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Effect of silicon application on soil and leaf nutrient status of Nagpur mandarin (*Citrus reticulata* blanco)

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Abstract

An investigation entitled "Effect of soil and foliar application of silicon on leaf nutrient status and soil properties of Nagpur mandarin (*Citrus reticulata* Blanco)" was carried out at the All India Coordinated Research Project (AICRP) on Fruits during two consecutive years, 2023-24 and 2024-25. The experiment was conducted to evaluate the effect of different levels of soil and foliar application of silicon on leaf nutrient status and soil properties and to determine the optimum level of silicon application for Nagpur mandarin. The experiment was laid out in a Factorial Randomized Block Design with sixteen treatment combinations. The results indicated that leaf nutrient status and soil available silicon were influenced by different levels of soil and foliar application of silicon. The combined soil application of calcium silicate @ 150 g plant⁻¹ through soil and foliar application of potassium silicate @ 3000 ppm recorded the highest leaf nitrogen, phosphorus, potassium, iron, zinc, manganese, copper and silicon contents along with the maximum soil available silicon. However, soil properties viz., pH, electrical conductivity, organic carbon and soil macronutrients were not influenced by silicon application.

Keywords: Nagpur mandarin, *Citrus reticulata* Blanco, silicon application, leaf nutrient status

Introduction

Nagpur mandarin (*Citrus reticulata* Blanco) is one of the most important commercial citrus cultivars grown in India and occupies a prominent position in the citrus industry due to its attractive orange-coloured fruits, excellent flavour, high juice content and superior nutritional quality. The cultivar is predominantly grown in the Vidarbha region of Maharashtra, which is recognised as the principal mandarin-producing belt of the country. According to the latest horticultural statistics, citrus is cultivated over about 11.4 lakh ha in India with an annual production of nearly 149 lakh tonnes, of which mandarin accounts for a major share (Anonymous, 2024) ^[1]. Maharashtra is one of the leading citrus-producing states, where Nagpur mandarin contributes substantially to farmers' income, employment generation and the horticultural economy of the region. The fruits are rich in vitamin C, sugars, organic acids, minerals and antioxidant compounds and are widely consumed both as fresh fruit and in processed products such as juice, squash, concentrates and marmalade (Gopalan *et al.*, 2012; FAOSTAT, 2024) ^[5, 8]. Although Nagpur mandarin is highly valued for its fruit quality, its productivity has remained below the genetic potential due to several production constraints such as nutrient imbalance, declining soil fertility, moisture stress, erratic rainfall, high temperatures during critical growth stages, inadequate nutrient management and the prevalence of physiological disorders. These factors adversely influence root growth, nutrient uptake, photosynthesis, flowering, fruit retention and fruit quality, ultimately resulting in poor orchard productivity and profitability (Sharma *et al.*, 2016; Srivastava and Singh, 2018) ^[27, 28]. Therefore, adoption of efficient nutrient management practices has become essential for sustaining productivity and maintaining soil health in mandarin orchards. Silicon (Si), the second most abundant element in the earth's crust after oxygen, has gained considerable attention in recent years because of its beneficial effects on plant growth, mineral nutrition and tolerance to environmental stresses. Although silicon is not recognised as an essential nutrient for higher plants, it is regarded as a beneficial element due to its positive influence on crop growth, productivity and stress tolerance (Epstein, 1999; Ma and Takahashi, 2002) ^[4, 17].

Silicon is absorbed by plants mainly in the form of monosilicic acid and is subsequently deposited as amorphous silica in plant tissues, where it strengthens cell walls, improves tissue rigidity and enhances resistance to lodging, pests and diseases (Ma *et al.*, 2001) ^[18]. Silicon also reduces transpiration losses, improves water use efficiency, maintains leaf erectness and enhances photosynthetic efficiency thereby improving plant performance under drought and heat stress (Savant *et al.*, 1999; Gong *et al.*, 2003) ^[7, 25].

Apart from its structural role, silicon plays an important role in improving nutrient use efficiency and maintaining soil fertility. It enhances the uptake and translocation of essential macro- and micronutrients, increases phosphorus availability, reduces nutrient fixation and alleviates aluminium and heavy metal toxicity. Silicon also activates antioxidant defence mechanisms, protects cellular membranes against oxidative damage and improves physiological processes associated with mineral nutrition and carbon assimilation (Liang *et al.*, 2007; Cooke and Leishman, 2016) ^[2, 14]. Consequently, silicon application contributes to improved plant vigour, leaf nutrient status, fruit quality and yield particularly under nutrient-deficient and moisture-stressed conditions.

