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Nutrients Status of Citrus Orchards of District Multan, Punjab, Pakistan

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ABSTRACT

Citrus is important and leading fruit crops across Pakistan now facing the decline qualitatively and quantitatively which directly affecting the total production per unit area. The major reason for these changes seems to be improper fertilization of nutrients. In this regard, an experiment has been conducted on the citrus orchards of district Multan, to evaluate the present condition of nutrients in soil and citrus plants. The relationship between soil properties, available nutrients in soil, and plants were also investigated. In 24 orchards, the soil samples at three different soil depths (0-15cm, 15-30cm, 30-45 cm) with 4–6-month-old leaves of the plant were collected. In soils, the N (100%), P (50%), B (70.83%), Fe (16.67%) and Zn (33.33%) were deficient at upper soil layer (0-15cm). The deficiency of these nutrients decreases with increasing soil depth. The leaf analysis of citrus plants showed that there was a deficiency of N (70.83%), P (66.66%), K (12.5%), Zn (66.6%) and B (50%). Among soil properties, the pH is negatively and significantly related to N, P, Fe, and Mn, while CaCO3 and EC showed a negatively significant correlation to P and B respectively at upper soil layer. Organic matter was positive and significantly related to P and Cu at upper soil layer. The significant correlation between soil properties and nutrients decreases with increasing soil depth. The K and Fe in the soil are directly associated with increasing its contents in the leaf.

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INTRODUCTION

Citrus cultivation holds a prominent position in Pakistan's agricultural landscape, ranking among the top citrus-producing nations globally (Jaskani & Abbas, 2007). Within this citrus spectrum, Kinnow (Citrus reticulate) emerges as a pivotal cultivar, predominantly cultivated in the Punjab region of Pakistan (Altaf *et al.*, 2009). The optimal growth, yield, and quality of citrus fruits hinge upon a delicate balance of essential nutrients, encompassing both macro and micronutrients (Phillips, 2004). However, despite its significant presence, Pakistan grapples with notably lower yields and quality of citrus fruits compared to other nations. Export opportunities, contingent upon fruit size and color, are often hindered by these deficiencies. Consequently, Pakistan's citrus orchards confront a twofold challenge: suboptimal nutrient levels in the soil and the resulting impact on fruit production (Ibrahim *et al.*, 2007). Studies reveal that Pakistani citrus orchards commonly exhibit deficiencies in key nutrients that plants derive from the soil, notably nitrogen (N), potassium (K), phosphorus (P), iron (Fe), and zinc (Zn)

(Ashraf *et al*., 2015). Citrus, being a high nutrition-demanding fruit crop (Wang *et al*., 2006), exhibits a substantial responsiveness to applied nutrients in the form of fertilizers. The root cause of declining citrus yields in Pakistan can be attributed to inadequate nutrient management practices within these orchards. This prevailing deficiency in both macro and micronutrients culminate in diminished citrus crop yields, a phenomenon well-documented in various regions, ultimately casting a shadow over the country's citrus productivity and economic vitality. To address this issue comprehensively, this research embarked on a survey of citrus orchards in the Multan district, seeking to ascertain the nutrient status of these vital agricultural landscapes. The investigation extends to the correlation between soil physico-chemical properties and the availability of macro and micronutrients, as well as the intricate relationship between available soil nutrients and plant nutrient uptake. In doing so, this study endeavors to shed light on the critical interplay between soil health and citrus crop prosperity, contributing valuable insights into the sustainable management of citrus orchards in Pakistan.

MATERIALS AND METHODS

Study Site and Sampling Procedures

The research was conducted in the Multan district, covering approximately 3,720 square km, located between longitudes 71° 02' and 71° 50' east and latitudes 29° 23' and 30° 27' north. This region is geographically surrounded by four districts i.e. Muzaffargarh in the West, Khanewal in the North, Khanewal and Lodhran in the East, and Bahawalpur in the South. Within Multan district, three distinct tehsils were examined: Multan, Shujabad, and Jalalpur.

Assessment of Citrus Orchard Soil and Leaf Fertility

During the year 2019, we conducted an extensive assessment of the fertility status of citrus orchards in Multan district. Our investigation encompassed a range of key soil parameters, including electrical conductivity (EC), pH levels, organic matter content (O.M %), calcium carbonate content ($CaCO3$ %), and the presence of various essential nutrients such as nitrogen (N), phosphorus (P), potassium (K), iron (Fe), copper (Cu), manganese (Mn), boron (B), and zinc (Zn). Additionally, we aimed to identify nutrient deficiencies within these orchards.

Sampling Procedures

Soil sampling was done systematically from three different depths: 0-15 cm, 15-30 cm, and 30-45 cm. In parallel, leaf samples were gathered from the same orchards. For leaf sampling, we selected healthy four- to six-month-old leaves originating from non-fruit bearing twigs during the spring growth period. Specifically, we collected leaves from 20 trees per orchard, and these leaves were sampled at chest height.

Soil and Plant Sample Analyses

To analyze soil samples, we began by drying them in the shade, followed by crushing and sieving through a 2mm sieve. Leaf samples were subjected to a cleaning process involving tap water and distilled-deionized water to ensure thorough decontamination. The samples were then dried in an oven at a consistent temperature of 70 ± 5°C for a duration of 72 hours. We employed a stainless-steel Wiley mill to grind the leaf blades effectively. For soil samples, analyses encompassed parameters such as EC, pH, and the availability of essential macro-nutrients including nitrogen (N), phosphorus (P), and potassium (K). To determine micronutrient levels in soil, we employed the DTPA extraction procedure and measured concentrations using an atomic absorption spectrophotometer. The presence of extractable boron (B) in soil was ascertained via the dilute-HCl method. Leaf samples underwent a wet digestion procedure for the determination of micronutrient levels (except for B) using an atomic absorption spectrophotometer. Citrus leaf samples were first subjected to dry ashing at 550°C for a duration of 4 hours, and B concentration was determined calorimetrically using the Azomethine-H method. The procedures for soil and plant analyses adhered to the guidelines outlined in the ICRADA manual 3rd edition (Ryan *et al*., 2001).

