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Relationship between soil properties and soil K forms in citrus orchards of central India

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ABSTRACT

Role of potassium in maintaining the quality of citrus fruits is well established. However, information about relationship between soil [properties and different forms of potassium is still little understood under citrus. With this objective, the present investigation was undertaken during 2020-2021. As many fifteen orchards were selected from seven locations of central India. The soil samples were collected from 0-30 cm (surface) and 30-60 cm (subsurface) cm and analysed for different physicochemical properties and soil K-fractions. The soil pH and EC varied narrowly with minimum variation, denoting that soils were non-saline in nature. However, soils were medium to high in organic carbon content coupled with slightly calcareous to highly calcareous nature of these soils. The amount of water soluble- K, exchangeable K, non-exchangeable K, lattice K and total K ranged from 21.19 to 31.54, 136.06 to 215.68, 311.07 to 450.79, 9415.58 to 9772.42 and 10031 to 10420 mg kg^{-1}, respectively, in surface soils. While in subsurface soils, these fractions of soil K viz., water soluble- K, exchangeable K, non-exchangeable K, lattice K and total K showed a comparatively narrower variation from 18.90 to 29.70, 125.08 to 205.73, 308.43 to 429.70, 9438.46 to 9791.05 and 10028 to 10400 mg kg^{-1} respectively, in subsurface soils. Our observations further showed that different soil K fractions decreased with soil depth; whereas, total and lattice potassium showed no definite trend with soil depth.

Keywords: Soil properties, mandarin orchards, surface soils, subsurface soils, potassium fractions, central |India

INTRODUCTION

Nagpur mandarin (*Citrus reticulata* Blanco) is locally known as orange or santra belongs to family Rutaceae (Srivastava and Kohli, 1997) being commercially grown in tropical and subtropical region of India (Srivastava and Singh, 2008a). Nagpur mandarins are one of the best mandarins in the world. India ranks 9th in mandarin producing countries. Citrus is cultivated extensively around on 1.85 lakh hectares area of Central India as an irrigated crop (Srivastava, 2024). The acreage under the crop is increasing exponentially each year due to its production economics as well as the cultivar suitability in this region (Dass and Srivastava, 1997; Srivastava and Singh, 2002). Potassium is the major nutrient , an abundant element in soils , but the K content of the soil is reported to vary as per crop rhizosphere and physico-chemical properties of soil (Srivastava and Singh, 2001; 2002; 2008b). Potassium exists in soil in different forms viz. water soluble, exchangeable, non-exchangeable (fixed), mineral K, lattice K and total K (Srivastava *et al.,* 1998; Ram *et al.,* 1995; Srivastava *et al.,* 2017). These fractions exist in dynamic equilibrium among themselves and these forms in turn govern the K nutrition to crops (Srivastava and Srivastava, 1992). But these forms are not homogeneously distributed in soils. Its amount in soil depends on the material, degree of weathering, K gains through manures and fertilizers and losses due to crop removal, erosion and leaching (Shirgure and Srivastava, 2013). Usually, the amounts of non-exchangeable and total K present in the soil are high compared to water soluble and exchangeable K (Singh *et al.,* 1999). The dynamics of potassium in soil depends on the magnitude of equilibrium among various forms and mainly governed by the physicochemical properties of soil. The bulk of soil potassium (about 98% of total K) usually exists in unavailable form in primary (micas and feldspars) and secondary (illite group) clay minerals (Singh *et al.,* 2014). In this

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background information, the present study was carried out to study the relationship between different physico-chemical properties of the soil collected under citrus and their relationship with soil K-fractions.

MATERIALS AND METHODS

Collection of soil samples

An exploratory survey of Nagpur mandarin (Citrus *reticulata* Blanco budded on rough lemon rootstock, *Citus jambhiri* Lush) orchards of Katol tahsil, Nagpur district was carried out during 2020 -21. A total of 15 mandarin orchards were identified on the bass of their production sustainability representing their age between 15 and 20-years. The soil samples were collected from surface (0-30cm) and subsurface (30-60cm) depth considering the distribution of their feeder roots (Huchche *et al.,* 1999).