The beneficial effects of silicon have been widely reported in several horticultural crops, including mango, banana, papaya, guava, grape and citrus. Both soil application of calcium silicate and foliar application of potassium silicate have been found to enhance nutrient uptake, improve fruit quality, increase stress tolerance and promote higher productivity. In citrus, silicon application has been reported to improve leaf nutrient concentration, chlorophyll content, fruit quality and tolerance to drought and salinity stress (Fatma *et al.*, 2017; Mohamed *et al.*, 2018; Masoud *et al.*, 2019; Mounika *et al.*, 2021) ^[6, 20, 22, 23]. Similar beneficial effects have also been reported in mango (Lokesh *et al.*,

2020; Kachhadia *et al.*, 2020) ^[11, 15], banana (Hanumanthaiah *et al.*, 2015; Vijayan *et al.*, 2021) ^[10, 29], guava (Das *et al.*, 2017) ^[3] and papaya (Patel *et al.*, 2021) ^[24], indicating the broad potential of silicon nutrition in improving growth, nutrient status and fruit productivity.

Despite the recognised benefits of silicon in many horticultural crops, systematic information on its integrated soil and foliar application in Nagpur mandarin under the semi-arid conditions of Vidarbha is limited. Moreover, information regarding its influence on leaf nutrient status and soil properties under these conditions is inadequate. Therefore, the present investigation was undertaken to evaluate the effect of soil and foliar application of silicon on leaf nutrient status and soil properties of Nagpur mandarin and to identify an appropriate silicon management strategy for improving nutrient uptake and sustaining orchard productivity.

Materials and Methods

The present investigation entitled "Effect of soil and foliar application of silicon on leaf nutrient status and soil properties of Nagpur mandarin (*Citrus reticulata* Blanco)" was conducted during 2023-24 and 2024-25 at the All India Coordinated Research Project (AICRP) on Fruits, Dr. PDKV Akola, Maharashtra. The experiment was undertaken to evaluate the effect of soil and foliar application of silicon on leaf nutrient status and soil properties of Nagpur mandarin and to determine the optimum level of silicon application. The experiment was laid out in a Factorial Randomized Block Design with sixteen treatment combinations replicated thrice. Four levels of soil application of calcium silicate viz., control (S₁), 50 g plant⁻¹ (S₂), 100 g plant⁻¹ (S₃) and 150 g plant⁻¹ (S₄) and four levels of foliar application of potassium silicate viz., control (F₁), 1000 ppm (F₂), 2000 ppm (F₃) and 3000 ppm (F₄) were evaluated in the present investigation.

Table 1: Effect of calcium silicate and potassium silicate on leaf nutrient status (pooled mean)

Leaf nutrient status								
Treatments	Leaf N (%)	Leaf P (%)	Leaf K (%)	Leaf Cu (ppm)	Leaf Zn (ppm)	Leaf Fe (ppm)	Leaf Mn (ppm)	Leaf Si (%)
S ₁	2.17	0.11	1.47	10.70	22.78	75.17	54.92	0.50
S ₂	2.33	0.12	1.53	10.89	23.85	78.63	60.18	0.63
S ₃	2.43	0.14	1.55	11.77	24.87	79.68	65.69	0.62
S ₄	2.49	0.15	1.55	11.73	25.63	81.80	70.42	0.68
'F' Test	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig
SE (m) ±	0.04	0.005	0.01	0.10	0.27	0.77	0.56	0.03
CD at 5%	0.11	0.02	0.03	0.31	0.80	2.30	1.67	0.09
F ₁	2.15	0.12	1.45	10.32	22.48	74.39	56.35	0.50
F ₂	2.31	0.12	1.52	10.85	23.07	78.02	59.46	0.63
F ₃	2.42	0.14	1.54	11.70	25.05	80.42	63.81	0.60
F ₄	2.53	0.16	1.60	12.23	26.53	82.45	71.58	0.70
'F' Test	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig
SE(m) ±	0.04	0.005	0.01	0.10	0.27	0.77	0.56	0.03
CD at 5%	0.11	0.02	0.03	0.31	0.80	2.30	1.67	0.09
Interaction Effect (S×F)								
S ₁ F ₁	1.92	0.10	1.41	10.26	21.27	72.02	51.18	0.39
S ₁ F ₂	2.09	0.10	1.49	10.36	21.94	74.57	52.30	0.54
S ₁ F ₃	2.22	0.12	1.44	10.87	23.01	74.88	52.66	0.40
S ₁ F ₄	2.44	0.13	1.56	11.29	24.89	79.20	63.55	0.68
S ₂ F ₁	2.10	0.11	1.47	10.37	22.15	73.53	54.23	0.51
S ₂ F ₂	2.26	0.16	1.53	10.67	23.18	77.10	56.33	0.72
S ₂ F ₃	2.43	0.12	1.54	10.91	24.09	80.75	58.19	0.64
S ₂ F ₄	2.52	0.15	1.59	11.62	25.96	83.13	71.96	0.65
S ₃ F ₁	2.33	0.12	1.49	10.27	22.36	75.48	54.68	0.57
S ₃ F ₂	2.36	0.14	1.51	11.75	24.12	78.85	62.06	0.56
S ₃ F ₃	2.46	0.15	1.57	12.32	25.68	80.93	71.18	0.64
S ₃ F ₄	2.58	0.17	1.61	12.75	27.30	83.45	74.82	0.70
S ₄ F ₁	2.25	0.14	1.43	10.36	24.13	76.52	65.32	0.53
S ₄ F ₂	2.54	0.14	1.57	10.61	23.02	81.55	67.17	0.70
S ₄ F ₃	2.56	0.16	1.59	12.70	27.42	85.10	73.20	0.71
S ₄ F ₄	2.60	0.18	1.62	13.26	27.97	84.03	75.98	0.77
'F' Test	Sig	NS	Sig	Sig	Sig	Sig	Sig	Sig
SE(m) ±	0.07	0.010	0.02	0.21	0.53	1.54	1.13	0.06
CD at 5%	0.23	-	0.06	0.62	1.59	4.60	3.35	0.18

