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Effect of Potassium Levels on Soil and Leaf Nutrient Status of Nagpur Mandarin (*Citrus reticulata*)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

Potassium regulates enzymatic activities and stomatal movement, improving water-use efficiency and sugar transport within plants. Along with phosphorus, it supports rapid root growth and promotes protein synthesis. It also improves plant health and resistance to diseases, pests, and nematodes. Potassium deficiency reduces photosynthesis and yield, while excess nitrogen with low potassium can lead to poor fruiting and physiological disorders. The study highlights the significance of balanced and split potassium application along with foliar nutrition in enhancing macro- and micronutrient uptake, which is crucial for sustainable

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citrus production systems. A field experiment was conducted during 2022–23 at farmers' fields in Pardi and Sawandri villages of Nagpur district on 10–12-year-old fruit-bearing orchards. The experiment included different potassium treatments and was laid out in a Randomized Block Design. Among all treatments, T_9 (RDF + 300 g K at BT (December) + 300 g K after 60 days + KNO_3 @ 1.5% spray after 90 days) was found significantly superior over other treatments. This treatment recorded higher leaf nutrient concentrations, including total nitrogen (2.19 and 2.29%), total phosphorus (0.099 and 0.123%), total potassium (1.40 and 1.46%), and total sulphur (0.24 and 0.23%) at Pardi and Sawandri villages, respectively. Similarly, total micronutrient content in leaves was also higher under this treatment, with iron (79.46 and 79.47 mg kg^{-1}), zinc (18.50 and 19.34 mg kg^{-1}), manganese (61.51 and 62.79 mg kg^{-1}), and copper (14.00 and 14.17 mg kg^{-1}) at Pardi and Sawandri, respectively. In addition, improved soil nutrient availability was observed with the same potassium treatment. The values recorded were nitrogen (322.50 and 331.30 kg ha^{-1}), potassium (498.19 and 435.32 kg ha^{-1}), iron (7.29 and 7.33 mg kg^{-1}), and zinc (0.86 and 0.84 mg kg^{-1}) at Pardi and Sawandri villages, respectively. Overall, the results indicated that the combined application of RDF with split doses of potassium and foliar spray of KNO_3 significantly enhanced both leaf nutrient status and soil nutrient availability in Nagpur mandarin orchards.

Keywords: Nagpur mandrin; potassium; available nutrient; total nutrient; Vidarbha region.

1. Introduction

Nagpur mandarin (*Citrus reticulata* Blanco) is an important fruit in genus citrus. It belongs to the family Rutaceae and sub family Aurantioideae. Nagpur mandarin having shizolysigenic oil gland and particular aroma indicating flavour of particular citrus species. Nagpur Mandarin is finest cultivar and extremely accepted in India as well as in world for its good quality fruits with high production. It is considered to be one of the most important cultivated species among citrus and is being commercially grown in specific region of the country like Nagpur mandarin in Central India, Khasi mandarin in North Eastern regions and Coorg mandarin in Southern regions (Vikee *et al.,* 2018). Though, it is grown in every state, certain pockets have emerged as the leading producers. Nagpur mandarin is chiefly grown in Satpura foot hills (Vidarbha region) of Central India.

The total production of Mandarin in India is 6.36 Million tones from an area of 0.48 million hectare with the productivity of 13.26 Million tones per hectare. In Maharashtra state, the acreage of Nagpur mandarin is around 1.26 lakh hectare area and the production is 7 lakh million tonnes. The Amravati and Nagpur districts of Maharashtra contribute about 80% of the total area under mandarin orchards in the state, sharing 48.88% and 31.45% respectively. With regard to the production of mandarin, Amravati district occupies 37.36% while Nagpur occupies 23.87% share in the Vidarbha citrus market (Anon., 2020). Vidarbha is India's only citrus growing region with two fruiting seasons (Ambia and Mrig). The fruit available from September to December is Ambia, which has a slightly sour taste. This is followed by the sweeter Mrig crop in February. Hence Nagpur mandarin enjoys favourable climatic conditions to provide bulk production twice a year.

Among the various factors affecting citrus crop production, balanced nutrition plays a crucial role. Several researchers have reported the favourable effects of potassium (K) on the growth and yield of citrus. Potassium not only enhances yield but also improves fruit quality and post-harvest storage life. It is removed in larger quantities compared to nitrogen (N) and phosphorus (P) (Embleton et al., 1967; Ranganna, 1986).