Statistical Analysis

We conducted descriptive statistical analyses to calculate the means and ranges of the collected data, utilizing Microsoft Excel 2013 for this purpose. Nutrient status was assessed by comparing our findings with established standard criteria for nutrient indexation. We also explored correlations between macro, micro-nutrients, and various soil properties, including pH, electrical conductivity, calcium carbonate content, and soil organic matter, employing SPSS statistical software. Additionally, we analyzed the correlations among soil-available nutrients and plant nutrient levels to gain further insights into nutrient interactions and dependencies.

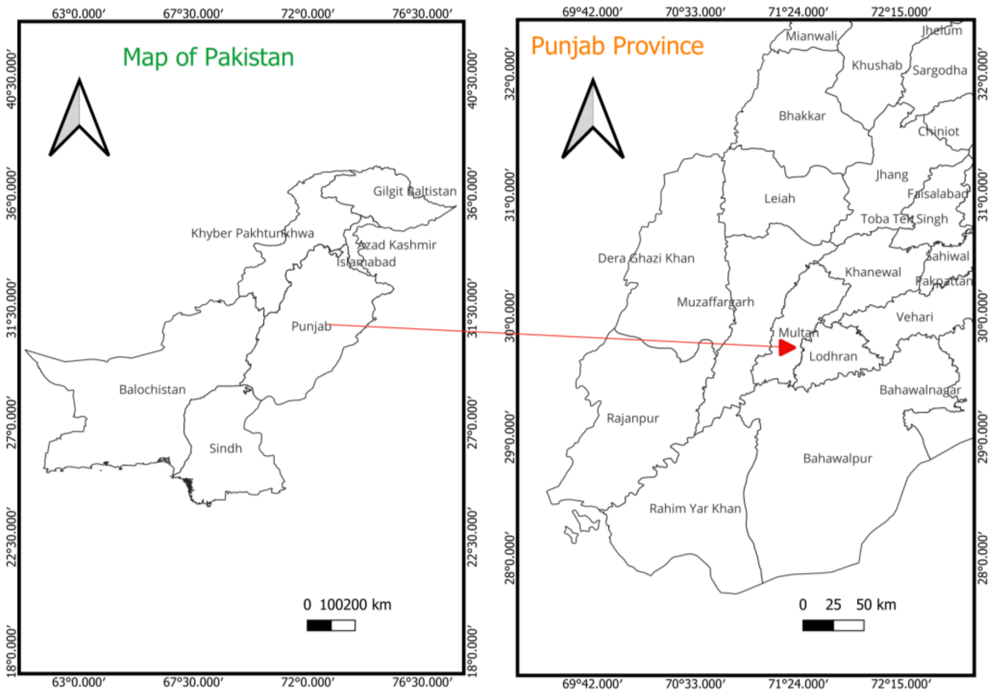

Figure 1. Geographical map of Pakistan and Punjab province. The arrow showing the location of district Multan in Punjab province.

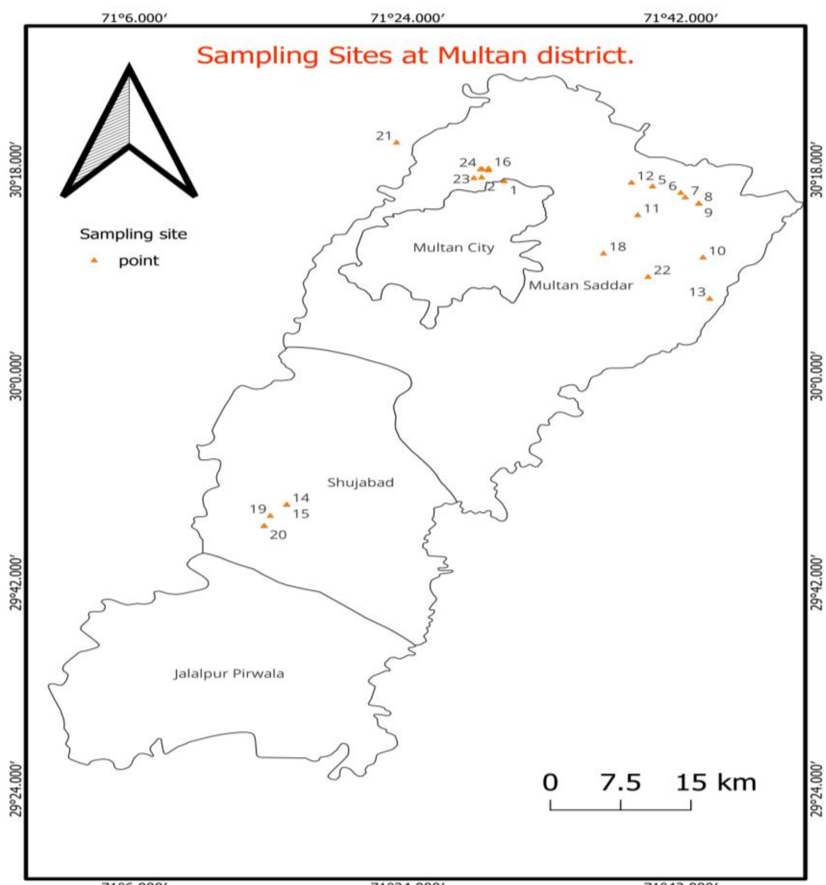

Figure 2. Plant and associated Soil sampling sites at Multan district of Punjab, Pakistan. The point showing 24 sampled orchards of Citrus in Multan districts.

