Soil Environ. 43(1): 27-35, 2024
DOI:10.25252/SE/2024/243148
Online ISSN: 2075-1141
Print ISSN: 2074-9546

Soil characterization and plant nutrient indexing of citrus orchards in the central Punjab of Pakistan

Muhammad Ashraf[1,3*], Asif Minhas[1], Sajid Masood[1], Naeem Akhtar[2], Sher Muhammad Shahzad[3] and Muhammad Asif[4]

[1]Department of Soil Science, Faculty of Agricultural Sciences & Technology, Bahauddin Zakariya University, Multan
[2]Department of Plant Breeding and Genetics, College of Agriculture, University of Sargodha, Sargodha
[3]Department of Soil & Environmental Sciences, College of Agriculture, University of Sargodha, Sargodha
[4]Department of Agronomy, College of Agriculture, University of Sargodha, Sargodha

***[Received:** November 13, 2023* ***Accepted:** April 03, 2024* ***Published Online:** May 31, 2024]*

Abstract

The district Toba Tek Singh is located in the center of Punjab province. It occupies 2nd important position in national citrus production after Sargodha, with citrus orchard area of 11412 hectares and annual production of 160758 tons. Citrus productivity in Pakistan, in general, and Toba Tek Singh, in particular, is far below its its potential which could be attributed to several factors but poor soil health and inadequate soil fertility may be considered an important reason. A comprehensive nutrient indexing survey of thirty citrus orchards grown in different parts of district Toba Tek Singh was conducted to evaluate the soil characteristics and plant nutrient status. GPS coordinates of selected sites were recorded prior to sampling. Soil samples were collected at 0-20 cm, 21-40 cm and 41-60 cm depth using standard procedure. Five soil samples were collected from each site to get a composite sample for each depth. The leaf samples were collected from the 7-month-old non-fruiting branches of plants around the tree canopy during the month of September, 2022. Five healthy and uniform citrus trees were sampled from each site to get a composite leaf sample. The soil samples were analyzed for pH, electrical conductivity (EC), soil organic matter (SOM) and calcium carbonate ($CaCO_3$). The soil and leaf samples were analyzed for macro and micronutrients. It was found that most of orchard soils of district Toba Tek Singh were moderately alkaline (pH 7.52-8.90), slight to strong calcareous (2-15% $CaCO_3$), non-saline (0.77-3.0 dS m^{-1} EC) and low in SOM (0.23-1.49%) with low to medium nitrogen (0.01-0.06%) and phosphorus (0.58-10.52 mg kg^{-1}) while medium to high potassium (56.47-315.34 mg kg^{-1}). The sampled soils were low to marginal in boron (0.09-0.72 mg kg^{-1}), copper (0.05-0.59 mg kg^{-1}), iron (0.23-10.75 mg kg^{-1}) and zinc (0.03-1.83 mg kg^{-1}) while adequate in manganese (1.35-26.20 mg kg^{-1}). Leaf analysis revealed that almost 50% orchards were deficient in phosphorus (0.05-0.23%) and potassium (0.40-1.76%), while having low to marginal values of copper (1.96-20.99 mg kg^{-1}), zinc (4.13-31.96 mg kg^{-1}), boron (3.12-95.40 mg kg^{-1}), manganese (42.62-96.46 mg kg^{-1}) but adequate iron (171-552 mg kg^{-1}). The surveyed orchard soils were mostly alkaline calcareous, deficient in organic matter and having low to moderate macro and micronutrients.

Keywords: Citrus, leaf analysis, marginal value, nutrient deficiency, nutrient indexing, soil characteristics

Introduction

Citrus (*Citrus reticulata*) is an important fruit crop growing on an area of 3.35 million hectares in more than 140 countries of the world with an annual production of 102.64 million tons (FAO, 2021). Citrus fruits are important and quick source of nutrients, vitamins, fiber, minerals, and many other necessary compounds required by human body (Liu *et al.*, 2012; Uthman and Garba, 2022). In Pakistan, it is grown on an area of about 0.193 million hectares with total production of 2.289 million tons and average fruit yield of 12.62 tons per hectare (Khan *et al.*, 2022). Although, citrus is grown in all the five provinces of Pakistan but is primarily adaptable to Punjab province with a share of 95% of the total fruit production (Altaf *et al.*, 2009). Important citrus growing districts in Punjab include Sargodha, Toba Tek Singh, Mandi Bahauddin, Sahiwal, Bahawalpur, Vehari and Khanewal. The major citrus varieties grown in Punjab are Kinnow and

***Email:** mashraf@bzu.edu.pk
Cite This Paper: Ashraf, M., A. Minhas, S. Masood, N. Akhtar, S.M. Shahzad and M. Asif. 2024. Soil characterization and plant nutrient indexing of citrus orchards in the central Punjab of Pakistan. *Soil Environ*. 43(1): 27-35.

Feutrell, covering 80% of the total citrus growing area (Altaf, 2006). Soil and climatic conditions of Punjab have added a distinctive flavor and taste in the Kinnow, making it a trademark of Pakistan. About 95% of the world's total production of Kinnow is yielded in Pakistan (FAO, 2021).