In Nagpur mandarin, potassium plays a key role in improving fruit quality. Nutritional potassium sprays enhance yield and quality attributes, especially juice recovery and ascorbic acid content. Potassium is essential for enzyme activation, cell division, photosynthesis, transport of photosynthates, and osmotic regulation (Meena et al., 2022). It also influences fruit size, rind thickness, and colour (Mongi & Obreza, 2003). Citrus fruits remove large amounts of potassium compared to other nutrients (Alva & Tucker, 1999). During fruit development, potassium moves from leaves to fruits and seeds (Mpelasoka et al., 2003). It is required for sugar and starch formation, protein synthesis, cell division, and neutralization of organic acids (Liu et al., 2000). Potassium also enhances fruit size, flavour, and colour and helps plants tolerate stress conditions like drought, cold, and flooding (Tiwari, 2005).

Potassium regulates enzymatic activities and stomatal movement, improving water-use efficiency and sugar transport within plants (Imas & Bansal, 1999). Along with phosphorus, it supports rapid root growth and promotes protein synthesis (Rodriguez et al., 2005). It also improves plant health and resistance to diseases, pests, and nematodes. Potassium deficiency reduces photosynthesis and yield, while excess nitrogen with low potassium can lead to poor fruiting and physiological disorders (Zaied et al., 2006). Even moderate potassium deficiency can reduce growth without visible symptoms, and by the time symptoms appear, yield losses are significant (Mustafa and Saleh, 2006). Potassium is highly mobile in plants and plays multiple metabolic roles, including regulation of water balance and improvement of fruit size.

Citrus crops remove more potassium (1.86–3.38 kg t^{-1} fruit) than nitrogen or phosphorus, indicating its importance in nutrient efficiency. Long-term studies in central India show significant potassium depletion in orchards, leading to reduced productivity (Dass & Srivastava, 1997). Although soils contain high total potassium, 90–98% remains unavailable. The response of citrus to potassium fertilization varies, especially in Vertisols, where soil properties like clay content and calcium–magnesium dominance affect potassium availability (Srivastava et al., 2008). Potassium fertilization improves root access and increases available potassium, enhancing uptake. Overall, potassium is essential for improving yield, fruit quality, and plant resilience, making it a key nutrient in citrus production systems.

This manuscript makes a valuable contribution to the scientific community by providing detailed insights into the role of potassium management in improving both soil fertility and plant nutrient status in Nagpur mandarin orchards. The study highlights the significance of balanced and split potassium application along with foliar nutrition in enhancing macro- and micronutrient uptake, which is crucial for sustainable citrus production systems. Furthermore, it generates location-specific evidence under Vertisol conditions, helping researchers and agronomists better understand nutrient dynamics in such soils. Overall, the findings offer practical implications for optimizing fertilizer strategies, thereby supporting improved productivity and resource-use efficiency in citrus cultivation.

1.1 Objective

1. To assess the effect of various levels of Potassium on the nutrient availability and leaf nutrient concentration of Nagpur mandarin

2. Materials and Methods

The field experiment was conducted at farmer's orchard in Pardi and Sawandri village of Nagpur district. 10–12-year-old fruit bearing orchard of Nagpur mandarin of nearly uniform growth was selected for the study. The experimental site was uniform and levelled.

2.1 Statistical Analysis

The layout of experiment at field was done by using randomized block design (RBD). The results obtained were statistically analyzed and appropriately interpreted as per the methods described in "Statistical method for Agricultural Workers" by Panse and Sukhatme (1985). Appropriate standard error (S.E.) critical differences (C.D.) at 5 per cent levels were worked out for interpretation of result.

Table 1. Details of experiment are given below

Sr. No.	Particulars	Specification
1	Location	Pardi and sawandri village, Dist. Nagpur
2	Crop	Mandarin
3	Scientific name	*Citrus reticulata* Blanco
4	Variety	Nagpur mandarin
5	Year of experiment	2022-23
6	Age of tree	10-12 years
7	Spacing	6 × 6
8	Experimental design	Randomized Block Design (RBD)
9	Number of treatments	Ten
10	Number of replications	Three
11	Recommended dose of fertilizer	1200 g N and 600 g P2O5 (g $plant^{-1}$)

Table 2. Treatment details

Treatment	Specifications
T_1	RDF
T_2	RDF + 400g K at BT (Dec)
T_3	RDF + 200g K at BT (Dec) + 200g K after 60 Days
T_4	RDF + 600g K at BT (Dec)
T_5	RDF + 300g K at BT (Dec) + 300g K after 60 Days
T_6	RDF + 800g K at BT (Dec)
T_7	RDF + 400g K at BT (Dec) + 400g K after 60 Days
T_8	RDF + 200g K at BT (Dec) + 200g K after 60 Days + KNO3 @ 1.5% spray after 90 Days
T_9	RDF + 300g K at BT (Dec) + 300g K after 60 Days + KNO3 @ 1.5% spray after 90 Days
T_{10}	RDF + 400g K at BT (Dec) + 400g K after 60 Days + KNO3 @ 1.5% spray after 90 Days