RESULTS

Physico-chemical Properties of Soils of Orchards in District Multan

The study involved a comprehensive analysis of soil physico-chemical characteristics at varying depths within the citrus orchards of Multan district. Composite soil sampling was done from 3 distinct depths: 0-15cm, 15-30cm, and 30-45cm, representing each orchard. These soil analyses results were classified into specific standards for each factor, as outlined by (Malik, 1984). One notable finding across all orchards within Multan district was the alkaline nature of the soil. Surface soil pH values ranged from 7.05 to 8.47, with a mean pH value of 7.98. This alkaline soil condition is of significance in the context of citrus cultivation. Another critical parameter, electrical conductivity (EC), serves as a measure of total dissolved salts within the soil. Elevated EC levels can impact plant growth and development by causing ion uptake imbalances and osmotic effects. The data presented in Table 1 indicated that most of the soil in the orchards exhibited non-saline characteristics, with electrical conductivity values ranging from 0.03 to 1.94 dSm^{-1}, well under the crucial level of 4 dSm-1. Notably, electrical conductivity levels were elevated in the upper soil depths. Soil organic matter (SOM), a crucial component influencing nutrient availability in the soil, was another focus of analysis. The results, detailed in Table 2, highlighted that a significant portion of the soils in Multan district's citrus orchards had low organic matter content. Specifically, organic matter content in upper layer ranged from 0.63% to 1.45%, averaging 0.90%. The prevalence of low SOM content is a noteworthy concern for soil fertility and the optimal growth of citrus crops. Additionally, the analysis revealed the presence of free calcium carbonate (CaCO3) in the soils, with contents ranging from 1.75% to 12%, and an average value of 5.88%. These findings indicated that the soils in these orchards were generally moderately calcareous, falling within the range of 8-12% CaCO3 content, as detailed in Table 1.

Macro-Nutrient Level of Orchards (Soil Sample) in District Multan

The assessment of soil macro, micro-nutrient content was conducted following established criteria as outlined in previous studies (Malik, 1984; Martens & Lindsay, 1990; Rashid, 1995). The same standardized soil sampling protocol used for the physico-chemical analysis was applied to gather soil samples for nutrient analysis. In general, the soils within the citrus orchards of Multan district exhibited consistent nutrient levels. Specifically, the upper surface soils (0-15 cm) displayed a nutrient content ranging from 0.02% to 0.04%, while the lower sub-soil layers (15-30 cm) contained nutrient levels within the range of 0.01% to 0.03%, as indicated in Table 2. Examining the data related to Olsen-P extractable phosphorus, it became evident that a majority of the soils in these citrus orchards exhibited lower phosphorus concentrations. Phosphorus levels within Multan's citrus orchards spanned from 5.87 mg kg^{-1} to 12.75 mg kg^{-1} in the plow layer, and from 5.35 mg kg^{-1} to 9.58 mg kg^{-1} in the sub-surface soil layer. Remarkably, approximately fifty percent of the soils in the upper surface layer were found to be deficient in phosphorus, as detailed in Table 2. Furthermore, the assessment of extractable-KNH_4OAC revealed a range of 80-270 mg kg^{-1} in the upper soil surface (0-15 cm) and 80-150 mg kg^{-1} in the lower soil surface (15-30 cm), as illustrated in Table 2.

Micro-Nutrient Level of Orchards (Soil Sample) in District Multan:

The boron (B) content analysis revealed variations in the upper soil surface (0-15 cm), ranging from 0.16 mg kg^{-1} to 0.78 mg kg^{-1}, averaging 0.41 mg kg^{-1}. In the lower surface soil (15-30 cm), B content fluctuated between 0.30 mg kg^{-1} and 0.58 mg kg^{-1}. Notably, B content exhibited a decreasing trend with increasing depth, as summarized in Table 3. Specifically, surface soils contained B concentrations ranging from 0.21 mg kg^{-1} to 0.66 mg kg^{-1}, while subsoils featured B content within the range of 0.11 mg kg^{-1} to 0.55 mg kg^{-1} (Table 3). Assessing copper (Cu) content, it's important to note that all the soils met the critical level for DTPA extractable Cu, set at 0.2 mg kg^{-1}, as suggested by (Ryan *et al.*, 2001). Thus, there are no indications of Cu deficiency in citrus crops grown within the Multan district. Turning to iron (Fe) content, the surface soils (0-15 cm) displayed a range of 3.75 mg kg^{-1} to 15.16 mg kg^{-1}, while the subsoils exhibited Fe content ranging from 3.45 mg kg^{-1} to 10.80 mg kg^{-1} (Table 3). The crucial level for DTPA extractable Fe, required for normal plant growth according to Rashid and Ryan (2004), is 4.5 mg kg^{-1} soil. Notably, only 16.67% of the orchards fell below this critical level in terms of Fe content. Manganese (Mn) content in the upper soil surface (0-15 cm) ranged from 2.40 mg kg^{-1} to 5.05 mg kg^{-1}, while in the lower soil surface (15-30 cm), it varied from 1.17 mg kg^{-1} to 4.70 mg kg^{-1} (Table 3).

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Table 1. Soil physicochemical properties of citrus orchards situated in Multan district.

Properties	Soil Depth(cm)	Range	Average	Classification criteria		
				Acidic	Slightly alkaline	Highly alkaline
pH				<7 *	7.1-8.4	>8.4
	0-15	7.05–8.47	7.98	2; 8.33% **	20; 83.33%	2; 8.33%
	15-30	7.57–8.76	8.12	0; 0%	21; 87.50%	3; 12.50%
	30-45	7.07–8.56	8.14	0; 0%	22; 91.67%	2; 8.33%
				Non-saline	Saline	Highly saline
EC (dSm^{-1})				<4	≥ 4	>4
	0-15	0.03–1.94	1.29	24; 100%	0; 0%	0; 0%
	15-30	0.02–1.78	1.14	24; 100%	0; 0%	0; 0%
	30-45	0.26–1.80	1.06	24; 100%	0; 0%	0; 0%
				Deficient	Satisfactory	Adequate
SOM (%)				<0.86%	0.86-1.29	>1.29
	0-15	0.63–1.45	0.9	18; 75%	4; 16.67%	2; 8.33%
	15-30	0.35–1.48	0.73	19; 79.17%	3; 12.5%	2; 8.33%
	30-45	0.37–0.78	0.58	24; 100%	0; 0%	0; 0%
				Slightly Calcareous	Moderately Calcareous	Highly Calcareous
$CaCO_3$ (%)				<8	8-12	12 -25
	0-15	1.75 – 12	5.88	19; 79.17%	5; 20.83%	0; 0%
	15-30	3 – 20	7.37	14; 58.33%	8; 33.33%	2; 8.33%
	30-45	4.10 – 21	10.1	5; 20.83%	15; 62.5%	4; 16.67%

The * showed the critical limit and **Number and percentage of samples lies in the criteria as described by Malik *et al.* (1984).