Globally, Pakistan occupies an important position in citrus production but the citrus productivity in general is almost stagnant or even declining in some parts of the country (Khan *et al.*, 2022). Low average yield of citrus may be attributed to several factors, but conventional nutrient management strategy might be a major factor (Ahmed and Saleem, 2006). The current nutrient management strategy is mainly based on macronutrients, mostly nitrogen (N) with occasional application of phosphorus (P) and potassium (K) while almost totally neglecting micronutrients (Noor *et al.*, 2019). Many studies have highlighted the deficiency of mineral nutrients, particularly, micronutrients such as zinc (Zn), copper (Cu), iron (Fe), manganese (Mn) and boron (B) in the citrus orchards of this part of the world (Zia *et al.*, 2006; Razi *et al.*, 2011; Ilyas *et al.*, 2015; Tahir, 2020). In a survey of 40 citrus orchards made by Haq *et al.* (1995), 50% soils have been found deficient in Zn and majority of the surveyed sites in B. According to Rashid *et al.* (1991), almost all the surveyed citrus orchards of Sargodha, 63% of Sahiwal and 88% of Faisalabad contained marginal to deficient Zn content. Ibrahim *et al.* (2007) also indicated the deficiencies of micronutrients like Zn, Cu, Fe and Mn in citrus orchards of Pakistan, and among these Zn deficiency is most common. A survey of citrus orchards in Malakand division has revealed the deficiency of Zn in 100%, Mn 96%, B 24% and Cu 16% orchards using leaf analysis as an indicator (Shah *et al.*, 2012). The deficiency of micronutrients in soil and plants might be attributed to low application rate coupled with low solubility and bioavailability (Ashraf *et al.*, 2012).

Toba Tek Singh, a district of Faisalabad division, is situated in the center of Punjab. It is located between 30° 33' to 31° 50 north latitudes and 72° 08' to 72° 68' east longitude and 115 m altitude. It touches the district Jhang on east and south, district Faisalabad on the west and north and river Ravi on the southeast side. It comprises of four tehsils namely Toba Tek Singh, Gojra, Kamalia and Pir Mahal. It has an area of 3252 km^2, population of 2,190,015 persons, population density 712.8 persons per km^2, population growth rate 1.6%, male population 50.2%, female population 49.8%, urban population 20.2% and literacy rate 66%. Major economic activity is agriculture with its livestock breeding and fishing accounts for 36.2%. Major crops include sugarcane, maize, and wheat while fruits are citrus and guava. It is 2^{nd} most important citrus growing district after Sargodha with citrus orchard area of 11412 hectares and annual production of 160758 tons.

The current study consists of a survey of thirty citrus orchards in four different tehsils of district Toba Tek Singh to determine soil characteristics and nutrient status in soil and citrus plants.

Materials and Methods

Thirty citrus orchards located in four different tehsils of district Toba Tek Singh of Punjab province were selected for soil and leaf sampling to investigate soil characteristics and the status of macro and micronutrients in soil and citrus plants. Soil samples from each citrus orchard were collected at three depths i.e. 0-20 cm, 21-40 cm and 41-60 cm during the month of September 2022. Five holes were made at each sampling site to get a composite soil sample for each depth. GPS Coordinates Apps 1.20, Financept was used to record GPS values of sampling sites for mapping the spatial variability. GPS coordinates are presented in Table 1. At the time of soil sampling, leaf samples were also collected from the same orchards. For this, 60-70 leaves of 7-month age from non-fruiting terminals were collected around the tree canopy at about 5-6 feet height randomly from about 20 trees per orchard (Sharma *et al.*, 2021).

The collected soil samples were dried under shade, crushed to powder, and passed through a 2 mm sieve. Soil samples were analyzed for pH, electrical conductivity (EC), calcium carbonate ($CaCO_3$) and organic matter according to the procedure described by Richards (1954). Total N, P, and K were determined following the methods described by Ryan *et al.* (2001). Micronutrients including Cu, Fe, Zn and Mn in soil were determined by the DTPA extraction procedure (Soltanpour and Schwab, 1977; Ponnamperuma *et al.*, 1981) and reading was taken on Atomic Absorption Spectrophotometer (Perkin Elmer Analyst-200, USA). The concentration of extractable B in soil was determined by Ryan *et al.* (2001) using Spectrophotometer (Beckman Coulter DU 730).

Leaf samples were washed with tap water immediately after collection, and then with distilled water in the laboratory for decontamination. The leaf samples were air dried and then placed in an oven for drying at 70±1°C for 72 hours (EYELA WFO–600ND; Tokyo Rikaikai Co., Ltd., Tokyo, Japan). The dried leaf samples were ground to 40 mesh using plant grinder (MF 10 IKA–WERKE, GMBH & CO. KG, Germany). The ground leaf samples (0.1 g) were digested with di-acid mixture of HNO_3 and $HClO_4$ (2:1 v/v) at 250ºC using hot plate (Miller, 1998). The concentration of Cu, Fe, Zn and Mn was determined using Atomic

Absorption Spectrophotometer (Ryan *et al.*, 2001). Dry ashing was done to determine leaf B concentration (Chapman and Pratt, 1961). Spectrophotometer (Beckman Coulter DU 730) was used to obtain absorbance measurements at 420 nm, and the concentration of B in the samples was calculated using the calibration curve (Malekani and Cresser, 1998). The following formula was used to compute the B concentration.

B (mg kg^{-1}) = mg kg^{-1} B (from calibration curve) × V / W

where, V = total volume of the plant digest (mL) and W = weight of dry plant sample (g) digested.

Descriptive statistics were used for the calculation of means and ranges using Microsoft excel 2013.

Results

Soil characterization

The data on soil pH for the surveyed orchards revealed that soil reactions were alkaline having pH from 7.29 to 8.93 with a mean value of 8.1 (Table 2). In the upper soil layer (0-20 cm), 16.67% samples had slightly alkaline pH, 76.67% moderately alkaline pH and 6.66% strongly alkaline pH. In the middle layer (21-40 cm), 16.67% samples showed slightly alkaline pH, 73.33% moderately alkaline pH and 10% strongly alkaline pH. In the lower soil layer (41-60 cm), 6.67% soil samples had slightly alkaline pH, 73.33% moderately alkaline pH and 20% strongly alkaline pH. Overall, the soils of citrus orchards of district Toba Tek Singh were moderately alkaline. There was a slight increase in soil pH with depth.