A. Initial Soil Analysis Data

Table 3. Initial soil physical Properties

Name of site	Particle size analysis			Water holding capacity (%)	Bulk Density (Mg m^{-3})	Hyd. Conductivity (cm hr^{-1})
	Sand (2.0-0.05) mm	Silt (0.05-0.002) mm	Clay (<0.002) mm			
Pardi	8.3	35.3	56.4	45.23	1.39	2.72
Sawandri	6.4	33.5	60.1	49.16	1.42	1.81

Table 4. Initial soil chemical Properties

Sr. No.	Particulars	Observation	
		Pardi	Sawandri
1	Ph	8.3	8.5
2	EC (dS m^{-1})	0.81	0.51
3	Soil organic carbon (g kg^{-1})	5.8	4.8
4	$CaCO_3$ (%)	4.9	5.8
5	Available Nitrogen (kg ha^{-1})	291.2	308.5
6	Available Phosphorus (kg ha^{-1})	20.8	26.2
7	Available potassium (kg ha^{-1})	436.3	403.5
8	Fe (mg kg^{-1})	4.28	4.34
9	Zn (mg kg^{-1})	0.69	0.71
10	Mn (mg kg^{-1})	8.6	8.4
11	Cu (mg kg^{-1})	1.67	1.93

3. Result and Discussion

The observations recorded on various aspects *viz.*, leaf and soil nutrient status of Nagpur mandarin during the course of investigation are presented here under appropriate heads.

3.1 Effect of Potassium on Leaf Macronutrient Content

3.1.1 Total Nitrogen Percentage

The data in respect of leaf N content (%) is presented in (Table 5) at Pardi and Sawandri village. The results revealed that the significantly higher leaf N content (2.19 and 2.29%) at Pardi and Sawandri village respectively, was recorded with the application of 300 g K at BT (Dec) + 300 g K after 60 days + KNO_3 @ 1.5% spray after 90 days along with recommended dose of fertilizers (T_9) followed by the treatment (T_{10}) RDF + 400 g K at BT (Dec) +400 g K after 60 Days + KNO_3 @ 1.5% spray after 90 Days However the treatment T_9 (RDF + 300 g K at BT (Dec) + 300 g K after 60 Days + KNO_3 @ 1.5% spray after 90 Days), T_{10} (RDF + 400 g K at BT (Dec) + 400 g K after 60 Days + KNO_3 @ 1.5% spray after 90 Days), T_7 (RDF + 400 g K at BT (Dec) + 400 g K after 60 Days) and T_6 (RDF + 800 g K at BT (Dec) were at par.

Wassel et al. (2007) also observed a progressive increase on N content in leaves with increasing nutrient quantities applied through drip N levels from 400 to 1000 g $tree^{-1}$.

Table 5. Effect of potassium on leaf macronutrients content in Nagpur mandarin

Treatment Details	Total N (%)		Total P (%)		Total K (%)		Total S (%)	
	Pardi	Sawandri	Pardi	Sawandri	Pardi	Sawandri	Pardi	Sawandri
T_1 (RDF)	1.86	1.99	0.087	0.106	0.98	1.03	0.17	0.17
T_2 (RDF+ 400 g K at BT (Dec)	1.90	2.04	0.087	0.108	1.12	1.16	0.18	0.17
T_3 (RDF+ 400 g K at BT (Dec) + 200 g K after 60 Days)	1.91	2.07	0.089	0.109	1.16	1.20	0.18	0.19
T_4 (RDF+ 600 g K at BT (Dec)	1.96	2.14	0.088	0.111	1.25	1.25	0.19	0.19
T_5 (RDF+ 300 g K at BT (Dec) + 300 g K after 60 Days)	2.03	2.13	0.089	0.115	1.32	1.34	0.20	0.20
T_6 (RDF+ 800 g K at BT (Dec)	2.13	2.23	0.092	0.117	1.34	1.36	0.20	0.21
T_7 (RDF+ 400 g K at BT (Dec) + 400 g K after 60 Days)	2.17	2.25	0.095	0.119	1.38	1.45	0.20	0.21
T_8 (RDF+ 200 g K at BT (Dec) + 200 g K after 60 Days + KNO_3 @ 1.5% spray after 90 Days)	2.97	2.11	0.090	0.111	1.20	1.24	0.21	0.21
T_9 (RDF+ 300 g K at BT (Dec) + 300 g K after 60 Days + KNO_3 @ 1.5% spray after 90 Days)	2.19	2.29	0.099	0.123	1.40	1.46	0.24	0.23
T_{10} (RDF+ 400 g K at BT (Dec) + 400 g K after 60 Days + KNO_3 @ 1.5% spray after 90 Days)	2.18	2.26	0.098	0.122	1.39	1.46	0.22	0.22
SE (M)±	0.03	0.02	0.001	0.001	0.01	0.01	0.01	0.01
CD at 5%	0.09	0.06	0.004	0.004	0.02	0.02	0.02	0.02