Table 2. Data summary of soil macro-nutrient in orchards of Multan district.

Nutrient	Depth (cm)	Range	Average	Low	Moderate	Adequate
Nitrogen (%)				<0.043 *	0.043–0.06	>0.06
	0-15	0.02 – 0.04	0.03	24;100%**	0; 0%	0; 0%
	15-30	0.01 – 0.03	0.02	24; 100%	0; 0%	0; 0%
	30-45	0.01 – 0.19	0.03	24; 100%	0; 0%	0; 0%
Phosphorus (mg kg^{-1})				< 7	7– 15	>15
	0-15	5.87 – 12.75	8.22	12; 50%	12; 50%	0; 0%
	15-30	5.35 – 9.58	7.15	13; 54.16%	11; 45.83%	0; 0%
	30-45	3.20 – 9.22	6.59	9; 37.5%	15; 62.5%	0; 0%

Potassium (mg kg-1)				<80	80 – 180	>180
	0-15	80 – 270.25	119.49	0; 0%	23; 95.83%	1; 4.17%
	15-30	80 – 150	107.79	0; 0%	24; 100%	0; 0%
	30-45	80.42–150.36	105.77	0; 0%	24; 100%	0; 0%

The * showed the critical limit and **Number and percentage of samples lies in the criteria as described by Malik et al. (1984).

Table 3. Data summary of soil micronutrient in orchards of Multan district.

Micronutrient	Range	Average	Low	Moderate	High
			mg kg-1		
Boron			<0.5*	0.5 – 1.0	>1.0
	0.16 – 0.78	0.41	17;70.83%**	7;29.17%	0; 0%
	0.30 – 0.58	0.41	21; 87.5%	3;12.5%	0; 0%
	0.16 – 0.49	0.3	24; 100%	0; 0%	0; 0%
Copper			<0.2		>0.2
	0.21 – 0.66	0.42	0; 0%		24; 100%
	0.11 – 0.55	0.33	1; 4.17%		23; 95.83%
	0.04 – 0.49	0.24	4; 16.67%		20; 83.33%
Iron			< 4.5		>4.5
	3.7 – 15.16	7.71	4; 16.67%		20;83.33%
	3.45 – 10.80	6.4	9; 37.5%		15;62.5%
	2.27 – 9.06	4.38	16; 66.66%		8;33.33%
Manganese			<1.0	1.0 – 2.0	>2.0
	2.40 – 5.05	3.76	0; 0%	0; 0%	24;100%
	1.17 – 4.70	2.34	0; 0%	10; 0%	14; 41.66%
	0.09 – 3.13	1	16; 66.66%	7; 29.17%	1;4.17%
Zinc			<0.5	0.5 – 1.0	>1.0
	0.18 – 3.50	0.95	8; 33.33%	9;37.5%	7; 29.17%
	0.18 – 2.24	0.58	13;54.16%	9; 37.5%	2; 8.3%
	0.12 – 0.48	0.24	24;100%	0; 0%	0; 0%

The * showed the critical limit and **Number and percentage of samples lies in the criteria as described by Lindsay and Martens, 1990.

Lastly, zinc (Zn) content in the surface soils spanned from 0.18 mg kg^{-1} to 3.50 mg kg^{-1}, and in the subsoil, it ranged from 0.18 mg kg^{-1} to 2.24 mg kg^{-1} (Table 3).

These findings collectively provide insights into the micronutrient status of the soils in the citrus orchards of Multan district, with specific attention to boron, copper, iron, manganese, and zinc content. The results indicate variations in micronutrient levels, which could inform targeted nutrient management strategies to optimize citrus crop health and yield in this region.

Macro-Nutrient Level of Orchards (Plant Sample) in District Multan

Nitrogen (N) concentration in the sampled citrus leaves exhibited a range from 0.70% to 3.70%. To determine the nutritional adequacy of N content in citrus leaves, a critical level of 2.2% was employed, as per guidelines set forth by (Jones & Embleton, 1969) and (Reuter, 1997). Interestingly, 71% of the plant samples were found to be deficient in N, as detailed in Table 4. Phosphorus (P) concentration in the citrus leaves spanned from 0.08% to 0.23%. Applying the criteria suggested by (Jones & Embleton, 1969) and (D. Reuter & Robinson, 1997), it was revealed that 66.6% of the samples fell within the deficiency range, while 33% exhibited a low range of P content (Table 4). Turning to potassium (K) concentration, it varied from 0.29% to 1.39% (Table 4). In accordance with the criteria established by Jones and Embleton (1969) and Reuter and Robinson (1997), 12.5% of plant samples were potassium deficient (Table 4).

Table 4. Macronutrient level in leaf samples of orchards in Multan district.

Nutrient	Range	Average	Deficient	Low	Moderate	High
			%			
Nitrogen	0.70 – 3.7	1.50	< 2.2*	< 2.2 – 2.3	< 2.3 – 2.6	< 2.6 – 2.95
			17; 70.83%**	1; 4.16%	6; 25.00%	0; 0.00%
Phosphorus	0.08 – 0.23	0.14	< 0.09	< 0.09 – 0.11	< 0.11– 0.16	< 0.16 – 0.29
			16; 66.66%	8; 33.33%	0; 0.00%	4; 16.66%
Potassium	0.29 – 1.39	0.74	< 0.40	< 0.4 – 0.69	< 0.69 – 1.09	< 1.09 – 2.00
			3; 12.50%	10; 41.67%	7; 29.17%	4; 16.67%

The * showed the critical limit and **Number and percentage of samples lies in the criteria as described by Jones and Embleton, 1969 and Reuter and Robinson, 1997.