Table 1: Geographical location of surveyed citrus orchards at district Toba Tek Singh

Orchard No.	Latitude	Longitude	Orchard No.	Latitude	Longitude	Orchard No.	Latitude	Longitude
1	31.119	72.5636	11	30.879	72.554	21	30.787	72.426
2	31.024	72.489	12	30.815	72.583	22	31.058	72.512
3	31.058	72.570	13	30.884	72.430	23	30.938	72.476
4	30.868	72.530	14	30.839	72.394	24	30.936	72.614
5	30.868	72.530	15	30.904	72.325	25	30.966	72.590
6	30.898	72.530	16	30.920	72.441	26	30.988	72.449
7	31.090	72.564	17	30.857	72.330	27	31.031	72.460
8	31.119	72.604	18	30.794	72.391	28	31.003	72.497
9	31.084	72.482	19	30.802	72.318	29	30.963	72.411
10	31.003	72.497	20	30.713	72.459	30	30.968	72.344

Table 2: Soil characterization of thirty citrus orchards at district Toba Tek Singh

Property	Depth (cm)	Range	Mean	Criteria			
				Acidic	**Slightly alkaline**	**Moderately alkaline**	**Highly Alkaline**
				<7	**7.4-7.8**	**7.9-8.4**	**8.5-9**
pH	0-20	8.14 – 8.90	8.14	0; 0	5; 16.67	23; 76.67	2; 6.66
	20-40	8.19 – 8.93	8.19	0; 0	5; 16.67	22; 73.33	3; 10
	40-60	7.52 – 8.78	8.25	0; 0	2; 6.67	22; 73.33	6; 20
				Non-saline <4			**Saline >4**
EC ($dS\ m^{-1}$)	0-20	0.77 – 2.45	1.68	30; 100			0; 0
	20-40	1.08 – 2.88	2.08	30; 100			0; 0
	40-60	1.24 – 3.00	2.28	30; 100			0; 0
				Slightly calcareous	**Moderately calcareous**		**Highly calcareous**
				<8	**8—12**		**>12**
$CaCO_3$ (%)	0-20	2.00 – 15.00	5.62	22; 73.33	7; 23.33		1; 3.34
	20-40	3.50 – 15.00	7.48	20; 66.66	6; 20		4; 13.33
	40-60	5.00 – 15.00	9.38	8; 26.66	16; 53.33		6; 20
				Deficient	**Adequate**		**High**
				<1.7%	**2-4%**		**>5%**
SOM (%)	0-20	0.88 – 1.49	0.88	30; 100	0; 0		0; 0
	20-40	0.61 – 0.9	0.61	30; 100	0; 0		0; 0
	40-60	0.23 – 0.8	0.46	30; 100	0; 0		0; 0

Criteria for soil characterization was followed as described by Malik *et al*. (1984).

Soil EC ranged from 0.77 to 3.0 dS m^{-1} with a mean value of 2.01 dS m^{-1}. In the upper soil layer, EC ranged from 0.77 to 2.45 dS m^{-1} with a mean value of 1.68 dS m^{-1}. In the middle layer, EC ranged from 1.08 to 2.88 dS m^{-1} with a mean value of 2.08 dS m^{-1}. In the lower layer, EC was found in the range of 1.24 to 3.0 dS m^{-1} with a mean value of 2.28 dS m^{-1}. Results revealed that citrus orchard soils of district Toba Tek Singh were non-saline, and salinity increased slightly with depth (Table 2).

$CaCO_3$ content varied from 2 to 15% with a mean value of 7.51%. It ranged from 2 to 15% in the upper layer where 73.33% soil samples were ranked slightly calcareous, 23.33% moderately calcareous and only 3.34% highly calcareous. In the middle layer, $CaCO_3$ ranged from 3.5 to 15% with 66.67% samples were ranked slightly calcareous, 20% moderately calcareous and only 13.33% highly calcareous. In the lower layer, $CaCO_3$ content ranged from 5 to 15% with 26.67% samples ranked slightly calcareous, 53.33% moderately calcareous and 20% highly calcareous (Table 2).

Table 3: Soil macronutrient status of thirty citrus orchards at district Toba Tek Singh

Macronutrient	Depth	Range	Mean	Criteria		
				Low	**Medium**	**High**
				<0.033	**0.033 - 0.067**	**>0.067**
N (%)	0-20	0.02 – 0.06	0.042	6; 20*	24; 80	0; 0
	20-40	0.02 – 0.04	0.027	23; 76.67	7; 23.33	0; 0
	40-60	0.01 – 0.03	0.021	30;100	0; 0	0; 0
				<6.2	**6.2 - 11.2**	**>11.2**
P (mg kg^{-1})	0-20	0.58 – 10.52	5.62	17; 56.67	13; 43.33	0; 0
	20-40	1.06 – 10.23	5.14	19; 63.33	11; 36.67	0; 0
	40-60	1.05 – 7.88	4.01	24; 80	6; 20	0; 0
				<80	**80 - 180**	**>180**
K (mg kg^{-1})	0-20	87.68 – 302.11	201.35	0; 0	13; 43.33	17; 56.67
	20-40	76.56 – 315.34	141.96	0; 0	25; 83.33	5; 16.67
	40-60	56.47 – 307.67	125.51	1; 3.33	28; 93.34	1; 3.33

