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Correlation of Soil Characteristics and Citrus Leaf Nutrients Contents in Current Scenario of Layyah District

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Abstract: Soil with low fertility is a big problem for achieving citrus productivity. In this regard, the management of macro and micronutrients is essential. Macro and micronutrient deficiency decreased the yield and the quality of citrus fruit. It is the need of the hour to classify the soil fertility status under changing climatic scenarios. The current soil fertility survey was conducted to examine the macro and micronutrient status in the citrus production area. In soil, three depths (0–15, 15–30, and 30–45 cm) were taken for sampling. For leaves, 4–6-months-old non-bearing twigs were sampled from 20 trees per orchard at breast height. Results showed that soil pH (7.1–8.4) was slightly alkaline, electrical conductivity (EC) was non-saline (<4 dSm^{-1}), soil organic matter (SOM) was deficient (<0.86%), and calcium carbonate ($CaCO_3$) was slight calcareous (<8%), at 0–15, 15–30, and 30–45 cm depths. The majority of soil samples were low in nitrogen (N) contents at all depths, i.e., (<0.043) 0–15 (85%), 15–30 (97%), and 30–45 (100%) cm depths. Phosphorus (P) was medium (7–15 mg kg^{-1}) at 0–15 cm (60%) but low (<7 mg kg^{-1}) at 15–30 (63%) and 30–45 cm (82%) depths. Potassium (K) was medium (80–180 mg kg^{-1}) at 0–15 (69%), 15–30 (69%), and 30–45 cm (10%) depths. Boron (B) and manganese (Mn) were medium, and Cu was high in 0.15 cm, but all were low at 15–30 and 30–45 cm depths. Iron (Fe) and zinc (Zn) were low at depths of 0–15, 15–30, and 30–45 cm. Most citrus leaves were deficient in N (94%), Fe (76%), Zn (67%), and B (67%). In conclusion, soil fertilization is not sufficient for optimum citrus yield because of alkaline pH and slight calcareous soil conditions in this region. Foliar application of nutrients is suggested instead of only soil fertilization, for better nutrient management in citrus orchards.

Keywords: calcium carbonate; macronutrients; micronutrients; pH; EC; organic matter

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1. Introduction

Citrus orchards face the problem of small fruit size, poor quality, and excessive premature fruit drop due to numerous factors [1]. These factors include site, climate, soil, irrigation, rootstock, insect pest, cultivar, and diseases, adversely affecting citrus productivity if not properly managed [1–3]. Among all factors, the management of soil fertility status is the most critical one. Agronomic and human activities, and factors including high soil pH, calcareousness, poor organic manures, and salinity, all negatively impact nutrient uptake and mobilization [4–7]. Mismanagement of fertilization has greatly impaired the citrus fruit yield and quality while enhancing fruit dropping [8]. Furthermore, widespread micronutrient deficiencies (rather than macronutrient deficiencies) constitute a more critical and in-depth problem that needs serious attention [1]. Earlier reports also indicate 8d the imbalanced and non-judicious use of fertilizers in citrus orchards [1]; that is why micronutrients management in citrus growing areas is of prime importance.

Citrus shares approximately 30% among the cultivated area of different orchards [9]. Because of its quality, higher yield (9.5 tons ha^{-1}), taste, and flavor compared to other fruits, it is cultivated mainly in the Punjab province (Pakistan), and the Kinnow variety of citrus covers about 80% of the total citrus cultivatable area of Punjab [9]. In Pakistan, citrus yield is relatively low compared to other countries, i.e., Brazil, which produces 40–60 tons of citrus ha^{-1} [10]. Deficiency of micronutrients, i.e., zinc (Zn), copper (Cu), boron (B), and iron (Fe), is the most widely reported cause of low citrus yield [11–14].