Micro-Nutrient Level of Orchards (Plant sample) in District Multan

Within the leaves of citrus trees, the concentration of boron (B) exhibited a wide range, spanning between 8.19 mg kg^{-1} to 65.19 mg kg^{-1}, as detailed in Table 1. Utilizing the criteria established by Jones and Embleton (1969) and Reuter and Robinson (1997), it was observed that 50% of leaves were classified as boron deficient, with an additional 29.16% falling into the low category (Table 1). Turning to copper (Cu) concentration, it ranged from 4.3 mg kg^{-1} to 13.54 mg kg^{-1} in the observed plant tissue (Table 5). Remarkably, the analysis indicated that an adequate concentration of Cu, exceeding 91.6%, was present in the sampled plants within the Multan district (Table 5). The concentration of iron (Fe) in citrus leaves exhibited a range from 151.8mg/kg to 197.8 mg/kg, encompassing the entire spectrum for citrus leaves (Table 5). Criteria established by Jones and Embleton (1969) and Reuter and Robinson (1997) suggested that all sampled leaves contained Fe concentrations above the adequate level of 36 mg kg^{-1}, achieving a 100% adequacy rate (Table 5). Manganese (Mn) concentration ranged from 9.96 mg kg^{-1} to 71.9 mg kg^{-1} within the plant samples. Criteria outlined by Jones and Embleton (1969) and Reuter and Robinson (1997) indicated that an adequate Mn concentration, accounting for 80%, was present in nearly all the sampled plant specimens (Table 5). In the case of zinc (Zn) concentration in citrus leaves, it spanned from 0.65 mg kg^{-1} to 23.3 mg kg^{-1}. The critical Zn level, as defined by Jones and Embleton (1969) and Reuter and Robinson (1997), is 16 mg kg^{-1}. Surprisingly, Zn was deficient in 66% of the orchards within the Multan district, as summarized in Table 5.

Table 5. Micronutrient level in leaf sample of orchards in Multan district.

Nutrient	Range	Average	Deficient	Low	Moderate	High
			mg kg^{-1}			
Boron	8.19 – 65.59	34.06	< 21* 12; 50.00%**	< 21 – 30 7; 29.16%	< 30 – 100 5; 20.83%	–
Copper	4.3 – 13.54	10.54	< 3.6 0; 0.00%	< 3.6 – 4.9 2; 8.30%	< 4.9– 16 22; 91.66%	–
Iron	197.80 – 572.90	359.55	< 36 0; 0.00%	< 36 – 59 0; 0.00%	< 59 – 120 0; 0.00%	< 120 24; 100%
Manganese	9.96 – 71.90	37.76	< 16 1; 4.16%	< 16 – 24 2; 8.33%	< 24 – 200 21; 87.50%	–
Zinc	0.65 – 23.33	9.38	< 16 16; 66.66%	< 16 – 24 8; 33.33%	< 24 – 200 0; 0.00%	–

The * showed the critical limit and **Number and percentage of samples lies in the criteria as described by Jones and Embleton, 1969 and Reuter and Robinson, 1997.

Table 6. Correlation among soil properties and available nutrients in soil (0 – 15cm).

	Available nutrients in soil (0 – 15cm)							
Properties	N	P	K	B	Cu	Fe	Mn	Zn
pH	-0.595**	-0.591**	-0.143	-0.249	-0.253	-0.583**	-0.421*	-0.125
EC	-0.164	-0.252	-0.061	-0.524**	-0.206	-0.091	-0.245	0.029
O.M	0.106	0.416*	0.107	0.281	0.420*	0.058	0.137	0.065
$CaCO_3$	-0.3	-0.629**	-0.357	-0.339	-0.394	-0.373	-0.282	-0.25

*Showed that the correlation is significant at the 0.05 level and ** showed that the correlation is significant at the 0.01 level.

Table 7. Correlation among soil properties and available nutrients in soil (15 – 30cm).

	Available nutrients in soil (15 – 30cm)							
Properties	N	P	K	B	Cu	Fe	Mn	Zn
pH	-0.15	-0.329	-0.396	0.034	0.017	-0.550**	-0.234	0.059
EC	-0.082	-0.227	-0.214	-0.394	-0.345	-0.263	-0.306	-0.101
O.M	0.126	0.243	0.131	0.026	-0.072	0.035	0.069	0.128
$CaCO_3$	-0.053	-0.114	-0.167	-0.0961	-0.429*	-0.844**	0.191	-0.104

*Showed that the correlation is significant at the 0.05 level and ** showed that the correlation is significant at the 0.01 level.