Criteria for critical concentration of available macronutrients in soil was followed as described Subbiah and Asiza (1956) for N, Olsen *et al*. (1954) for P, and Jackson (1967) for K. *Number of samples; percent of total samples. * is not indicated any where in the table

Table 4: Soil micronutrient status of thirty citrus orchards at district Toba Tek Singh

Nutrient (mg kg^{-1})	Depth (cm)	Range	Mean	Criteria			
				Very Low	**Low**	**Marginal**	**Adequate**
				<0.25	**0.25 - 0.5**	**0.51 - 0.75**	**0.76 - 1.00**
B	0-20	0.21 – 1.0	0.60	4; 13.33	7; 23.33	9; 30	10; 33.34
	20-40	0.11 – 0.67	0.35	9; 30	13; 43.33	8; 26.67	0; 0
	40-60	0.09 – 0.72	0.28	14; 46.67	10; 33.33	6; 20	0; 0
				<0.10	**0.10 - 0.20**	**0.21 - 0.40**	**>0.40**
Cu	0-20	0.06 – 0.59	0.35	2; 6.67	4; 13.33	15; 50	9; 30
	20-40	0.05 – 0.48	0.26	2; 6.67	5; 16.67	19; 63.33	4; 13.33
	40-60	0.05 – 0.42	0.16	3; 10	17; 56.67	9; 30	1; 3.33
				<2.5	**2.5 - 4.5**	**4.6 - 7.5**	**>7.5**
Fe	0-20	0.23 – 10.75	4.39	9; 30	8; 26.67	9; 30	4; 13.33
	20-40	0.98 – 7.78	4.25	8; 26.67	8; 26.67	13; 43.33	1; 3.33
	40-60	0.99 – 6.45	3.69	6; 20	16; 53.33	8; 26.67	0; 0
				<1.0	**1.0 - 2.0**	**2.1 - 4.0**	**>4.0**
Mn	0-20	1.35 – 26.20	9.73	0; 0	1; 3.33	5; 16.67	24; 80
	20-40	3.45 – 20.9	8.19	0; 0	0; 0	2; 6.67	28; 93.33
	40-60	1.34 – 19.20	8.54	0; 0	0; 0	2; 6.67	28; 93.33
				<0.30	**0.30 - 0.60**	**0.61 - 1.5**	**>1.5**
Zn	0-20	0.13 – 1.83	0.58	7; 23.34	9;30	13; 43.33	1; 3.33
	20-40	0.04 – 0.77	0.38	14; 46.66	10; 33.34	6; 20.0	0; 0
	40-60	0.03 – 0.39	0.20	27; 90.0	3; 10.0	0; 0	0; 0

Criteria for critical concentration of available micronutrients in soil was followed as described by Singh (1998). *Number of samples; percent of total samples. ? * is not indicated any where in the table

Soil organic matter (SOM) varied from 0.23% to 1.20% with a mean value of 0.63%. In the upper layer, SOM varied from 0.49% to 1.20% with mean value of 0.85%. In the middle soil layer, SOM ranged from 0.36% to 0.88% with a mean value of 0.61%. In the lower layer, it ranged from 0.23% to 0.64% with a mean value of 0.42%. It was noteworthy that all the orchard soils of district Toba Tek Singh contained organic matter below the critical level as described by Feller and Beare (1997). SOM decreased greatly with soil depth (Table 2).

Soil nutrients status

Nitrogen concentration in the upper soil layer ranged from 0.02 to 0.06% with a mean value of 0.042%. In the upper layer, N concentration was found low in 20% while medium in 80% of the surveyed orchards. In the middle soil layer, N concentration ranged from 0.02 to 0.04% with a mean value of 0.027%. In this layer, 76.67% samples had low while 23.33% had medium N concentration. In the lower soil layer, N concentration ranged from 0.01 to 0.03% with a mean value of 0.021%. In this layer, all sample showed low N concentration. The criteria for soil N was followed as described by Subbiah and Asiza (1956). Soil N concentration was decreased with soil depth (Table 3).

Soil P concentration ranged from 0.58 to 10.52 mg kg^{-1} with a mean value of 5.62 mg kg^{-1} in the upper layer. About 57% samples had low P concentration in this layer. In the middle soil layer, P concentration ranged from 1.06 to 10.23 mg kg^{-1} with a mean value of 5.14 mg kg^{-1}, and 63.33% samples had low P. In lower soil layer, P varied from 1.05 to 7.88 mg kg^{-1} with a mean value of 4.01 mg kg^{-1}, and 80% samples had low P concentration. The criteria for soil P was followed as described by Olsen *et al.* (1954). Highest P concentration was found in the upper layer and decreased with soil depth (Table 3).

Soil K concentration in the upper soil layer ranged from 87.68 to 302.11 mg kg^{-1} with a mean value of 201.35 mg kg^{-1}, and 43.33% samples had medium K while 56.67% samples had high K. In the middle soil layer, 83.33% samples had medium K and 16.67% samples had high K. In the lower soil layer, 93.34% samples had medium K while 3.33% samples had low and high K concentration. The criteria for soil K was followed as described by Jackson (1967). Like N and P, highest K concentration was found in the upper soil layer and decreased with soil depth at all sampling sites (Table 3).

Zn concentration ranged from 0.03 to 1.83 mg kg^{-1} with a mean value of 0.39 mg kg^{-1}. In the upper layer of 20 cm, Zn concentration varied from 0.13 to 1.83 mg kg^{-1} with a mean value of 0.58 mg kg^{-1}. In this layer, 23.34% samples had very low Zn, 30% samples contained low Zn, 43.33% samples had marginal Zn and only 3.33% samples had adequate Zn concentration. In the middle layer, 46.66% soil samples had very low Zn concentration, 33.34% had low and 20% samples showed marginal value of Zn. In the lower layer, 90% samples showed very low Zn concentration and 10% samples had low Zn concentration. Zn concentration dropped greatly with depth, and only one sample out of thirty showed adequate value (Table 4).