It has been observed that Zn deficiency results in less fruit number per tree and low fruit quality [14,15]. It acts as a co-factor for a number of enzymes. These enzymes are involved in regulating the growth and development of chloroplast development [16]. Balance fertilization of Zn also decreases premature fruit drop and regulation of ascorbic acid content and total soluble solids [17]. The role of Cu is vital in photosynthesis, pollen viability, carboxylation efficiency, respiration, fruit set, and water use efficiency. Limited uptake of Cu also resulted in conditions called 'ammoniation', 'die back', and 'exanthema'. Under Cu deficiency, hardened gum with the brown area on the fruit rind also appeared [11]. Boron caused pollen grains, fruit set, elongation of the pollen tube, and yield improvement. It activates dehydrogenase enzymes, nucleic acid, sugar translocation, and hormones [18]. Iron acts as a catalyst in redox reactions. It regulates photosynthesis, respiration, and sulfate-nitrate reduction. The deficiency of Fe is also associated with chlorosis. It also decreases canopy volume, and the fruit-set results in reduced yield [19,20]. The deficiency of these micronutrients can be overcome by soil and foliar application of inorganic fertilizers [21–25].

The selection of nutrients application depends on soil characteristics. The soil organic matter contents, electrical conductivity, and pH regulates not only macronutrients (N, P, and K) but also micronutrients (Zn, Fe, B, and Cu) for better uptake in plants [26]. High soil pH usually results in the precipitation of nutrients. On the other hand, an increase in soil electrical conductivity due to higher water-soluble salts changes the osmotic potential of the soil solution. This change in the osmotic potential of soil solution resulted in lower nutrient levels in the plants.

Furthermore, limited organic matter in soil decreases microbial proliferation and causes alteration in C: N ratio, disturbing the available nutrients pool in the soil [27]. The presence of calcium carbonate ($CaCO_3$) as a parent material also affects the mobility and bioavailability of macro and micronutrients in the soil [28]. Furthermore, the distribution of particles according to their size, which decided the soil texture, played an imperative role in managing soil fertility status for cultivation for all crops [29]. Therefore, for the selection of fertilizer application method and the management of soil nutrients, the determination of such soil attributes is urgent [26].

Accordingly, the current survey was conducted to explore the soil attributes responsible for the unavailability of micronutrients in citrus orchards of Layyah district. This study will help to bridge the knowledge gap regarding micronutrient management in Layyah district soil and uptake optimization in citrus leaves. It will also help growers to interlink soil attributes with nutrient management at their sites according to their agroclimatic zone.

It is hypothesized that poor soil fertility and low organic contents in Layyah district soil might be a major cause of the deficiency of micronutrients in citrus leaves.

2. Materials and Methods

2.1. Extent and Locations of Areas

The survey area for indexing the citrus orchards' nutritional status consisted of one district, i.e., Layyah. The Layyah district covers about 6289 square kilometers and is situated between latitude 30°45′ and 31°24′ N and longitude 70°44′ and 71°50′ E. It is present in Sindh–Saghar Doab between the Chenab and Sindh rivers. Its shape is semi-rectangular, and the land is primarily sandy (Figure 1). Its length is around 88 km from east to west, while its width from north to south is about 72 km. It is surrounded by Jhang district in the east, Bhakkar district in the north, and Muzaffargarh district in the south. The Sindh River flows on its west side. The district is divided into Layyah, Karor Lal Esan, and Choubara tehsils for civil administration. The citrus orchards of Layyah were assessed for fertility and salinity status during 2018. For this, 48 orchards were examined [30].