3.1.2 Total Phosphorus Percentage

The data in respect of leaf P content (%) is presented in Table 5 at Pardi and Sawandri village. The data of experimentation revealed that significantly higher leaf P content (0.099 and 0.123%) at Pardi and Sawandri village respectively, was observed in treatment receiving 300 g K at BT (Dec) + 300 g K after 60 days + KNO_3 @ 1.5% spray after 90 days along with recommended dose of fertilizers (T_9) followed by application of 400 g K at BT (Dec) + 400 g K after 60 days + KNO_3 @ 1.5% spray after 90 days along with recommended dose of fertilizers (T_{10}).

However the treatment T9 (RDF + 300 g K at BT (Dec) + 300 g K after 60 Days + KNO_3 @ 1.5% spray after 90 Days), T_{10} (RDF + 400 g K at BT (Dec) + 400 g K after 60 Days + KNO_3 @ 1.5% spray after 90 Days) and T_7 (RDF + 400 g K at BT (Dec) + 400 g K after 60 Days) were at par which with each other. The lowest leaf P content was recorded in treatment receiving only RDF. Kuchanwar *et al*. (2017) observed maximum leaf nutrient content of N (2.63%) and P (0.18%) with 160 per cent of RDF through fertigation in Nagpur mandarin.

3.1.3 Total Potassium Percentage

The data in respect of leaf K content (%) is presented in Table 5 at Pardi and Sawandri respectively. The application of 300 g K at BT (Dec) + 300 g K after 60 days + KNO_3 @ 1.5% spray after 90 days along with recommended dose of fertilizers (T_9) significantly recorded highest leaf K content (1.40 and 1.46%) at Pardi and Sawandri village respectively, followed by application of 400 g K at BT (Dec) + 400 g K after 60 days + KNO_3 @ 1.5% spray after 90 days along with recommended dose of fertilizers (T_{10}).

However the treatment T_9 (RDF + 300 g K at BT (Dec) + 300 g K after 60 Days + KNO_3 @ 1.5% spray after 90 Days), T_{10} (RDF + 400 g K at BT (Dec) + 400 g K after 60 Days + KNO_3 @ 1.5% spray after 90 Days) and T_7 (RDF + 400 g K at BT (Dec) + 400 g K after 60 Days) were at par which with each other. The lowest leaf K content was recorded in recommended dose of fertilizer.

Reddy *et al.* (1991) analysed leaf samples of 12 to 15 years old trees (cv. Satgudi and Mosambi) from 9 orchards in February, April, July and October, observed that, the mean K content was optimum i.e. 1.00-1.70% concentration and observed that, the nutrient decreased in leaves between flowering and fruit harvest.

3.1.4 Total Sulphur Percentage

The data in respect of leaf S content (%) is presented in Table 5 at Pardi and Sawandri respectively. The application of 300 g K at BT (Dec) + 300 g K after 60 days + KNO_3 @ 1.5% spray after 90 days along with recommended dose of fertilizers (T_9) significantly recorded highest leaf S content (0.24 and 0.23%) at Pardi and Sawandri village respectively, followed by application of 400 g K at BT (Dec) + 400 g K after 60 days + KNO_3 @ 1.5% spray after 90 days along with recommended dose of fertilizers (T_{10}) which was statistically at par with each other. The lowest leaf S content was recorded in recommended dose of fertilizer (0.17%) at Pardi and Sawandri village respectively. Similar result also reported by Muhammad *et al.* (2007) they observed that Potassium application enhances sulphur uptake in leaves due to improved root activity and better nutrient translocation, leading to a slight increase in total sulphur percentage. This is mainly because potassium maintains ionic balance and activates enzymes involved in sulphur metabolism. Additionally, improved soil conditions and nutrient availability (especially under sulphur amendments) further support higher S accumulation in plant tissues.

3.2 Effect of Potassium on Total Leaf Micronutrient Content

The data regarding the concentration of copper, iron, manganese and zinc in leaf after harvesting of the crop in Nagpur mandarin are presented below.

3.2.1 Iron (mg kg^{-1})

The data in respect of leaf Fe content (mg kg^{-1}) is presented in Table 6 at Pardi and Sawandri respectively. The highest leaf Fe content 79.46 and 79.47 mg kg^{-1} at Pardi and Sawandri village respectively recorded in treatment (T_9) 300 g K at BT (Dec) + 300 g K after 60 days + KNO_3 @ 1.5% spray after 90 days along with recommended dose of fertilizers, followed by application of 400 g K at BT (Dec) + 400 g K after 60 days + KNO_3 @ 1.5% spray after 90 days along with recommended dose of fertilizers (T_{10}) which was statistically at par with each other. The lowest leaf Fe content was recorded in recommended dose of fertilizer.