Mn concentration in soil was found adequate in most of the surveyed orchards in accordance with the criteria defined by Singh (1998). Only 3.33% samples contained low and 16.67% marginal values in the upper layer of 20 cm. Almost, similar trend was found in other two layers (Table 4). Fe concentration ranged from 0.23 mg kg^{-1} to 10.75 mg kg^{-1} with a mean value of 4.09 mg kg^{-1}. In the upper layer, 30% samples had very low, 26.67% low, 30% marginal and 13.33% adequate level. Almost, similar trend was found in two other soil layers (Table 4). Average Cu concentration was found 0.35 mg kg^{-1} in the upper soil layer where 6.67% samples contained very low, 13.33% low, 50% marginal and 30% adequate level. In the middle soil layer, only 13.33% samples had adequate level while 86.67% sample had very low to marginal value. Copper was found more deficient in the lower layer where only one out of thirty samples had adequate value according to the criteria defined by Singh (1998). Boron concentration varied with soil depth, maximum value in the upper layer ranged from 0.21 mg kg^{-1} to 1.0 mg kg^{-1} with a mean value of 0.60 mg kg^{-1} (Table 4). In the upper layer, 13.33% samples had very low B, 23.55% low, 30% marginal, and 33.34% adequate level. In lower layer, all the samples had low to marginal B concentration in accordance with the criteria defined by Singh (1998).

Leaf nutrient status

Leaf P concentration varied from 0.05 to 0.23% with a mean value of 0.12%. According to the criteria described by Sarangthem *et al.* (2014), 23.33% samples had deficient, 23.33% low, 33.34% adequate and 20% high P concentration (Table 5). Leaf K concentration ranged from 0.40 to 1.76% with a mean value of 1.08%. The criteria described by Sarangthem *et al.* (2014) was used to classify the citrus orchards in accordance with leaf K concentration. Results revealed that 10% orchards were found deficient, 40% low and 50% adequate in leaf K concentration (Table 5).

Data regarding leaf status of micronutrients (Table 6) revealed that Cu concentration in the surveyed citrus orchards varied from 1.96 to 20.99 mg kg^{-1} with a mean value of 7.13 mg kg^{-1}. It was found that 16.67% of survey orchards had

Table 5: Leaf macronutrient status of thirty citrus orchards at district Toba Tek Singh

Nutrient	Range	Mean	Deficient	Low	Optimum	High
			<0.09	**0.09 - 0.11**	**0.12 - 0.16**	**0.17 - 0.29**
P (%)	0.05 – 0.23	0.12	7; 23.33*	7; 23.33	10;33.34	6; 20.0
			<0.4	**0.4 - 0.69**	**0.70 - 1.09**	**1.1 - 2.0**
K (%)	0.40 – 1.76	1.08	3; 10.0	12; 40.0	15; 50.0	0; 0.0

Criteria for critical concentration of macronutrients in citrus leaves was followed as described by Sarangthem *et al.* (2014). *Number of samples; percent of total samples. * is not indicated any where in the table

Table 6: Leaf micronutrient status of thirty citrus orchards at district Toba Tek Singh

Nutrient (mg kg^{-1})	Range	Mean	Deficient	Low	Optimum	High
			<3	**3-10**	**11-16**	**17-20**
Cu ()	1.96 – 20.99	7.13	5; 16.67	18; 60	7; 23.33	-
			<81	**81-119**	**120-219**	**>219**
Fe	171 – 552	344	0; 07	0; 0	1; 3.33	29; 96.67
			<36	**36-58**	**59-84**	**85-118**
Mn	42.62 – 96.46	60.34	0; 0	15; 50	14; 46.67	1; 3.33
			<16	**16-24**	**25-100**	**101-200**
Zn	4.13 – 31.96	16.67	16; 53.34	10; 33.33	4; 13.33	0; 0
			<20	**20-35**	**36-100**	**101-200**
B	3.12 – 95.40	33.14	11; 36.67	5; 16.66	14; 46.67	0; 0

Criteria for critical concentration of micronutrients in citrus leaves was followed as described by Sarangthem *et al.* (2014). *Number of samples; percent of total samples. * is not indicated any where in the table

deficient, 60% low while only 23.33% adequate Cu concentration. Manganese concentration ranged from 42.62 to 96.46 mg kg^{-1} with a mean value of 60.34 mg kg^{-1}. It was found that 50% of surveyed orchards had low, 46.67% adequate and 3.33% high Mn concentration. Iron concentration ranged from 171.01 to 552.74 mg kg^{-1} with a mean value of 344.24 mg kg^{-1} in the surveyed orchards. It was found that 50% of surveyed orchards had high, 46.67% excess while 3.33% adequate Fe concentration. Zinc concentration ranged from 4.13 to 31.96 mg kg^{-1} with a mean value of 16.67 mg kg^{-1}. It was found deficient in 53.34%, low in 33.33% and adequate in only 13.33% of surveyed orchards. Boron concentration varied from 3.12 to 95.40 mg kg^{-1} with a mean value of 33.14 mg kg^{-1}. It was found deficient in 36.67, low in 16.66 and adequate in 46.67% of the surveyed orchards. The concentration of micronutrients in citrus leaf was compared with the standard values described by Sarangthem *et al.* (2014).