The pooled data presented in Table 1 revealed that soil application of calcium silicate, foliar application of potassium silicate and their interaction significantly influenced the leaf nutrient status of Nagpur mandarin.

Soil application of calcium silicate significantly improved the concentration of both macro- and micronutrients in leaves. Among the soil treatments soil application of calcium silicate @ 150 g plant⁻¹ recorded the highest leaf nitrogen (2.49%), phosphorus (0.15%), potassium (1.55%), zinc (25.63 ppm), iron (81.80 ppm), manganese (70.42 ppm) and silicon (0.68%). However, these parameters were found at par with soil application of 100 g plant⁻¹. Leaf copper content was maximum in S₃ (11.77 ppm), which was statistically comparable with S₄ (11.73 ppm). The lowest nutrient concentrations were consistently recorded under the control treatment with leaf nitrogen (2.17%), phosphorus (0.11%), potassium (1.47%), copper (10.70 ppm), zinc (22.78 ppm), iron (75.17 ppm), manganese (54.92 ppm) and silicon (0.50%).

The improvement in leaf nutrient status with increasing calcium silicate levels may be attributed to enhanced root growth, greater nutrient availability in the rhizosphere and improved absorption and translocation of nutrients. Silicon also enhances membrane stability, reduces oxidative damage and improves root hydraulic conductivity thereby facilitating efficient uptake of both macro- and micronutrients. Increased silicon accumulation in leaf tissues further promotes nutrient use efficiency and maintains favourable physiological activity under field conditions. These findings are consistent with those reported by Ma and Yamaji (2006) [16], who demonstrated that silicon enhances nutrient uptake through improved root function. Epstein (1999) [4] and Marschner (2012) [19] also reported that silicon promotes balanced mineral nutrition by improving nutrient absorption and translocation. Similar beneficial effects of calcium silicate on leaf nutrient composition in citrus and other horticultural crops have been reported by Matichenkov and Bocharnikova (2001) [21] and Guntzer *et al.* (2012) [9].

Foliar application of potassium silicate significantly increased leaf nutrient concentrations compared with the control. Among the treatments foliar application potassium silicate @ 3000 ppm recorded the highest leaf nitrogen (2.53%), phosphorus (0.16%), potassium (1.60%), copper

(12.23 ppm), zinc (26.53 ppm), iron (82.45 ppm), manganese (71.58 ppm) and silicon (0.70%). These parameters were found at par with foliar application of potassium silicate 2000 ppm. The lowest nutrient concentrations were observed under the control. Foliar-applied potassium silicate is readily absorbed through leaf tissues, supplying both potassium and soluble silicon directly to metabolically active organs. Silicon strengthens cell walls, enhances chloroplast function and improves photosynthetic efficiency resulting in increased nutrient assimilation. In addition, potassium plays a vital role in enzyme activation osmotic regulation and assimilate translocation, thereby contributing to improved nutrient accumulation in leaves. The present findings corroborate those of Liang *et al.* (2015) [13], who reported enhanced nutrient uptake following foliar silicon application. Similar observations were made by Keeping (2017) [12] and Savvas and Ntatsi (2015) [26] who attributed improved leaf nutrient composition to enhanced physiological activity, photosynthesis and nutrient use efficiency in silicon-treated plants.