Table 6. Effect of sulphur on leaf micronutrients content in Nagpur mandarin

Treatment Detail	Total Fe (mg kg^{-1})		Total Zn (mg kg $^{-1}$)		Total Mn (mg kg $^{-1}$)		Total Cu (mg kg $^{-1}$)	
	Pardi	Sawandri	Pardi	Sawandri	Pardi	Sawandri	Pardi	Sawandri
T_1 (RDF)	74.45	74.85	15.38	15.76	55.23	55.58	10.31	10.30
T_2 (RDF + 400 g K at BT (Dec)	75.01	75.22	15.45	16.49	56.23	56.57	10.84	10.68
T_3 (RDF + 200 g K at BT (Dec) + 200 g K after 60 Days)	75.45	75.90	16.34	16.36	56.91	57.18	11.49	11.03
T_4 (RDF + 600 g K at BT (Dec)	75.78	76.76	16.79	16.97	58.25	58.05	11.29	12.22
T_5 (RDF + 300 g K at BT (Dec) + 300 g K after 60 Days)	75.84	76.93	16.45	17.04	58.90	58.86	11.93	12.70
T_6 (RDF + 800 g K at BT (Dec)	77.00	77.99	17.12	17.39	59.35	59.00	12.44	13.07
T_7 (RDF + 400 g K at BT (Dec) + 400 g K after 60 Days)	77.80	77.82	17.23	17.63	60.09	59.63	13.33	13.71
T_8 (RDF + 200 g K at BT (Dec) + 200 g K after 60 Days + KNO_3 @ 1.5% spray after 90 Days)	76.09	77.28	16.33	17.00	57.34	60.65	13.15	13.49
T_9 (RDF + 300 g K at BT (Dec) + 300 g K after 60 Days + KNO_3 @ 1.5 spray after 90 Days)	79.46	79.47	18.50	19.34	61.51	62.79	14.00	14.17
T_{10} (RDF + 400 g K at BT (Dec) + 400 g K after 60 Days + KNO_3 @ 1.5% spray after 90 Days)	78.88	79.09	18.07	18.35	60.91	61.46	13.35	13.97
SE (m) $\pm$	0.31	0.36	0.38	0.45	0.46	0.33	0.22	0.20
CD at 5%	0.92	1.06	1.14	1.33	1.38	0.99	0.64	0.61

Table 7. Effect of potassium on soil macronutrient availability

Treatment Detail	N (kg ha^{-1})		P (kg ha^{-1})		K(kg ha^{-1})	
	Pardi	Sawandri	Pardi	Sawandri	Pardi	Sawandri
T_1 (RDF)	292.30	308.47	21.73	26.13	435.24	405.36
T_2 (RDF + 400 g K at BT (Dec)	301.43	311.90	22.25	27.10	472.20	420.11
T_3 (RDF + 200 g K at BT (Dec) + 200 g K after 60 Days)	303.50	314.03	21.97	26.97	470.43	418.64
T_4 (RDF + 600 g K at BT (Dec)	310.57	315.57	21.48	27.81	482.63	424.58
T_5 (RDF + 300 g K at BT (Dec) + 300 g K after 60 Days)	309.60	317.60	22.92	27.92	487.48	422.29
T_6 (RDF + 800 g K at BT (Dec)	322.37	321.97	21.59	28.03	496.05	431.77
T_7 (RDF + 400 g K at BT (Dec) + 400 g K after 60 Days)	318.57	325.13	23.22	28.24	498.19	429.71
T_8 (RDF + 200 g K at BT (Dec) + 200 g K after 60 Days + KNO_3 @ 1.5% spray after 90 Days)	320.47	315.23	23.52	27.76	485.55	424.83
T_9 (RDF + 300 g K at BT (Dec) + 300 g K after 60 Days + KNO_3 @ 1.5 spray after 90 Days)	322.50	331.30	23.67	28.47	495.49	433.69
T_{10} (RDF + 400 g K at BT (Dec) + 400 g K after 60 Days + KNO_3 @ 1.5% spray after 90 Days)	321.50	328.63	23.28	29.07	496.92	435.32
SE (m) $\pm$	**2.66**	**2.53**	1.65	0.55	**3.37**	**1.67**
CD at 5%	**7.90**	**7.50**	NS	NS	**10.02**	**4.95**

Shirgure and Srivastava (2013) observed that, the K fertigation treatment with mono potassium phosphate recorded the highest concentration of micronutrients (127.1 mg kg^{-1} Fe, 60.1 mg kg^{-1} Mn, 10.9 mg kg^{-1} Cu and 26.2 mg kg^{-1} Zn) compared to rest of the other fertigation treatments potash fertilizers.