Discussion

The characteristics of orchard soils in terms of pH, EC, $CaCO_3$ and organic matter are critical for citrus growth, fruit yield and quality due to their vital role in soil health, nutrients solubility and bioavailability. Alkaline pH in the surveyed areas was attributed to low rainfall, dominance of basic cations in the parent material, net evapotranspiration and low organic matter content (Zhang *et al.*, 2019). The threshold level of EC for citrus is 1.4 dS m^{-1}, and a reduction of 13% in fruit yield could occur for each 1 dS m^{-1} increase in EC above threshold level (Murkute *et al.*, 2005). Although, all survey orchard soils were non-saline having EC <4 dS m^{-1} but EC was higher than threshold level for citrus indicating that higher EC could be an important cause for a significant decline in citrus fruit yield and quality in the surveyed areas (Ziogas *et al.*, 2021). The higher EC in the surveyed citrus orchards might be due to arid climate, use of saline water and salty nature of parent material (Ashraf and Saeed, 2006). The slight increase in EC with soil depth could be due to leaching of soluble salts associated with regular irrigation practice in citrus orchards (Iqbal *et al.*, 2020). Being sensitive to salts, all growth and development stages of citrus including flowering, fruit setting, fruit maturity, fruit yield and quality could adversely be affected by salinity, causing a significant loss in fruit yield and quality at relatively low EC level (Othman *et al.*, 2023). Soil calcareousness in the surveyed areas could be associated with arid and semi-arid climate due to limited Ca leaching. Calcareousness could also be attributed to parent material being rich in $CaCO_3$ such as calcareous glacial tills, limestone, and shells, and parent material that was relatively young, and experienced little weathering (Taalab *et al.*, 2019). The surveyed orchard soils were found deficient in organic matter which could be the major reason for poor nutrient availability as well as uptake and use efficiencies. The reasons for low organic matter in the surveyed orchards were mainly attributed to high temperature, low rainfall, intensive farming, use of only synthetic fertilizers, no/ low addition of manures (Zahid *et* *al.*, 2020). Moreover, the local farming community did not add farmyard manure to their citrus orchards. It was elucidated that organic matter decomposed rapidly due to high temperature, and it could also be an important reason of low SOM in Pakistan (Ali *et al.*, 2019).

Nitrogen and P were found low to medium while K medium to high in the surveyed orchard soils. According to Subbiah and Asiza (1956), adequate level of N in soil should be 0.6%. Low N availability in soil could be attributed to low SOM, high N losses by ammonia volatilization, denitrification, and leaching (Maqsood *et al.*, 2016). Adequate P level for optimum citrus growth and yield should be more than 11 mg kg^{-1} (Olsen *et al.*, 1954). Low P availability in surveyed orchard soils was mainly associated with high pH and calcareousness (Kwakye *et al.*, 2023), low organic matter (Zahid *et al.*, 2020), and low P addition (Ashraf *et al.*, 2009). Ahmad *et al.* (2022) also found P deficiency in citrus orchards of Layyah district of Punjab province which could be associated with alkaline calcareous nature of soil.

Micronutrients, particularly Zn, B, and Cu were relatively more deficient in the surveyed area. The reasons for deficiency of these micronutrients could be poor replenishment, alkaline pH, calcareousness of the soils in these regions. Furthermore, farmers mostly applied macronutrients which stimulated the vegetative growth, and leading to a marked depletion of micronutrients in soil (Zekri and Obreza, 2003; Noor *et al.*, 2019). The soils of Pakistan were derived from alluvium and loess parent material having pH more than 8 (alkaline) and calcareousness (8-12% free $CaCO_3$) with very low organic matter (<1%), causing the low solubility and bioavailability of micronutrients in these soils (Ahmad *et al.*, 2022).

Leaf P was found mostly deficient in the surveyed areas which could be associated with alkaline pH, low SOM, and high $CaCO_3$ (Zahid *et al.*, 2020, Kwakye *et al.*, 2023). Optimum P availability was found at pH 6-6.5. Under acidic soil conditions, P precipitated with Al, Fe and Mn which declined its solubility and availability to plants, leading to low P concentration in plant tissues. At alkaline pH, P reacted with calcium, and fixed as calcium phosphate, reducing P concentration in plant tissues (Ashraf *et al.*, 2009). Leaf K in citrus leaves was found mostly optimum, indicating good K availability in orchard soils due to dominance of mica minerals and irrigation with canal water.

The deficient level of micronutrients, particularly Zn, B and Cu in citrus leaves in the surveyed orchards was associated with their low solubility and availability in soils owing to alkaline and calcareous nature of soil with low organic matter. Some previous studies, for example, Zia *et al.* (2006); Ibrahim *et al.* (2007); Razi *et al.* (2011); Ilyas *et al.* (2015) had reported the deficiency of mineral nutrients, particularly micronutrients such as Cu, Zn, Fe, Mn, and B in the citrus orchards of Pakistan. Low leaf status of micronutrients could also be attributed to poor efficiency of applied micronutrients mainly because of high pH, low SOM, and calcareousness in soil (Ashraf *et al.*, 2013; Pachuau *et al.*, 2019).

Conclusions

The orchard soils of surveyed area in district Toba Tek Singh were alkaline calcareous with low SOM. Although, these soils were non-saline but still EC was beyond the threshold level of citrus. Nitrogen and P were low to medium while K was adequate in most of the surveyed orchards. Leaf P was found deficient to low while leaf K was adequate to high in the surveyed orchards. Among the micronutrients, Zn, B, and Cu were found deficient while Fe and Mn were adequate in the surveyed citrus orchards according to the standard criteria.