Analysis of soil samples

The soil pH and EC were determined by digital meter using glass electrode and and conductivity meter, respectively, in 1:2:5 soil: water ratio as described by Jackson (1973). Organic carbon was determined as per wet digestion method as described by Jackson (1973). Calcium carbonate was estimated by rapid titration method using phenolphthalein indicator as described by Piper (1966). The processed samples were analysed for different K fraction by adopting standard analytical procedures. Water soluble- K was determined by using saturation method (Jackson, 1973), while exchangeable- K was determined by using 1N ammonium acetate extraction (Piper, 1966). Non-exchangeable K was determined by using 1N boiling HNO_3 extraction method (Jackson, 1973). Lattice- K was determined by subtracting the sum of above 3 fractions from total potassium (Ranganathan and Satyanarayana, 1980).Total K was determined by using HF digestion method (Jackson, 1973).

RESULTS AND DISCUSSION

Changes in soil physico-chemical properties

The soils of Nagpur mandarin orchards showed the majority of soils as slightly acidic to slightly alkaline in nature (Table 1), with soils showing slightly higher pH with increase in the depth of soils.The pH of surface soil varied from 6.59 to 8.00, and considering all the surface soils, soil pH increased with depth (Table 1). Whereas, in subsurface soils, soil pH varied from 7.00 to 8.20. Similar observations were earlier recorded by Surwase *et al.* (2016) who reported pH of soils of Kalmeshwar tahsil of Nagpur mandarin orchards varying between 6.5 and 8.8 Indicating moderately alkaline to strongly alkaline in nature. The EC of all these soils were observed less than 1 dS m^{-1}. The EC ranged from 0.188 to 0.275 dS m^{-1} in surface soils; whereas in subsurface soils, soil EC ranged from 0.212 to 0.299 dS m^{-1} Nagpur mandarin orchards. The range of EC of both surface and subsurface layers soil were within the acceptable limit of growing Nagpur mandarin as suggested previously by number of studies (Srivastava and Singh, 2002a ; 2002b). These ranges of soil EC showed that all the soils were non-saline in nature and suitable for healthy plant growth (Table 1). Previous studies reported that the EC of soils at all the depths of citrus orchards included in this study was below 4.0 dS m^{-1} which align these results as non-saline (Shah *et al.,* 2012; Srivastava *et al.,* 2008).

The data regarding the organic carbon (Table 1) showed that in surface soil, it varied from 6.10 to 10.91 g kg^{-1}; whereas, it varied from 5.90 to 9.85 g kg^{-1} in subsurface soils of mandarin orchards. Similar findings were reported by Fang *et al.* (2010) who studied the soil fertility and physical properties of citrus orchards displaying organic matter content in soils ranging between 2.0 and 54.9 g kg^{-1}. While, the data pertaining $CaCO_3$ (Table 1), it ranged from 2.00 to 6.00 percent in surface and 2.50 to 6.50 percent in subsurface soils. Similar findings were reported by other studies (Srivastava and Singh , 2004; 2005; Srivastava , 2012) in Vidarbha region of Maharashtra while suggesting the soil suitability criteria in relation to optimum fruit yield of Nagpur mandarin , which later formed the basis for developing the soil health card for the first time in Nagpur mandarin.