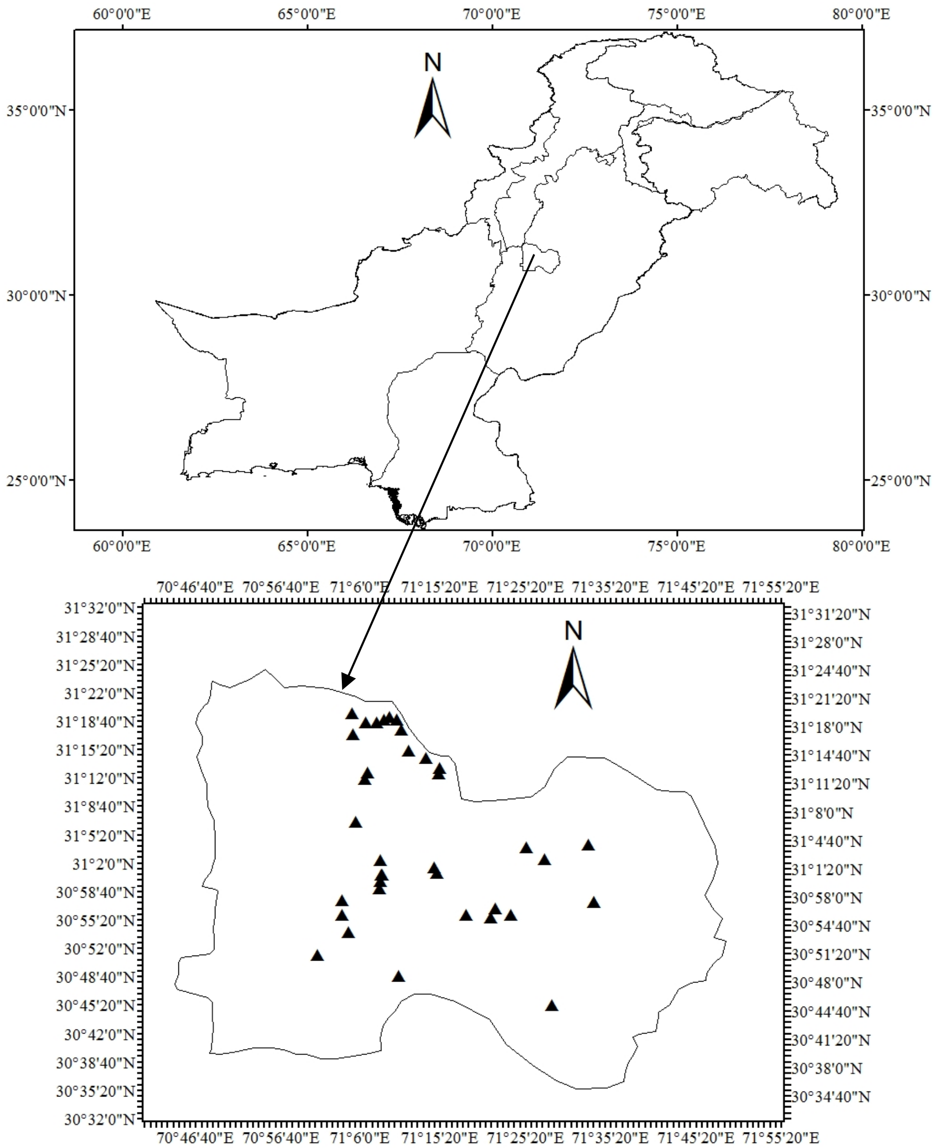

Figure 1. Geographical location of citrus plant tissues (leaves) and associated soil sampling Sites in Layyah district.

2.2. Sampling of Leaves and Soil

Citrus orchards soil samples (texture sandy loam; parent material rolling sand plains and fresh alluvium; dominant soil series Bhakkar, Banda, Bhutesar, Fazilpur and Shahdara) [31] were collected randomly from 3 depths, i.e., 0–15, 15–30, and 30–45 cm, during the 2nd week of September 2018. There were 3 replicates. Meanwhile, leaves were also sampled from the same orchard, and 4–6 month-old spring growth and non-bearing twigs leaves were sampled from 20 trees orchard^{-1} at breast height.

2.3. Soil and Plant Tissue Preparation

The collected soil samples were dried under shade, crushed, and powdered and passed through a 2 mm sieve. Leaf samples were also washed with tap water first and then with distilled- deionized water to decontaminate them, and then they were placed in an oven for drying at 70 ± 1 °C for 72 h [32]. A stainless-steel Wiley mill was used for grinding leaf blades.