References

Ahmad, N., S. Hussain, M.A. Ali, A. Minhas, W. Waheed, S. Danish, S. Fahad, U. Ghafoor, K.S. Baig, H. Sultan, M.I. Hussain, M.J. Ansari, T.D. Marfo and R. Datta. 2022. Correlation of soil characteristics and citrus leaf nutrients contents in current scenario of Layyah district. *Horticulturae* 8: 61.

Ahmed, A. and M.T. Saleem. 2006. Citrus and its nutrition. *Farming Outlook* 5: 11–19.

Ali, I., G. Nabi, S.M. Gill and M. Mahmood-ul-Hassan. 2019. Crop residue management in rice-wheat system of Pakistan and its impact on yield and nutrient uptake. *International Journal of Biosciences* 14: 221–236.

Altaf, N. 2006. Embryogenesis in undeveloped ovules of citrus cultivars in response to gamma radiation. *Pakistan Journal of Botany* 38: 589–595.

Altaf, N., A.R. Khan, L. Ali and I.A. Bhatti. 2009. Invitroculture of kinnow explants. *Pakistan Journal of Botany* 41: 597-602.

Ashraf, M., Rahmatullah, M.A. Maqsood, S. Kanwal, M.A. Tahir and L. Ali. 2009. Growth responses of wheat cultivars to rock phosphate in hydroponics. *Pedosphere* 19 (3): 398–402.

Ashraf, M. and M.M. Saeed. 2006. Effect of improved cultural practices on crop yield and soil salinity under relatively saline groundwater applications. *Irrigation and Drainage System* 20: 111–124.

Ashraf, M.Y., F. Hussain, M. Ashraf, J. Akhter and G. Ebert. 2013. Modulation in yield and juice quality characteristics of citrus fruit from trees supplied with zinc and potassium foliarly. *Journal of Plant Nutrition* 36: 1996–2012.

Ashraf, M.Y., M. Yaqub, J. Akhtar, M.A. Khan, M.A. Khan and G. Ebert. 2012. Control of excessive fruit drop and improvement in yield and juice quality of kinnow (*Citrus deliciosa* x *Citrus nobilis*) through nutrient management. *Pakistan Journal of Botany* 44: 259–265.

Cartwright, B., K.G. Tiller, B.A. Zarcinas, and L.R. Spouncer. 1983. The chemical assessment of the boron status of soils. *Australian Journal of Soil Research* 21: 321–332.

Chapman, H.D. and P.F. Pratt. 1961. *Methods of Analysis for Soils, Plants and Water*. University of California, Berkeley, CA, USA.

Cartwright, B., K.G. Tiller, B.A. Zarcinas, and L.R. Spouncer. 1983. The chemical assessment of the boron status of soils. *Australian Journal of Soil Research* 21:321–332.

FAO. 2021. Citrus Fruit Statistical Compendium. Food and Agriculture Organization of the United Nations, Rome, Italy. Accessed on 15-09-2023.

Feller, C. and M.H. Beare. 1997. Physical control of soil organic matter dynamics in the tropics. *Geoderma* 79(1–4): 69–116.

Haq, I.U., A. Ghani and H.U. Rehman. 1995. Nutritional status of citrus orchards in NWFP and the effect of fertilizer application on fruit production. Directorate of Soils and Plant Nutrition, A.R.I, Tarnab, Peshawar, NWFP Pakistan. *Technical Bulletin* 1/95.

Ibrahim, M., N. Ahmad, S.A. Anwar and T. Majeed. 2007. Effect of micronutrients on citrus fruit yield growing on calcareous soils. P. 179–182. In: Advances in Plant and Animal Boron Nutrition. Fangsen, X.U. H.E. Goldbach, P.H. Brown, R.W. Bell, T. Fujiwara, C.D. Hunt, S. Goldberg and L. Shi (eds.). Springer, Netherlands,.

Ilyas, A., M.Y. Ashraf, M. Hussain, M. Ashraf, R. Ahmed and A. Kamal. 2015. Effect of micronutrients (Zn, Cu and B) on photosynthetic and fruit yield attributes of *Citrus reticulata* blanco var. kinnow. *Pakistan Journal of Bot*any 47: 1241–1247.

Iqbal, N., M. Ashraf, M. Imran, H.A. Salam, F.U. Hasan and A.D. Khan. 2020. *Groundwater Investigations and Mapping in the Lower Indus Plain*. Pakistan Council of Research in Water Resources (PCRWR), Islamabad. 70 p.

Jackson, M.L. 1967. *Soil Chemistry Analysis*. Prentice-Hall of India Pvt. Ltd., New Delhi, p 498.

Khan, A.A., M.A. Zeshan, Y. Iftikhar, M. Mubeen, M. Sohail, S. Bashir, M.A. Rehman and M.U. Ghani. 2022. Current status of citrus tristeza virus in major citrus growing areas of Sargodha, Pakistan. *Sarhad Journal of Agriculture* 38(4): 1412–1418.

Kwakye, S., D.M. Kadyampakeni, K. Morgan, T. Vashisth and A. Wright. 2022. Effects of iron rates on growth and development young Huanglongbing-affected citrus trees in Florida. *Horticultural Science* 57(9): 1092–1098.

Liu, Y.Q., E. Heying and S.A. Tanumihardjo. 2012. History, global distribution, and nutritional importance of citrus fruits. *Comprehensive Reviews in Food Science and Food Safety* 11: 530–545.

Malik, D., M. Khan and T. Chaudhry 1984. Analysis method for soil, plant, and water. Soil fertility survey and soil testing institute, Punjab, Lahore, Pakistan

Maqsood, M.A., U.K. Awan, T. Aziz, H. Arshad, N. Ashraf and M. Ali. 2016. Nitrogen management in calcareous soils: Problems and solutions. *Pakistan Journal of Agricultural Sciences* 53(1): 79–95.