Table 1: Physico-chemical properties of soils at 0-30 cm and 30-60 cm depths under Nagpur mandarin orchards of central India

Sr. No.	Locations	Depth (cm)	pH	EC (dSm^{1})	OC ($g\ kg^{-1}$)	$CaCO_3$ (%)
1	Ladgaon	0-30	7.82	0.223	6.23	6.00
		30-60	7.90	0.275	6.00	6.50
2	Ladgaon	0-30	7.90	0.228	9.21	3.00
		30-60	7.90	0.245	9.10	3.50
3	Ladgaon	0-30	7.82	0.257	8.35	2.00
		30-60	7.90	0.260	8.00	2.50
4	Dhiwarwadi	0-30	7.72	0.255	7.53	5.25
		30-60	7.80	0.299	7.31	5.25
5	Dhiwarwadi	0-30	7.89	0.188	6.45	3.75
		30-60	7.90	0.224	6.20	5.00
6	Dhiwarwadi	0-30	8.00	0.263	10.05	5.50
		30-60	8.20	0.274	9.85	5.80
7	Fetri	0-30	7.32	0.275	8.32	3.50
		30-60	7.50	0.298	8.25	3.75
8	Lamdhan	0-30	7.21	0.198	10.91	3.28
		30-60	7.30	0.212	8.52	4.85
9	Lamdhan	0-30	6.79	0.261	9.80	3.75
		30-60	7.10	0.273	7.00	4.50
10	Lamdhan	0-30	7.13	0.233	8.37	3.00
		30-60	7.20	0.233	7.25	3.53
11	Kalkuhi	0-30	6.96	0.277	8.70	4.75
		30-60	7.10	0.279	7.55	5.25
12	Kalkuhi	0-30	6.59	0.225	6.29	3.80
		30-60	7.08	0.237	6.00	4.00
13	Parsodi	0-30	6.63	0.216	9.72	4.25
		30-60	7.10	0.288	8.90	5.00
14	Parsodi	0-30	6.80	0.238	6.10	3.90
		30-60	7.00	0.295	5.90	4.00
15	Amnergondhi (rithi)	0-30	7.04	0.213	10.02	4.85
		30-60	7.30	0.229	9.80	5.00

These observations further showed that calcareous soils (pH 7.41 to 8.38) with high free $CaCO_3$ content (3.13 to 15.48%) indicated the moderate to high calcareous nature of Nagur mandarin growing soils.

Depthwise changes in forms of soil potassium

Different forms of potassium are considered quite important to know the potassium supplying status of the soil. Potassium from minerals are gradually released to more available form. About 1 to 10 percent of total K is present in non-exchangeable form which are slowly made available to plants on account of its fixation by soil colloids (Srivastava and Srivastava, 1992a; 1992b). The knowledge of various forms of K viz., water-soluble, exchangeable and non-exchangeable and an understanding of conditions controlling the availability to growing crops is important for the appraisal of the available K in the soil (Srivastava and Mousavi, 2025).

Water soluble K: The water-soluble potassium is the fraction of soil potassium that is readily assessable to plants. Nevertheless, this is very small fraction of total potassium and even in the fertile soil; this form alone cannot fulfill the major K- requirement of the citrus plants. Water soluble K is taken up directly by plants but is usually found in low quantities in soils. The data on water soluble potassium of soils (Table 2) revealed that water soluble K in surface soils of mandarin orchards ranged from 21.19 to 31.54 mg kg^{-1}; whereas in subsurface soils, water soluble K varied from 18.90 to 29.70 mg kg^{-1}.The lowest water-soluble K of 21.19 mg $kg^{-1}$was observed in location 7 (Fetri) and highest 31.54 mg kg^{-1} in the location 15 (Amnergondhi) considering the surface soils. Whereas in subsurface soil layer, the lowest water-soluble K of 18.90 mg kg^{-1} was recorded at location 2 (Ladgaon) and highest of 29.70 mg kg^{-1} was observed at location 15 (Amnergondhi). Similar findings were observed by Saini and Grewal (2014), who reported that the water-soluble potassium ranging from the 8 to 58 mg kg^{-1}. The readily available or water soluble- K was reported to be a dominant fraction in the initial stage ; while exchangeable and non-exchangeable contributed more at the later stages of plant growth (Sharma *et al.,* 2009).

