manure, especially vermicompost, either alone or in combination with inorganic fertilizers, green manure (*Crotalaria juncea* L.) or biofertilizers (*Azotobacter* + PSB), increased soil carbon content.

Table 2: Effect of integrated nutrient management on chemical properties of soil

Treatments		Soil pH		Electrical conductivity (dS m^{-1})		Calcium carbonate (%)		Soil organic carbon (g kg^{-1})	
		2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
T_1	Only FYM @ 50 kg $tree^{-1}$ + Biofertilizers	7.61	7.59	0.27	0.26	3.72	3.70	6.23	6.34
T_2	100% Recommended dose of NPK	7.63	7.61	0.28	0.27	3.74	3.77	6.19	6.27
T_3	100% Recommended dose of N only + FYM @ 50 kg $tree^{-1}$ + Biofertilizers	7.60	7.59	0.25	0.23	3.70	3.69	6.28	6.41
T_4	100% Recommended dose of N and P + FYM @ 50 kg $tree^{-1}$ + Biofertilizers	7.60	7.58	0.25	0.24	3.69	3.67	6.34	6.49
T_5	T_2 + FYM @ 50 kg $tree^{-1}$ + Biofertilizers	7.58	7.56	0.26	0.25	3.69	3.66	6.39	6.57
T_6	T_2 + FYM @ 50 kg $tree^{-1}$ + Biofertilizers + S	7.57	7.55	0.26	0.25	3.70	3.64	6.43	6.62
T_7	T_2 + FYM @ 50 kg $tree^{-1}$ + Biofertilizers + S + Zn	7.57	7.56	0.25	0.24	3.66	3.65	6.42	6.62
T_8	T_2 + FYM @ 50 kg $tree^{-1}$ + Biofertilizers + S + Zn + Fe	7.56	7.54	0.25	0.23	3.67	3.65	6.41	6.63
T_9	T_2 + FYM @ 50 kg $tree^{-1}$ + Biofertilizers + S + Zn + Fe + B	7.58	7.56	0.26	0.24	3.66	3.66	6.40	6.59
SE m (±)		0.03	0.03	0.02	0.02	0.05	0.03	0.04	0.06
CD at 5%		NS	NS	NS	NS	NS	NS	0.13	0.18

Available nutrient status

Available nitrogen

The data presented in Table 3 for the available N status indicate that the highest available nitrogen was recorded in all treatments with 100% NPK + FYM @ 50 kg $tree^{-1}$ + Biofertilizers + S (312.2 to 325.0 kg ha^{-1}), while the lowest was recorded in the treatment with only FYM @ 50 kg $tree^{-1}$ + Biofertilizers (T_1) (291.7 and 299.8 kg ha^{-1}) for the years

2021–22 and 2022–23, respectively. This highlights that a balanced application of organic manure and inorganic fertilizer improves soil health and nutrient availability compared to organic or inorganic treatments alone. Considerable improvement in available N status was observed in all the treatments involving the combined application of organic and inorganic fertilizers, i.e., 100% NPK + FYM @ 50 kg tree^{-1} + Biofertilizers. This is attributed to the improved physical properties of the soil coupled with the microbial population. The microbial activity further increased due to the availability of organic matter along with readily available N from inorganic fertilizers (Pareek *et al.*, 2018). The availability of nitrogen was increased with the addition of nitrogenous fertilizer in the FYM amended plots, indicating that an appropriate combination of inorganic fertilizer and organic manure is required for proper management of nitrogen (Manna *et al*., 2005). Many earlier studies showed an increase in available N with the application of organic manures, biofertilizers and inorganic fertilizers (Marathe and Bharambe, 2005) [22] and vermicompost and inorganic fertilizers (Biswas *et al.*, 2012) [06].

Available phosphorus

The data presented in Table 3 indicate that the maximum build-up in available phosphorus was observed with the application of 100% NPK FYM @ 50 kg tree^{-1} + Biofertilizers + S (20.80 and 23.00 kg ha^{-1}), while the lowest was found in the treatment with only organic inputs (T_1) (18.49 and 19.42 kg ha^{-1}) for the years 2021–22 and 2022–23, respectively. Considerable improvement in available P status was observed in all the treatments involving the combined application of organic and inorganic fertilizers, i.e., 100% NPK + FYM @ 50 kg tree^{-1} + Biofertilizers. This may be due to the residual effect of applied fertilizer and the mineralization of organic sources or to the solubilization of nutrients from the native sources during the process of decomposition. Whereas, Selvi *et al.* (2003) [35], in a long-term fertilizer experiment, noted that the application of 10 t ha^{-1} FYM along with 100% NPK recorded a significantly higher influence on available P (19.48 kg ha^{-1}) as compared to the other treatments in *Vertic Ustropept*. Khokle (2016) [18] also reported that the available P content in soil was significantly improved with the application of organic, inorganic and organic + inorganic sources of nutrients as compared to the control. Several workers reported an increase in soil available P content with the application of FYM + inorganic fertilizers (Thakur *et al.*, 2009) [41], vermicompost + biofertilizers + inorganic fertilizers (Kakraliya *et al.*, 2017; Nakade *et al*., 2021) [16, 28].