DISCUSSION

Physicochemical Properties of Soil

The alkaline nature of soils found in the citrus orchards of Multan district can be attributed to several factors, including the composition of the parent material, calcareousness, low organic matter content, and the region's limited rainfall. Such conditions are typical in regions with alluvium-derived soils and are known to result in elevated pH levels (Lindsay, 1979). This alkaline pH has significant implications for soil fertility, particularly with regard to the availability of essential plant nutrients. In our study, deficiencies in key micronutrients i.e. boron (B), zinc (Zn), and copper (Cu), similarly macronutrients like nitrogen (N) and phosphorus (P), were observed. These findings align with previous research conducted by Rashid (1995), who reported that over 80% of soils in this district exhibited pH levels exceeding 8.00. Electrical conductivity (EC) values were notably higher in the upper soil depth. This observation can be attributed to the use of saline-sodic water for irrigation, a common practice among local farmers. Such water sources tend to accumulate salts near the soil's surface rather than at lower soil depths (Murtaza *et al*., 2006). Additionally, chemical fertilizer application, especially in high doses, can contribute to increased salt accumulation in the upper soil layers (Ahmadi & Souri, 2018; Dehnavard *et al*., 2017). These findings corroborate the results of a study by Ashraf *et al*. (2015). One prominent issue identified in the citrus orchards of Multan district was the low soil organic matter (SOM) content in the soil. Soil organic matter is vital for soil health and plays a crucial role in fostering optimal citrus growth and development. The scarcity of organic matter in these orchards may be attributed to the region's high temperatures and limited rainfall. It is worth noting that the local farming community seldom practices the application of farmyard manure (FYM) in citrus orchards, despite the availability of various organic sources such as crop remaining, animal manure, rice husk, and sugar industry waste in Pakistan (Khan *et al*., 2015). The rapid decomposition of organic matter under high temperatures, as documented by (Sierra *et al*., 2015), contributes to this deficiency. Similar findings regarding the reduction of soil organic matter due to high temperatures were reported by (Sarwar, 2005). Research conducted by (Azam, 1988; Rashid, 1994) consistently revealed low O.M contents, typically below 1%, in the surface soils of Punjab province. Lime content was more in the lower soil depths as compared to the upper soil layers. This is because the parent material of most of the Pakistan's soil is calcareous in nature and also due to the increased application of phosphorus (P) fertilizers in these soils (Mukhtar *et al*., 2011). According to (Shahid *et al*., 2009) the presence of alluvium materials and Aeolian movement are primary factors contributing to the higher concentration of calcium carbonate (CaCO3) in Pakistani soils. (Jamal & Jamal, 2018) also noted a significant increase in CaCO3 content. The calcareous and alkaline characteristics of these soils, as evidenced by their high pH levels, are known to be associated with deficiencies in zinc (Zn) and iron (Fe) (Souri & Hatamian, 2019). Nonetheless, the high pH levels of these soils contribute to the deposition of CaCO3, further influencing their overall nutrient profile.

Macro and Micronutrients in Soil

The nutrient assessment in our study was conducted after the harvest of the crop, and it was observed that a significant portion of the nitrogen (N) is applied in form of chemical fertilizer and had been utilized by the crop. Furthermore, a limited quantity of organic manures was also applied in the orchards. Many growers expressed concerns that the use of manure might cause pathological diseases. Additionally, broadcasting of nitrogenous fertilizers contributed to losses of the applied N (Rashid, 1994). In terms of phosphorus (P), deficiencies were prevalent, with 50% of surface soils exhibiting P deficiency. A predominant reliance on nitrogenous fertilizers by most farmers in the region has contributed to this deficiency. Notably, over 70% of soils in the Punjab province have been reported to be deficient in P content (Malik, 1984; Rashid, 1994). Conversely, the analysis revealed that most of the soil samples of the Multan district orchards contained adequate amounts of potassium (K). This finding is consistent with previous research conducted by (Ranjha *et al*., 2002) and Rashid (1995), which also indicated sufficient K levels in the region. Boron (B) deficiency emerged as a prominent issue, with 70.83% of surface soils and 87.5% of subsoils found to be deficient, based on a critical level of 0.5 mg/kg (Rashid, 1994). This deficiency aligns with the findings of (Imtiaz *et al*., 2010), who concluded that 70% of Pakistani soils, including those in citrus orchards, suffered from B deficiency. This suggests that B deficiency is a widespread micronutrient disorder in citrus orchards across the Multan district. Rashid (1995, 1996) similarly observed B deficiency in 41% of Multan soil samples on a soil test basis. Copper (Cu) deficiency, on the other hand, was not suspected in citrus orchards within the Multan district. This result is consistent with findings in other citrus orchards across the Punjab province (Rashid *et al*., 1991; Zia *et al*., 2004). Cu deficiency has only been reported on a wide scale in the Sargodha district orchards (Siddiq *et al*., 2011), which controverts the results of nutrient management studies showing limited Cu deficiency in districts Sargodha, Sahiwal, and Faisalabad, affecting only 5% of the surveyed orchards (Rashid *et al*., 1991). Same findings have been concluded in subsequent trials (Ibrahim *et al*., 2007; Zia *et al*., 2004). Due to the absence of field trial data on citrus response to fertilization of copper, it is challenging to assert the widespread occurrence of Cu deficiency in Pakistani citrus orchards, and it appears to be of localized nature. Manganese (Mn) deficiency is rarely reported in Pakistan, with only a few exceptions, such as instances of large-scale Mn deficiency (e.g., 27% in

Sargodha citrus orchards, Siddiq *et al*., 2011, and 96% in orchards of Swat and Malakand, Shah *et al*., 2012). However, other studies, such as Rashid *et al*. (1991), reported that 96% of orchards in Sargodha, Faisalabad, and Sahiwal are not deficient in Mn. Similar results have been concluded in citrus orchards across the Punjab province (Ibrahim *et al*., 2007; Zia *et al*., 2004). In our current nutrient indexing study, 33.33% of surface soils and 54.16% of subsoils were deficient in zinc (Zn). Widespread Zn deficiency has also been identified in cotton fields in Lodhran (44%), Khanewal (46%), and Multan (42%) (Rashid, 1995; Rashid, 1994). This deficiency can be attributed to the inherently low availability of micronutrients, including Zn, in most Pakistani soils, primarily due to their alkaline calcareous nature. The presence of CaCO3 in the soil has been shown to decrease nutrient availability (Obreza & Rouse, 1993). This condition is compounded by the fact that Pakistani soils often arise from highly alkaline calcareous parent materials, resulting in low micronutrient status. It is important to note that Zn deficiency is not limited to alkaline calcareous soils but can also affect other types of soils, including submerged soils, whether naturally occurring or human-induced. In light of these findings, comprehensive field experimentation is warranted to determine the specific Zn fertilizer requirements for crops, particularly those sensitive to Zn deficiency.