3.2.2 Zinc (mg kg^{-1})

The data in respect of leaf Zn content (mg kg^{-1}) is presented in Table 6 at Pardi and Sawandri respectively. The highest leaf Zn content 18.50 and 19.34 mg kg^{-1} at Pardi and Sawandri village respectively recorded in treatment (T_9) 300 g K at BT (Dec) + 300 g K after 60 days + KNO_3 @ 1.5% spray after 90 days along with recommended dose of fertilizers, followed by application of 400 g K at BT (Dec) + 400 g K after 60 days + KNO_3 @ 1.5% spray after 90 days along with recommended dose of fertilizers (T_{10}) which was statistically at par with each other. The lowest leaf Zn content was recorded in RDF. The lowest leaf Fe content was recorded in recommended dose of fertilizer.

Reddy *et al.* (1991) analysed leaf samples of 12 to 15 years old trees (cv. Satgudi and Mosambi) for Fe, Mn, Cu and Zn concentration and observed that, concentration of all the nutrient decreased in leaves between flowering and fruit harvest and reported that, the Zn content in leaves was 14.25-34.50 mg kg^{-1}.

3.2.3 Manganese (mg kg^{-1})

The data in respect of leaf Mn content (mg kg^{-1}) is presented in Table 6 at Pardi and Sawandri respectively The significantly highest leaf Mn content 61.51 and 62.79 mg kg^{-1} at Pardi and Sawandri village respectively, recorded in treatment (T_9) 300 g K at BT (Dec) + 300 g K after 60 days + KNO_3 @ 1.5% spray after 90 days along with recommended dose of fertilizers, followed by application of 400 g K at BT (Dec) + 400 g K after 60 days + KNO_3 @ 1.5% spray after 90 days along with recommended dose of fertilizers (T_{10}) which was statistically at par with each other. The lowest leaf Mn content was recorded in RDF. Chahill *et al*. (1991) suggested optimum value of leaf Mn as 62.0 ppm for citrus plant. Also, Srivastava *et al.* (2022) gives the optimum range of Mn concentration 54.8-84.6 mg kg^{-1}.

3.2.4 Copper (mg kg^{-1})

The data in respect of leaf Cu content (mg kg^{-1}) is presented in Table 6 at Pardi and Sawandri respectively. The highest leaf Cu content 14.00 and 14.17 mg kg^{-1} at Pardi and Sawandri village respectively recorded in treatment (T_9) 300 g K at BT (Dec) + 300 g K after 60 days + KNO_3 @ 1.5% spray after 90 days along with recommended dose of fertilizers. The lowest leaf Cu content was recorded in recommended dose of fertilizer. Srivastava *et al.* (2022) gives the optimum range of copper concentration 9.8-17.6 mg kg^{-1} in Nagpur mandarin leaves.

3.3 Effect of Potassium on Soil Macronutrient Availability

3.3.1 Available Nitrogen (kg ha^{-1})

The data in respect of soil available nitrogen is presented in (Table 7) at Pardi and Sawandri village. The results revealed that the significantly higher soil available nitrogen (322.50 and 331.30 kg ha^{-1}) at Pardi and Sawandri village respectively, was recorded with the application of 300 g K at BT (Dec) + 300 g K after 60 days + KNO_3 @ 1.5% spray after 90 days along with recommended dose of fertilizers (T_9). The lowest soil available nitrogen was recorded with the application of RDF. Ommala Kuchanwar *et al.* (2017) observed that, maximum available soil nutrient content such as N (260.93), P (21.22) and K 453.30 kg ha^{-1} due to higher application of fertilizers (160 per cent RDF) through fertigation.

3.3.2 Available Phosphorus (kg ha^{-1})

The data in respect of soil available phosphorus is presented in (Table 7) at Pardi and Sawandri village. The results revealed that the non-significantly higher soil available phosphorus (23.67 and 28.47 kg ha^{-1}) at Pardi and Sawandri village respectively, was recorded with the application of 300 g K at BT (Dec) + 300 g K after 60 days + KNO_3 @ 1.5% spray after 90 days along with recommended dose of fertilizers (T_9).