2.4. Soil Chemical and Nutrients Analysis

Soil samples were analyzed for EC [33] and pH [34]. For pH determination, 1:1 ratio soil and deionized water paste was made. However, for the analysis of soil EC 1:10 ratio, soil and deionized water were mixed. After that, extract was taken and run on recalibrated (with 0.01 N KCl) EC meter. Standard published protocols were followed for the analysis of soil organic matter [35] and $CaCO_3$ [36]. Soil samples were digested with sulphuric acid for analysis of total N [37]. Extraction of soil P was done with Olsen's reagent. Next, blue color detection was made at 880nm wavelength on spectrophotometer for the computation of final soil available P [38]. Extraction of K was done with ammonium acetate solution. All the extracted samples were run on flamephotometer (PFP 7, Jenway) for the determination of K [39]. Micronutrients (Zn, Cu, Fe, and Mn) in soil were determined by the DTPA extraction procedure [40], 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. [41].

2.5. Leaves Nutrients Analysis

Analysis of macronutrients in leaves was performed by following the sulphuric acid digestion on a hot plate at 380 °C [42]. After digestion, Kjeldhals distillation apparatus was utilized for the analysis of total nitrogen [43,44]. For the determination of P and K in leaf samples, di-acid (HNO_3–$HClO_4$ = 2:1 ratio v/v) digestion was done on the hot plate at 250 °C [44–46]. Spectrophotometer (absorbance at 420 nm) and flamephotometer (PFP 7, Jenway, Staffordshire, UK) were used for the final determination of P (ammonium vanadate–ammonium molybdate yellow color method) and K, respectively. For leaves, the wet digestion procedure [47] was adopted to determine micronutrients, except for B on atomic absorption spectrophotometer. Leaf samples were dry-ashed at 550 °C for 4 h and B concentrations were calorimetrically using Azomethine-H [48].

2.6. Statistical Analysis

The standard statistical procedure was adopted for the statistical analysis of data [49]. Descriptive statistics were applied for the calculation of means and ranges of collected data (Statistix 8.1). Nutrient status was compared with standard criteria for nutrient indexation. Pearson correlation was determined to assess positive and negative correlations. Microsoft word 365 was used for the development of tables [49]. For the assessment of principal component analysis, Origin2021Pro was used [50].

3. Results and Discussion

3.1. Soil Particles

A large portion of the soil was enriched with sand particles in 0–45 cm depth. Silt ranged from 6–36% at 0–15 cm depth, to 7–33% at 15–30 cm depth, to 7–30% at 30–45 cm depth. However, clay was present with mean values of 15.81, 16.73, and 20.87% at 0–15, 15–30, and 30–45 cm depths, respectively (Table 1).

Table 1. Summary of selected sand, silt and clay contents of soils of citrus orchards in Layyah district. There were 48 sites at which sampling was performed. Means are an average of 3 replicates.

Attributes	Units	Soil Depth (cm)	Range	Mean
Sand	%	0–15	53–77	65.29
		15–30	56–76	66.52
		30–45	55–72	62.15
Silt		0–15	6–36	18.90
		15–30	7–33	16.75
		30–45	7–30	16.96
Clay		0–15	8–21	15.81
		15–30	9–22	16.73
		30–45	10–33	20.87

3.2. Soil pH and Electrical Conductivity (EC)

All the studied soils (0–15cm depth), alkaline with pHrnge 7.7 to 8.6. The pH of majority soil samples, i.e., 41 (85.41%), 39 (81.25%), and 39 (81.25%), were in 7.1–8.4 slightly alkaline range at 0–15, 15–30, and 30–45 cm depths (Table 2). These soils' high pH was due to the alluvium parent material, calcareousness, low organic matter, and low rainfall. Pakistani soils are generally alkaline, having alkaline soil pH of more than 7 [51]. The calcareousness and alkalinity of Pakistani soils are due to parent material [52]. A similar result was reported regarding the alkaline soil pH of mango orchards [53]. The pH of the Pakistani soils is basic [54]. The availability of most of the plant nutrients decreases with an increase in soil pH [55]. Similar findings were made by Ashraf et al. [56], who noted that more than 80% of soils of this district had a pH greater than 8.5.