Macro and Micronutrients in Plant

The nitrogen data obtained from both soil testing and plant analysis were in agreement. Sampling was conducted during the later stages of growth and fruit development. It was observed that only a small number of farmers use crop residues as manure, and very few growers utilized animal manure in their orchards. Nitrogen application was typically a one-time event, primarily in the form of urea and DAP, often applied in a broadcast manner, increasing the likelihood of nitrogen losses. The practice of green manure and a more strategic approach to nitrogen application may help mitigate these losses in the future. Phosphorus data also concurred between soil and plant tissue analysis. The limited use of phosphate fertilizers by farmers has contributed to the low availability of phosphorus (P), exacerbated by edaphic conditions characterized by alkaline pH levels and calcareousness. Several years ago, P was deficient in cotton crops (Rashid, 1995; 1996). To achieve optimal citrus growth and produce good-quality fruit, it is imperative to address the need for phosphorus fertilizer application. Until recently, there was limited information available regarding the boron (B) nutritional level of plants. Recent studies by Rashid (1995; 1996) reported over 50% deficiency of boron in cotton plants in South Punjab and demonstrated yield increases through B fertilizer application. These findings emphasize the importance of addressing B nutrition in citrus orchards. Adequate copper (Cu) levels for crop growth were found in both plant and soil analyses. Similar results were observed in orchards in Sargodha and Faisalabad districts (Ibrahim *et al*., 2007; Rashid *et al*., 1991). Rashid's research (1995; 1996) in cotton grown in Lodhran, Khanewal, and Multan districts also indicated sufficient Cu levels. These findings underscore the adequacy of Cu for crop growth in the region. Plant analysis, according to criteria established by Jones and Embleton (1969) and Reuter and Robinson (1997), revealed that all sampled citrus leaves contained more than the adequate level of iron (Fe), defined as less than 36 mg/kg. This finding was consistent with earlier research conducted in cotton crops in Lodhran, Khanewal, and Multan districts (Rashid, 1995; Rashid, 1994), indicating adequate Fe levels in the region. There was no Mn deficiency in cotton crops in Khanewal, Lodhran, and Multan districts (Rashid, 1995; Rashid, 1994b). Similar results were found in citrus orchards in the same districts (Ibrahim *et al*., 2007; Ranjha *et al*., 2002; Rashid *et al*., 1991). These findings suggest that Mn deficiency is not a widespread concern in the region. On the other hand, there was 66% Zinc (Zn) deficiency in citrus orchards in Multan. Both soil, plant analysis indicated that over 40% of the citrus samples had deficient levels of DTPA-TEA extractable Zn. This highlights the pressing need for further research and intervention to address Zn deficiency in citrus orchards. Similar Zn deficiency issues were observed in citrus orchards in Sargodha, Sahiwal, and Faisalabad, as reported in other studies (Ibrahim *et al*., 2007; Ranjha *et al*., 2002; Rashid *et al*., 1991).

Correlation between Soil Properties and Available soil Nutrients

The results of this study revealed several significant correlations between soil properties and nutrient concentrations, shedding light on the complex interactions governing nutrient availability in Multan soils. Firstly, the nitrogen (N) concentration in soil exhibited a significant negative correlation with pH,

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implying that as soil pH levels increased, N concentration decreased. This phenomenon may be attributed to the volatilization losses of nitrogen that tend to occur at higher pH levels. In contrast, soil organic matter (OM) showed a non-significant yet positive correlation with soil N concentration, indicating that higher levels of organic matter can enhance N retention in the soil. These findings were same as the research conducted by (Bhat *et al*., 2017) and (Kumar *et al*., 2014), which also concluded similar correlations. Additionally, the absence of significant correlations between N and other soil properties in the subsurface soil samples suggests a more complex relationship in lower soil layers. Secondly, the study found that phosphorus (P) levels in soil was significantly and negatively correlated with soil pH and soil calcium carbonate (CaCO3) content. High pH levels and CaCO3 content were associated with reduced P concentration in the soil, likely due to the conversion of soluble P into less available forms, such as calcium and magnesium phosphate compounds. Interestingly, soil organic matter exhibited a significant positive correlation with soil P concentration, suggesting that organic matter helps reduce P fixation by forming humus complexes. These results align with findings from Bhat *et al*. (2017) and (Patil *et al*., 2008). Subsurface analysis also supported these trends, as it showed similar behavior and non-significant relationships with soil physicochemical properties. Thirdly, the study revealed that soil potassium (K) concentration showed non-significant and negative correlation with soil electrical conductivity (EC) and pH. Higher levels of soil pH and EC were associated with lower K concentration in Multan soils, possibly influenced by the lime content in the lower layers of soil. However, soil organic matter and CaCO3 showed non-significant yet positive correlations with soil K concentration. This could be due to the higher lime content in lower soil layers, as suggested by Obreza and Rouse (1993). (Khadka *et al*., 2016) also reported a significant and positive correlation between K and organic matter. The subsurface investigation displayed a negative relationship between K and CaCO3, likely influenced by the higher lime content at lower depths. Fourthly, the results indicated that boron (B) concentration in soil had a significant negative correlation with EC, suggesting that higher EC levels were associated with lower B concentration. However, soil organic matter showed a positive correlation with B concentration in Multan soils. The subsurface analysis followed a similar trend, except for a non-significant positive correlation with soil pH. (Sharma & Chaudhary, 2007) also proposed that varying levels of pH, organic matter, and lime content could influence nutrient concentration in the lower soil layers. Additionally, at higher pH levels, the available form of B (B $(OH)_3$) may convert into a less available form (B (OH)4), potentially contributing to the negative correlation (Khadka *et al*., 2016). Furthermore, the study found that copper (Cu) concentration in soil displayed a non-significant and negative correlation with pH, EC, and CaCO3 levels. Elevated soil pH, electrical conductivity (EC), and soil CaCO3 content were associated with decreased Cu concentration in Multan soils. Conversely, soil organic matter exhibited a significant and positive correlation with Cu concentration. This indicates that higher soil organic matter (SOM) levels in the soil enhance Cu retention. The subsurface analysis also revealed a significant and negative correlation between Cu and CaCO3 at lower depths. (Das, 2000) suggested that at higher pH levels, Cu may precipitate as Cu (OH)2 and $CuOH^+$, reducing its concentration. Khadka *et al*. (2016a) reported a similar positive correlation between Cu and organic matter. Additionally, the study demonstrated that iron (Fe) concentration in soil had a significant and negative correlation with soil pH, while EC and CaCO3 showed non-significant negative correlations. Higher soil pH and EC levels, along with increased CaCO3 content, were linked to reduced Fe concentration in Multan soils. Soil organic matter, however, displayed a non-significant but positive correlation with Fe concentration, suggesting that higher organic matter levels enhance Fe retention in the soil. Subsurface analysis confirmed a significant and negative correlation between Fe and soil pH. These findings corroborate the idea that higher pH and lime content can reduce Fe availability (Katyal & Sharma, 1991). Moreover, the study revealed that manganese (Mn) concentration in soil exhibited a significant negative correlation with pH and non-significant positive correlations with organic matter. However, Mn concentration showed non-significant and negative correlations with EC and CaCO3 content. Elevated pH, EC, and CaCO3 levels were associated with decreased Mn concentration in Multan soils. The subsurface investigation displayed a non-significant positive correlation between Mn and lime content. Katyal and Sharma (1991) reported a good relationship between Mn and soil pH, but our study suggests that the formation of oxides (Mn^{3+} and Mn^{4+}) from Mn^{2+} at high pH levels might reduce Mn availability in surface soil (Khadka *et al*., 2016). Finally, the results indicated that zinc (Zn) concentration in soil exhibited negative correlations with soil pH, EC, and CaCO3. Higher pH and CaCO3 content were linked to reduced Zn concentration in Multan soils, potentially due to increased precipitation reactions. Conversely, EC and organic matter showed positive correlations with Zn concentration, suggesting that higher EC levels and organic matter content contribute to greater Zn availability. Subsurface analysis displayed a similar trend, with pH showing a non-significant yet positive correlation with Zn. These results align with previous studies by Katyal and Sharma (1991) and Khadka *et al*. (2016), emphasizing the impact of pH on Zn availability and the role of Zn adsorption in determining its solubility (Lindsay, 1979). In conclusion, this study unveiled complex relationships between soil properties and nutrient concentrations in Multan soils. These findings highlight the importance of managing soil pH, organic matter content, and calcium carbonate levels to optimize nutrient availability and promote healthy crop growth in the region. Further research is needed to explore the underlying mechanisms governing these interactions and develop tailored nutrient management strategies for Multan soils.