Table 8. Effect of potassium on leaf micronutrients content in Nagpur mandarin

Treatment Detail	Fe ($mg\ kg^{-1}$)		Zn($mg\ kg^{-1}$)		Mn ($mg\ kg^{-1}$)		Cu ($mg\ kg^{-1}$)	
	Pardi	**Sawandri**	**Pardi**	**Sawandri**	**Pardi**	**Sawandri**	**Pardi**	**Sawandri**
T_1 (RDF)	4.36	4.39	0.70	0.71	8.69	8.65	1.76	1.88
T_2 (RDF + 400 g K at BT (Dec)	4.72	4.74	0.73	0.74	8.71	8.66	1.78	1.90
T_3 (RDF + 200 g K at BT (Dec) + 200 g K after 60 Days)	5.01	5.04	0.72	0.74	8.68	8.50	1.68	1.89
T_4 (RDF + 600 g K at BT (Dec)	5.44	5.46	0.75	0.76	8.73	8.47	1.73	1.85
T_5 (RDF + 300 g K at BT (Dec) + 300 g K after 60 Days)	6.01	6.04	0.77	0.79	8.76	8.61	1.76	1.84
T_6 (RDF + 800 g K at BT (Dec)	6.26	6.29	0.82	0.81	8.77	8.73	1.78	1.92
T_7 (RDF + 400 g K at BT (Dec) + 400 g K after 60 Days)	7.07	7.09	0.84	0.83	8.81	8.77	1.81	1.94
T_8 (RDF + 200 g K at BT (Dec) + 200 g K after 60 Days + KNO_3 @ 1.5% spray after 90 Days)	6.05	6.14	0.81	0.80	8.84	8.82	1.84	1.94
T_9 (RDF + 300 g K at BT (Dec) + 300 g K after 60 Days + KNO_3 @ 1.5 spray after 90 Days)	7.29	7.33	0.86	0.84	8.89	8.83	1.89	2.01
T_{10} (RDF + 400 g K at BT (Dec) + 400 g K after 60 Days + KNO_3 @ 1.5% spray after 90 Days)	7.12	7.21	0.85	0.83	8.87	8.81	1.87	2.02
SE (m) $\pm$	0.49	0.50	0.03	0.03	0.14	0.13	0.06	0.05
CD at 5%	1.46	1.50	0.10	0.08	NS	NS	NS	NS

The lowest soil available phosphorus was recorded with the application RDF (21.73 and 26.13 kg ha^{-1}) at Pardi and Sawandri village respectively. High fertigation frequency ameliorates situation, since there is a continuous forced mass flow, which goes from the surface into the soil. Increased saturation of P fixation sites in the soil due to high frequency and application rate results in higher amounts of P released to solution, which combined with the forced flow of water into the soil, facilitates the distribution and the consequent increased levels of P (Duenhas *et al.* 2002).

3.3.3 Available Potassium (kg ha^{-1})

The data in respect of soil available potassium is presented in (Table 7) at Pardi and Sawandri village. The results revealed that, the significantly higher soil available potassium (498.19 kg ha^{-1}) was recorded with the application of RDF + 400 g K at BT (Dec) + 400 g K after 60 Days (T_7). The lowest soil available nitrogen was recorded with the application of RDF (435.24 kg ha^{-1}) at Pardi village.

The results revealed that, the significantly higher soil available potassium (435.32 kg ha^{-1}) was recorded with the application of 400 g K at BT (Dec) + 400 g K after 60 days + KNO_3 @ 1.5% spray after 90 days along with recommended dose of fertilizers (T_{10}). The lowest soil available nitrogen was recorded with the application of RDF (405.36 kg ha^{-1}) at Sawandri village. Srivastava *et al.,* (2022) developed the DRIS based soil fertility and leaf nutrient standards and they observed available potassium range is 272.4 to 301.4 kg ha^{-1}.

3.4 Effect of Potassium on Soil Micronutrient Availability

The over exploitation of soil which are naturally degraded are confronted by a number of problems, among them micronutrient deficiency is common feature in soils of India reported by Meena (2022) and in particular Fe, Mn, Cu and Zn deficiencies are of paramount importance in soils of Maharashtra. In view of the fact that pH, ESP and $CaCO_3$ controls the availability of micronutrients in shrink swell soils, the presence of excess powdery lime ($CaCO_3$) reduces the availability of phosphorous and micronutrients like Zn, Mn, Fe and Cu in mandarin orchard in Vidarbha region.

3.4.1 DTPA Extractable Iron

Data pertaining to iron as influenced due to the potassium application is presented in table 8. The results revealed that, the potassium application influenced over this character during experimentation. It was seen from the observations that, iron value ranged from 4.36 - 7.29 & 4.39 - 7.33 mg kg^{-1} at Pardi and Sawandri village respectively.