The data in Table 2 revealed that most of the soil was non-saline (lower below the critical level of 4 dSm^{-1}). The EC of soil samples (48) ranged from 0.20 to 1.96 dSm^{-1} at 0–15, 15–30, and 30–45 cm depths. The presence of a higher sand fraction in the current soil study is linked with the low salts in the soil. Higher sand fractions might play an imperative role in leaching water-soluble salts in these soils. Our results corroborate the findings of Ashraf et al. [56]. According to them, the texture of the soil is a permanent soil property that directly affects the retention of nutrients and salt ions in the soil. The development of macropores due to large particle size resulted in the gravitational movement of water [29]. Furthermore, sand is a neutral particle. It cannot compete with clay particles in terms of nutrient holding capacity [27].

Table 2. Summary of selected physico-chemical properties of soils of citrus orchards in Layyah district. There were 48 sites at which sampling was performed. Means are an average of 3 replicates.

		Soil Depth (cm)	**Range**	**Mean**	**Acidic**	**Slightly Alkaline**	**Highly Alkaline**
pH	-	0–15	7.76–8.58	8.24	<7 * / 0 **; 0% ***	7.1–8.4 / 41; 85.42%	>8.4 / 7; 14.58%
		15–30	7.62–8.93	8.27	<7 / 0; 0%	7.1–8.4 / 39; 81.25%	>8.4 / 9; 18.75%
		30–45	7.69–8.70	8.25	<7 / 0; 0%	7.1–8.4 / 39; 81.25%	>8.4 / 9; 18.75%
EC	dSm^{-1}	Soil Depth (cm)	Range	Mean	Normal	Slightly Saline	Highly Saline
		0–15	0.20–1.88	1.14	<4 / 48; 100%	>4 / 0; 0%	>4 / 0; 0%
		15–30	0.21–1.96	1.18	<4 / 48; 100%	>4 / 0; 0%	>4 / 0; 0%
		30–45	0.20–1.96	1.12	<4 / 48; 100%	>4 / 0; 0%	>4 / 0; 0%
SOM	%	Soil Depth (cm)	Range	Mean	Low	Medium	High
		0–15	0.25–0.93	0.59	<0.86 / 45; 93.75%	0.86–1.29 / 3; 6.25%	>1.29 / 0; 0%
		15–30	0.20–0.85	0.41	<0.86 / 48; 100%	0.86–1.29 / 0; 0%	>1.29 / 0; 0%
		30–45	0.05–0.67	0.30	<0.86 / 48; 100%	0.86–1.29 / 0; 0%	>1.29 / 0; 0%
$CaCO_3$	%	Soil Depth (cm)	Range	Mean	Low	Medium	High
		0–15	1.45–17.5	7.94	<8 / 29; 60.42%	8–12 / 14; 29.16%	12–25 / 5; 10.42%
		15–30	1.30–12.6	5.78	<8 / 38; 79.17%	8–12 / 9; 18.75%	12–25 / 1; 2.08%
		30–45	1.50–18.9	8.38	<8 / 28; 58.33%	8–12 / 9; 18.75%	12–25 / 11; 22.92%

Source for nutrients ranges and critical levels were assessed according to Malik et al. [57].* Critical level, ** number of samples, and *** percentage of samples.

3.3. Soil Organic Matter (SOM)

Soil organic matter (SOM) is a vital soil component that affects the nutrient availability in soil. Most of the soils of citrus orchards of Layyah district had low organic matter content (Table 2) that ranged in the surface soil from 0.25 to 0.93%, having an average value of 0.59% in 0–15 cm plough layer. Most soils had less than 0.86% organic matter, which is essential for better crop growth. The cardinal reason for low organic matter in this district's orchard might be high temperature and low rainfall. Moreover, the citrus growers do not apply farmyard manure, and green manuring is not practiced in this area [56]. Most of the researchers reported low SOM contents and generally less than 1% in the surface soils of the Punjab province [56].

3.4. Soil Calcium Carbonates

This district's soils of citrus orchards have been calcareous, having 1.45 to 17.5% $CaCO_3$ and a mean value of 7.94% at 0–15 cm depth. In 15–30 cm depth, $CaCO_3$ ranged between 1.30 and 12.6, with a mean of 5.78%. This soil generally belongs to moderately calcareous soil (8–12%) (Table 2). However, high soil reaction (pH) caused deposition of $CaCO_3$ in our soils, and more than 72% area had high $CaCO_3$ contents. The calcareous nature of the soil is generally conducive to the deficiencies of P and micronutrients, except for Mo and Cl.