The interaction between soil and foliar silicon application was significant for all leaf nutrient parameters (Table 1). The soil application of calcium silicate @ 150 g plant⁻¹ along with foliar application of potassium silicate @ 3000 ppm recorded the highest concentrations of leaf nitrogen, phosphorus, potassium, copper, zinc, iron, manganese and silicon. However, these parameters were found comparable with soil application of calcium silicate @ 100 g plant⁻¹ along with foliar application of potassium silicate @ 3000 ppm. The lowest nutrient concentrations were recorded under the untreated combination (S₁F₁). The superior performance of the combined treatment may be attributed to the complementary effects of soil- and foliar-applied silicon. Soil application ensured continuous silicon availability and improved root-mediated nutrient absorption, whereas foliar application provided a rapid supply of soluble silicon and potassium to leaves. This integrated approach enhanced nutrient acquisition, translocation and utilization, resulting in greater accumulation of macro- and micronutrients in leaf tissues. Similar synergistic effects of integrated silicon application have been reported by Ma and Yamaji (2006), Guntzer *et al.* (2012) [9, 16] and Liang *et al.* (2015) [13].

Table 2: Effect of calcium silicate and potassium silicate on soil nutrient status

Treatments	Soil nutrient status					
	Soil pH	EC (dS/m)	Organic carbon (%)	N (kg ha ⁻¹)	P (kg ha ⁻¹)	K (kg ha ⁻¹)
Soil application (S)						
S ₁	7.61	0.29	0.64	209.02	15.55	327.10
S ₂	7.65	0.31	0.67	211.55	16.29	341.27
S ₃	7.62	0.33	0.70	215.26	17.21	358.61
S ₄	7.67	0.32	0.71	215.30	17.49	377.43
'F' Test	NS	NS	NS	NS	NS	NS
SE(m) ±	0.06	0.007	0.013	1.25	0.21	4.88
CD at 5%	-	-	-	-	-	-
Foliar application (F)						
F ₁	7.67	0.31	0.67	212.03	16.13	343.68
F ₂	7.64	0.32	0.69	210.82	16.40	347.57
F ₃	7.59	0.31	0.68	213.19	16.81	359.43
F ₄	7.65	0.30	0.68	215.10	17.19	353.73
'F' Test	NS	NS	NS	NS	NS	NS
SE(m) ±	0.06	0.007	0.013	1.25	0.21	4.88
CD at 5%	-	-	-	-	-	-
Interaction effect (S × F)						
'F' Test	NS	NS	NS	NS	NS	NS
SE(m) ±	0.12	0.014	0.03	2.51	0.43	9.76
CD at 5%	-	-	-	-	-	-

The pooled data presented in Table 2 revealed that soil application of calcium silicate, foliar application of potassium silicate and their interaction did not significantly influence soil pH, electrical conductivity (EC), organic carbon (OC) or available nitrogen, phosphorus and potassium after harvest. Under soil application, pH ranged from 7.61 to 7.67, EC from 0.29 to 0.33 dS m⁻¹ and organic carbon from 0.64 to 0.71%, while available nitrogen, phosphorus and potassium varied from 209.02-215.30 kg ha⁻¹, 15.55-17.49 kg ha⁻¹ and 327.10-377.43 kg ha⁻¹, respectively. Similarly, under foliar application pH ranged from 7.59 to 7.67, EC from 0.30 to 0.32 dS m⁻¹, organic carbon from 0.67 to 0.69%, available nitrogen from 210.82 to 215.10 kg ha⁻¹, phosphorus from 16.13 to 17.19 kg ha⁻¹ and potassium from 343.68 to 359.43 kg ha⁻¹. Although slight numerical increases were observed with higher levels of calcium silicate and potassium silicate, these differences were statistically non-significant. The interaction between soil and foliar application of silicon was non-significant for soil pH, EC, organic carbon and available nitrogen, phosphorus and potassium.

Conclusion

The interaction of soil application of calcium silicate @ 100 g plant⁻¹ along with foliar application of potassium silicate @ 3000 ppm was found to be the most effective treatment for improving the leaf nutrient status of Nagpur mandarin. This treatment enhanced the concentrations of leaf nitrogen, phosphorus, potassium, zinc, copper, iron, manganese and silicon indicating improved nutrient uptake and accumulation. Therefore, the combined application of 100 g plant⁻¹ calcium silicate and 3000 ppm potassium silicate can be recommended as an effective silicon management practice for improving the leaf nutritional status of Nagpur mandarin.

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