The results revealed that, the significantly higher soil available iron (7.29 and 7.33 mg kg^{-1}) at Pardi and Sawandri village respectively, was recorded with the application of 300 g K at BT (Dec) + 300 g K after 60 days + KNO_3 @ 1.5% spray after 90 days along with recommended dose of fertilizers (T_9). The lowest soil available iron was recorded with the application of RDF (4.36 and 4.39 mg kg^{-1}) at Pardi and Sawandri village respectively. Similar results also reported by Khokhar *et al.* (2012) they observed that, Fe and Zn varied from 1.76-5.68 and 0.80-2.56 in different productive Kinnow orchards grown. DTPA-extractable iron (Fe) in soils ranged from **1.76 to 5.68 ppm**, indicating generally low availability. Most soil samples were found **deficient in iron**, especially under alkaline soil conditions. Higher Fe availability was associated with better nutrient status but showed **negative correlation with high pH and EC**. Low DTPA-extractable iron is mainly due to **high soil pH (alkaline conditions)**, which converts Fe into insoluble forms unavailable to plants.

3.4.2 DTPA Extractable Zinc

Data pertaining to zinc as influenced due to the potassium application is presented in table 8. The results revealed that, the potassium application influenced over this character during experimentation. It was seen from the observations that, zinc value ranged from 0.70 - 0.86 and 0.71 - 0.84 mg kg^{-1} at Pardi and Sawandri village respectively. The results revealed that, the significantly higher soil available zinc (0.86 and 0.84 mg kg^{-1}) at Pardi and Sawandri village respectively, was recorded with the application of 300 g K at BT (Dec) + 300 g K after 60 days + KNO_3 @ 1.5% spray after 90 days along with recommended dose of fertilizers (T_9).

The lowest soil available zinc was recorded with the application of RDF (0.70 and 0.71 mg kg^{-1}) at Pardi and Sawandri village respectively. Similar results were reported by Jibhkate *et al.* (2009) reported in their studies on micronutrient status of soil of Katol tahsil in Nagpur district and reported that DTPA extractable zinc ranged from 0.24 to 0.67 mg kg^{-1}. Similar results were also shown by Srivastava *et al.* (2022) that, the concentration of Zn in soil ranged from 0.59 to 1.26 mg kg^{-1}.

3.4.3 DTPA Extractable Manganese

Data pertaining to manganese as influenced due to the potassium application is presented in table 8. It was seen from the observations that, manganese value ranged from 8.69 - 8.89 & 8.47- 8.83 mg kg^{-1} at Pardi and Sawandri village respectively. The results revealed that, the lightly higher available manganese content (8.89 and 8.83 mg kg^{-1}) were found at Pardi and Sawandri village respectively with the application of 300 g K at BT (Dec) + 300 g K after 60 days + KNO_3 @ 1.5% spray after 90 days along with recommended dose of fertilizers (T_9). However, the treatment differences were not significant. Similar results were also shown by Chavan *et al.* (2018) that, the application of potassium increased soil macronutrient availability (N, P, K), which indirectly influenced micronutrient dynamics including manganese. However, DTPA-extractable Mn showed non-significant variation, indicating that potassium had limited direct effect on Mn availability in soil . This may be due to Mn being more controlled by soil pH and redox conditions rather than macronutrient interactions.

3.4.4 Copper (mg kg^{-1})

Data pertaining to copper as influenced due to the potassium application is presented in table 8. It was seen from the observations that, copper value ranged from 1.68 - 1.89 & 1.84 - 2.02 mg kg^{-1} at Pardi and Sawandri village respectively. The results revealed that the slightly higher available copper content (1.89 mg kg^{-1}) was found at Pardi village with the application of 300 g K at BT (Dec) + 300 g K after 60 days + KNO_3 @ 1.5% spray after 90 days along with recommended dose of fertilizers (T_9). However, the treatment differences were not significant.

The slightly higher available copper content (2.02 mg kg^{-1}) at sawandri village with the application of RDF + 400 g K at BT (Dec) + 400 g K after 60 Days + KNO_3 @ 1.5% spray after 90 Days (T_{10}). However, the treatment differences were not significant. Similar results were also shown by Srivastava *et al.* (2022) that, the concentration of Cu in soil ranged from 2.5 to 5.1 mg kg^{-1}.

4. Conclusion

From the present study it can be concluded that, application of RDF (1200g N + 600g P_2O_5) along with 300 g K at BT (Dec) + 300 g K after 60 Days + KNO3 @ 1.5% spray after 90 days was found enhancing fruit yield and quality of Nagpur mandarin. Also, found beneficial for increasing leaf nutrient status and soil fertility. proved most effective in enhancing macro- and micronutrient availability and uptake. Improved nutrient status indicates better physiological functioning of plants, which ultimately contributes to higher productivity and fruit quality. The study also highlights the importance of potassium management in Vertisol conditions, where nutrient availability is often constrained. These findings emphasize that integrated nutrient management practices can optimize fertilizer use efficiency and sustain long-term soil health. Therefore, adoption of appropriate potassium fertilization strategies can play a crucial role in improving citrus production and ensuring sustainable orchard management.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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Competing Interests

Authors have declared that no competing interests exist.

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