Exchangeable K: The exchangeable K is readily available to the growing citrus plant. Exchangeable K is the popular index for K-fertility, so far consisting to 0.9 to 2 percent of the total K in soils. The data on exchangeable K in surface soil ranged from 136.06 to 215.68 mg kg^{-1} and in subsurface layers, it ranged from 125.08 to 205.73 mg kg^{-1} (Table 2). The lowest exchangeable K 136.06 mg kg^{-1} was observed at the location 1 (Ladgaon) and highest.

Table 2: Different forms of soil potassium at 0-30cm and 30-60 cm depths in Nagpur mandarin orchards of central India

Sr. No.	Locations	Depth (cm)	WS-K (mg kg^{-1})	ExK (mg kg^{-1})	NEK (mg kg^{-1})	LK (mg kg^{-1})	TK (mg kg^{-1})
1	Ladgaon	0-30	25.07	136.06	439.99	9749.88	10351
		30-60	23.80	134.11	400.51	9771.58	10330
2	Ladgaon	0-30	21.83	140.50	390.25	9772.42	10325
		30-60	18.90	125.08	386.97	9791.05	10322
3	Ladgaon	0-30	21.65	165.90	337.59	9694.86	10220
		30-60	21.00	160.75	332.16	9701.09	10215
4	Dhiwarwadi	0-30	24.42	185.71	345.53	9584.34	10140
		30-60	21.80	178.87	337.43	9561.90	10100
5	Dhiwarwadi	0-30	26.04	150.60	358.52	9514.84	10050
		30-60	25.00	143.07	340.07	9521.86	10030
6	Dhiwarwadi	0-30	28.31	195.78	403.33	9415.58	10043
		30-60	26.72	176.76	398.06	9438.46	10040
7	Fetri	0-30	21.19	170.92	411.24	9676.36	10280
		30-60	19.60	146.02	398.15	9706.23	10270
8	Lamdhan	0-30	21.83	185.82	311.07	9512.28	10031
		30-60	19.60	178.91	308.43	9521.06	10028
9	Lamdhan	0-30	25.07	175.88	390.15	9673.90	10265
		30-60	23.45	155.97	384.88	9675.70	10240
10	Lamdhan	0-30	24.56	205.35	370.50	9550.59	10151
		30-60	22.00	185.82	355.84	9576.34	10140
11	Kalkuhi	0-30	28.31	175.85	418.60	9675.24	10298
		30-60	26.65	165.92	410.06	9672.37	10275
12	Kalkuhi	0-30	26.23	159.60	350.61	9582.56	10119
		30-60	22.48	136.06	345.34	9596.12	10100
13	Parsodi	0-30	28.31	215.68	375.50	9560.51	10180
		30-60	25.50	201.14	369.16	9569.20	10165
14	Parsodi	0-30	25.07	195.78	434.34	9644.81	10300
		30-60	22.50	181.23	423.33	9657.94	10285
15	Amnergondhi (rithi)	0-30	31.54	215.68	450.79	9721.99	10420
		30-60	29.70	205.73	429.70	9734.87	10400

and highest of 205.73 mg kg^{-1}at the location 15 (Amnergondhi) in subsurface layer of Nagpur mandarin orchards. While, Location 15 (Amnergondh) soils, the exchangeable -K content was observed highest in both surface and sub-surface layer of soil of Nagpur mandarin orchards. Similar findings were earlier observed by Dhakad *et al.*(2017) who conducted an experiment carrying 120 GPS - based surface soil samples (0-15cm) collected from twenty-three villages of four blocks of Gwalior district and the average values for water soluble-K, exchangeable-K, non-exchangeable-K. Lattice-K and total K were observed as 15.1, 230.5, 548.4 mg Kg^{-1}, 1.403% and 1.482%, respectively.