Correlation between Plant Nutrients and Available Soil Nutrients

The correlation analysis conducted in this study showed the relationships between plant nutrients and the availability of nutrients in the soil. The results revealed several noteworthy findings, as summarized in Table 7, and supported by previous research. Firstly, the analysis showed that all the studied nutrients in plants exhibited positive correlations with each other. This means that there were interdependencies among the nutrient concentrations in plant tissues. Notably, potassium (K) and iron (Fe) displayed a significant and positive correlation, indicating that changes in the concentration of one of these elements were associated with corresponding changes in the other. This correlation suggests that these two nutrients may have some shared influences or mechanisms affecting their uptake and utilization by plants. Furthermore, the research findings indicated that the application of phosphorus (P) to the soil had a notable impact on the uptake of P by plants. This observation underscores the significance of soil P levels in influencing the P content of plant tissues. When P is readily available in the soil, it enhances the capacity of plants to absorb and assimilate this essential nutrient, leading to increased P concentrations in plant tissues. This correlation between soil P availability and plant P content aligns with previous research findings reported by (Kumar *et al*., 2014; Nandapure *et al*., 2011; Sahay *et al*., 2005; Singh *et al*., 2011). These studies collectively support the idea that optimizing soil P levels through appropriate fertilization practices can contribute to improved P uptake and nutrient balance in plants. In summary, the correlation analysis conducted in this study highlights the interconnectedness of plant nutrient concentrations and underscores the importance of soil nutrient availability, particularly phosphorus, in influencing plant nutrient uptake. These findings provide valuable insights into nutrient management strategies for enhancing crop nutrient content and overall plant health. Further research is encouraged to explore the specific mechanisms and interactions governing these correlations, contributing to the development of more targeted and effective nutrient management practices in agriculture.

Table 8. Correlation between nutrients in plant sample and available nutrients in upper surface of soil (0 – 15cm).

	Soil available nutrient							
Plant nutrients	N	P	K	B	Cu	Fe	Mn	Zn
N	0.036							
P		0.118						
K			0.664**					
B				0.125				
Cu					0.399			
Fe						0.443*		
Mn							0.307	
Zn								0.258

*Showed that the correlation is significant at the 0.05 level and ** showed that the correlation is significant at the 0.01 level.

CONCLUSION

In conclusion, the comprehensive survey of citrus orchards in Multan district has shed light on the pressing issue of severe nutrient deficiencies in these orchards, specifically concerning nitrogen (N), phosphorus (P), boron (B), and zinc (Zn). While potassium (K), iron (Fe), copper (Cu), and manganese (Mn) levels were within the optimal range, the deficits in these key elements have significantly impacted the growth and yield of citrus plants. Achieving maximum citrus yields is contingent upon maintaining a balanced nutrient profile in the soil. The findings from this survey underscore the critical need for a well-informed and proactive approach to address these nutritional deficiencies in citrus orchards. It is imperative that an extensive and carefully designed experimental program be initiated to investigate and determine the most effective strategies for rectifying these deficiencies. The successful development of precise and targeted fertilizer regimens, tailored to the specific needs of citrus crops in Multan district, is essential to bolster their growth and productivity. By addressing these nutrient deficiencies through evidence-based interventions, the citrus industry in the region can thrive, contributing to improved agricultural outcomes and economic prosperity. In summary, this survey highlights the urgency of addressing nutrient deficiencies in citrus orchards and calls for concerted efforts to launch comprehensive research programs aimed at optimizing fertilizer application methods and doses to remedy these deficiencies. This proactive approach will be instrumental in ensuring the sustainable growth and vitality of citrus orchards in Multan district, ultimately benefiting local farmers and the broader agricultural sector.

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