Available potassium

The highest availability of potassium was found in treatments with 100% NPK + FYM @ 50 kg tree^{-1} + Biofertilizers (364.0 and 377.8 kg ha^{-1}), while the lowest was noted in treatments with only FYM @ 50 kg tree^{-1} + Biofertilizers (T_1) (339.7 and 346.2 kg ha^{-1}) for the years 2021–22 and 2022–23, respectively. Considerable improvement in available K status was observed in all the treatments involving the combined application of organic and inorganic fertilizers, i.e. 100% NPK + FYM @ 50 kg tree^{-1} + Biofertilizers. The increase in K availability is attributed to the direct addition of K through fertilizers to the available pool of soil. It also solubilized K from K-bearing minerals by the organic acids released from the organic manures, besides the reduction in K-fixation and release of K due to considerable improvement in soil interaction of organic available K was also matter with clay reported with the incorporation of FYM + inorganic fertilizers (Kharche *et al.*, 2013) [17]. Considerable improvement in soil interaction of organic available K was also reported with clay with the incorporation of FYM + inorganic fertilizers (Bhattacharyya *et al*., 2009; Zhang *et al*., 2015) [05] [45], FYM + biofertilizers + inorganic fertilizer (Ennab, 2016) [10] and FYM + wheat straw + green manure + inorganic fertilizer (Kumar *et al*., 2012) [20].

Available sulphur

The available sulphur content indicated that continuous application of 100% NPK along with FYM helped maintain available sulphur in the soil. The further addition of sulphur fertilizer improved its availability for the crop. The highest available sulphur was observed in treatments with 100% NPK + FYM @ 50 kg tree^{-1} + Biofertilizers + S (T_6) (15.50 and 16.17 mg kg^{-1}), while the significantly lowest available sulphur was noted in treatment 100% NPK (T_2) (14.01 and 14.12 mg kg^{-1}). The data on available sulphur content clearly shows that the application of 100% NPK + FYM and only FYM @ 50 kg ha^{-1} + Biofertilizers treatment maintained available sulphur in the soil. Continuous growing of Nagpur mandarin without application of S-containing fertilizers caused a low level of available sulphur. Available sulphur content in treatments devoid of applied S, i.e., 100% NPK (T_2), 100% N only + FYM @ 50 kg tree^{-1} + Biofertilizers (T_3), 100% Recommended dose of N and P + FYM @ 50 kg tree^{-1} + Biofertilizers (T_4) and 100% NPK + FYM @ 50 kg tree^{-1} + Biofertilizers (T_5), where P was substituted by diammonium phosphate, showed not much improvement in available sulphur indicating that sulphur should be an important ingredient in the fertilizer schedule, either to be supplied through organic or chemical fertilizers. It may be due to the continuous use of diammonium phosphate as a P source, which resulted in low content in100% NPK treatments, causing a reduction in crop yields as compared to a single superphosphate application. Similarly, Akbari *et al.* (2011) [01] indicated the significant maximum value of sulphur (23.9 mg kg^{-1}) under treatment RDF: 12.5–25.0 kg NP ha^{-1} + 500 kg gypsum ha^{-1} as compared to other treatments. Our results are similar to the findings of Kumar *et al.* (2008) [19] reported that, crop residues with and without organic manures (FYM and GM) significantly increased the available S content of soil compared with 100% NPK alone.

Table 3: Effect of integrated nutrient management on available nutrient status of soil

Treatments		Available N (kg ha^{-1})		Available P (kg ha^{-1})		Available K (kg ha^{-1})		Available S (mg kg^{-1})	
		2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
T_1	Only FYM @ 50 kg tree^{-1} + Biofertilizers	291.7	299.8	18.49	19.42	339.7	346.2	14.30	14.47
T_2	100% Recommended dose of NPK	294.8	302.4	19.17	20.55	344.6	352.1	14.01	14.12
T_3	100% Recommended dose of N only + FYM @ 50 kg tree^{-1} + Biofertilizers	298.5	310.8	18.81	19.96	341.7	348.4	14.42	14.62
T_4	100% Recommended dose of N and P + FYM @ 50 kg tree^{-1} + Biofertilizers	304.4	315.6	20.22	22.20	343.8	350.3	14.57	14.85
T_5	T_2 + FYM @ 50 kg tree^{-1} + Biofertilizers	307.5	319.5	20.75	22.88	361.0	376.6	14.84	15.03
T_6	T_2 + FYM @ 50 kg tree^{-1} + Biofertilizers + S	311.7	324.0	20.80	22.97	363.9	377.5	15.49	16.17
T_7	T_2 + FYM @ 50 kg tree^{-1} + Biofertilizers + S + Zn	312.2	325.0	20.69	22.98	363.8	375.4	15.50	16.13
T_8	T_2 + FYM @ 50 kg tree^{-1} + Biofertilizers + S + Zn + Fe	311.7	324.1	20.65	23.00	362.0	377.8	15.45	16.11
T_9	T_2 + FYM @ 50 kg tree^{-1} + Biofertilizers + S + Zn + Fe + B	311.0	322.6	20.73	22.95	364.0	376.9	15.48	16.14
SE m (±)		2.53	2.94	0.55	0.81	4.16	5.31	0.29	0.41
CD at 5%		7.59	8.82	1.65	2.44	12.47	15.93	0.86	1.23

Conclusion

Thus, based on the outcomes of the integrated nutrient management, it can be said that applying farmyard manure in addition to chemical and biofertilizers has helped to improve the physical and chemical properties of the soil, which in turn has improved soil quality under Nagpur mandarin cultivation in Vertisol.

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