44 Non-exchangeable K: The total K present in non-exchangeable form is slowly made available on account of its fixation by soil colloids (Srivastava, 2024). The non-exchangeable K (table 2) showed a variation from 311.07 to 450.79 mg kg^{-1} in surface soil layer; whereas it varied from 308.43 to 429.70 mg g^{-1} in surface layers of Nagpur mandarin orchards. The lowest non-exchangeable -|K of 311.07 mg $kg^{-1}$was recorded at location 8 (Lamdhan) and highest of 450.79 mg kg^{-1}at location 15 (Amnergondhi) in surface soil of orchards. Whereas, considering subsurface soils, the lowest non-exchangeable -|K of 308.43 mg kg^{-1} was observed at location 8 (Lamdhan) and highest of 429.70 mg kg^{-1} registeredat location 15 (Amnergondhi). These observations suggested the lowest non-exchangeable K in Lamdhan area and highest non-exchangeable K in Amnergondhi (rithi) growing Nagpur mandarin. Similar observations were earlier made byGangopadhyay *et al.* (2005) studying the forms of potassium and recorded that non-exchangeable potassium varied from 410.5 to 844.5 mg kg^{-1} with a mean value of 523.3 mg kg^{-1}. According to increasing order of plant availability, soil K exists in four forms i.e. mineral (5000-25000 ppm), non-exchangeable (50750 ppm), exchangeable (40-600 ppm) and solution (1-10 ppm). K -cycling or transformations among the K forms in soils are dynamic. Soils that are rich in vermiculite and micas have large amounts of non-exchangeable K, whereas soil containing kaolinite, quartz and other siliceous minerals contain less available and exchangeable K (Srivastava, 2011; Sparke and Huang, 1985).

Lattice K: The data regarding the lattice K (Table 2) showed that the lattice K ranged from 9415.58 to 9772.42 mg kg^{-1} in surface soils and it varied from 9438.46 to 9791.05 mg kg^{-1} in subsurface layers of mandarin orchards soils. The lowest lattice- K of 9415.58 mg $kg^{-1}$was observed at location 6 (Dhiwarwadi) and highest of 9772.42 mg kg^{-1}at location 2 (Ladgaon) in surface layer of soil. While, lattice-K of 9438.46 mg $kg^{-1}$was observed at location 6 (Dhiwarwadi) and 9791.05 mg kg^{-1}at location 2 (Ladgaon) considering subsurface layer of soil in Nagpur mandarin orchards. The observations suggested the lowest lattice- K was observed in Dhiwarwadi area and highest lattice -K in Ladgaon area considering both surface as well as subsurface layers of soil. The similar results were presented by Dhakad *et al,* (2017).who reported that the values of lattice- K ranged from 10720 to 17290 mg kg^{-1}.

Total-K: The data obtained from the investigation regarding total K of Nagpur mandarin orchards (Table 2) showed that total-K in surface soils ranged from 10031 to 10420 mg kg^{-1}; whereas it ranged from 10028 to 10400 mg kg^{-1} in subsurface soils of mandarin orchards. The lowest total K of 10031 mg $kg^{-1}$was observed in location 8 (Lamdhan) and highest 10420 mg kg^{-1} in location 15 (Amnergondhi) in surface layer of soil. Whereas, in subsurface layer lowest 10028 mg kg^{-1} total-K was recorded in location 8 (Lamdhan) and highest of 10040 mg kg^{-1} in location 15 (Amnergondhi) in Nagpur mandarin orchards. Similar findings were observed by Dhakad *et al.* (2017) who reported total potassium having a wide variation from 11270 to 18590 mg Kg^{-1} under different blocks with an average value of 14820 mg kg^{-1}. Similarly, Anupama *et al,* (2018) carried out a study on the fractions of potassium in surface and surface soils and reported total- K raning from 8550.50 to 16490.60 mg kg^{-1} with mean value 12855.24 mg kg^{-1}in surface soil and in subsurface soil, it ranged from 9445.60 to 16785.60 mg kg^{-1} with mean value 12714.73 mg kg^{-1}.

These observations suggested a strong relationship of different soil properties with different soil K-fractions, which in turn, dictated the fruit yield and quality both.

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