Miller, R.O. 1998. Nitric–perchloric wet acid digestion in an open vessel. p. 57-62. In: *Handbook of Reference Methods for Plant Analysis*. Y.P. Kalra, (eds.). CRC Press, Washington DC.

Murkute, A.A., S. Sharma and S.K. Sing. 2005. Citrus in terms of soil and water salinity: A review. *Journal of Scientific and Industrial Research* 64: 393–402.

Noor, Y., Z. Shah and M. Tariq. 2019. Effect of zinc and boron using different application methods on yield of citrus (Sweet orange) in calcareous soils. *Sarhad. Journal of Agriculture* 35(4): 1247–1258.

Olsen, S.R., C.V. Cole, F.S. Watanabe and L.A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *USDA Circular.* pp 939–919.

Othman, Y.A., M.B. Hani, J.Y. Ayad and R. St. Hilaire. 2023. Salinity level influenced morpho-physiology and nutrient uptake of young citrus rootstocks. *Heliyon* 9: e13336.

Pachuau, R., B. Singh, J. Lalnunpuia and Lalthamawii. 2019. Effect of organic manures on growth, yield and quality of Assam Lemon [*Citrus limon* (L.) Burm.]. *International Journal of Current Microbiology and Applied Sciences* 8(9): 1009–101.

Ponnamperuma, F.N., M.T. Caytan and R.S. Lantin. 1981. Dilute hydrochloric acid as an extractant for available zinc, copper, and boron in rice soils. *Plant and Soil* 61: 297–310.

Rashid, A., F. Hussain, R. Rashid and J. Din. 1991. Nutrient status of citrus orchards in Punjab. *Pakistan Journal of Soil Science* 6: 25–28.

Razi, M.F.D., I.A. Khan and M.J. Jaskani. 2011. Citrus plant nutritional profile in relation to Huanglongbing prevalence in Pakistan. *Pakistan Journal of Agricultural Sciences* 48: 299–304.

Richards, L. A. 1954. *Diagnosis and Improvement of Saline and Alkali Soils.* U.S. Department. Agriculture Handbook 60. U.S. Government Printing Office, Washington, DC.

Ryan, J., G. Estefan and A. Rashid. 2001. *Soil and Plant Analysis Laboratory Manual*. 2nd Ed. Jointly published by the International Center for Agricultural Research in the Dry Areas (ICARDA) and National Agricultural Research Center (NARC), Aleppo, Syria, 172p..

Sarangthem, I., L.D. Sharma and A.K. Srivastava. 2014. Development of nutrient diagnostic technique for Khasi Mandarin (*Citrus reticulata* Blanco) grown in Manipur. *Journal of Indian Society of Soil Science* 62(2): 118–125.

Shah, Z., M.Z. Shah, M. Tariq, H. Rahman, J. Bakht, Amanullah and M. Shafi. 2012. Survey of citrus orchards for micronutrients deficiency in Swat valley of North Western Pakistan. *Pakistan Journal of Botany* 44: 705–710

Singh, A., M. Bakshi, A.S. Brar and S.K. Singh. 2019. Effect of micro-nutrients in Kinnow mandarin production: A review. *International Journal of Chemical Studies* 7(3): 5161–5164.

Singh, M.V. 1998. 28th Progress report of AICRP on micro and secondary nutrients and pollutant elements in soil and plants. IISS, Bhopal, 102p.

Soltanpour, P.N. and A.P. Schwab. 1977. A new soil test for simultaneous extraction of macro and micro-nutrients in alkaline soils. *Communication in Soil Science and Plant Analysis* 8: 195–207.

Subbiah, B.V. and G.L. Asiza. 1956. A rapid procedure for determination of available nitrogen in soils. *Current Science* 25: 259–261.

Taalab, A.S., G.W. Ageeb, H.S. Siam and S.A. Mahmoud. 2019. Some characteristics of calcareous soils. A review. *Middle East Journal of Agricultural Research* 08(1): 96–105

Tahir, R. 2020. Impact of foliar application of Zn on growth yield and quality production of citrus: A Review. *Indian Journal of Pure and Applied Biosciences* 8: 529–534.

Uthman, A. and Y. Garba. 2023. Citrus mineral nutrition and health benefits: a review. Citrus research-horticultural and human health aspects. IntechOpen. doi: 10.5772/intechopen.107495.

Zahid, A., S. Ali, M. Ahmed and N. Iqbal. 2020. Improvement of soil health through residue management and conservation tillage in rice-wheat cropping system of Punjab, Pakistan. *Agronomy* 10: 1844.

Zekri, M. and T.A. Obreza. 2003. Micronutrient deficiencies in citrus: Iron, zinc and manganese. Document SL 204, a fact sheet of the Soil and Water Science Department, Florida, Cooperative Extension Service, Institute of Food and Agricultural Services, University of Florida. http://edis.ifas.ufl.edu.

Zhang, Y.Y., W. Wu and H. Liu. 2019. Factors affecting variations of soil pH in different horizons in hilly regions. *PLoS One* 14(6): e0218563.

Zia, M.J., R. Ahmad, I. Khaliq, A. Ahmad and M. Irshad. 2006. Micronutrient status and management in orchard soil: applied aspects. *Soil and Environment* 25: 6–16.

Ziogas, V., G. Tanou, G. Morianou and N. Kourgialas. 2021. Drought and salinity in citriculture: optimal practices to alleviate salinity and water stress. *Agronomy* 11: 1283.