3.5. Total Nitrogen

In all three depths, soils of orchards were low in N, ranging from 0.01% to 0.04%. It was noted that only 7 and 1% soils samples from 0–15 and 15–30 cm depths were medium in N, respectively (Table 3). No soil sample was found in high N at 0–45 cm depths. On average, 0–15 cm depth was relatively higher (0.03%) in N compared to 15–30 and 30–45 cm (0.03%). Low organic-matter-carrying soils usually have low N. This decrease in N contents is mainly attributed to volatilization losses of NH_4+ and leaching of NO_3^- [58]. Sandy soil texture also facilitates the less absorption and high leaching losses of fertilizers as nitrate ion [59].

Table 3. Summary of data showing soil macronutrient status of citrus orchards in Layyah district. There were 48 sites at which sampling was performed. Means are average of 3 replicates.

Nutrients	Units	Soil Depth (cm)	Range	Mean	Low	Medium	High
N	%	0–15	0.013–0.047	0.03	<0.043 * / 41 **; 85.42% ***	0.043–0.06 / 7; 14.58%	>0.06 / 0; 0%
		15–30	0.01–0.043	0.02	<0.043 / 47; 97.91%	0.043–0.06 / 1; 2.08%	>0.06 / 0; 0%
		30–45	0.0–0.03	0.02	<0.043 / 48; 100%	0.043–0.06 / 0; 0%	>0.06 / 0; 0%
P	$mg\ kg^{-1}$	0–15	3.4–10.67	7.51	<7 / 19; 39.58%	7–15 / 29; 60.42%	>15 / 0; 0%
		15–30	2.76–9.97	6.20	<7 / 30; 62.50%	7–15 / 18; 37.50%	>15 / 0; 0%
		30–45	1.14–8.97	4.59	<7 / 39; 81.25%	7–15 / 9; 18.75%	>15 / 0; 0%
K		0–15	66–137	103.46	<80 / 15; 31.25%	80–180 / 33; 68.75%	>180 / 0; 0%
		15–30	60–132	99.47	<80 / 15; 31.25%	80–180 / 33; 68.75%	>180 / 0; 0%
		30–45	108–151	121.62	<80 / 0; 0%	80–180 / 48; 100%	>180 / 0; 0%

Source for nutrients ranges and critical levels were assessed according to Malik et al. [57]. * Critical level, ** number of samples, and *** percentage of samples.

3.6. Extractable Phosphorus

Data regarding extractable phosphorous is presented in Table 3 and shows that most of the soil of citrus orchards was found to be deficient in phosphorus. The phosphorus concentration in surface soil (0–15 cm) varied from 3.4 to 10.67 mg kg^{-1} (19% deficient and 29% medium in fertility), while in the subsoil (15–30 cm) it ranged from 2.76–9.97 mg kg^{-1} (30% deficient and 18% medium in fertility). On an average, P was almost deficient at 0–15 cm depth (7.51 mg/kg soil), 15–30 cm (6.20 mg/kg soil) depth, and 30–45 cm depth (4.59 mg/kg soil). The deficiency of P was associated with the higher $CaCO_3$ contents in the soil. When pH is increased and comes in alkaline conditions, it facilitates phosphatic fertilizers' precipitation with the Ca. The resulting Ca-P complex remained undissolved in soil solution and made P fixation in the soil [60].

3.7. Extractable Potassium

The ammonium acetate extractable-K (NH_4OAC) ranged from 66–137 mg kg^{-1} in the 0–15 cm layer soils and 60–132 mg kg^{-1} in the subsoil 15–30 cm (Table 3). Results showed that 15% of soil samples had low K contents (<80 mg kg−1), while 33% had medium K at 0–15 cm depth. No samples at 0–15 and 15–30 cm depths were found high in K contents. It was also noted that all the soil samples have medium K contents at 30–45 cm depth. On an average, K contents at 0–15 cm,15–30 cm, and 30–45 cm were 103.46, 99.47, and 121.64 mg/kg soil. The variation in the soil K contents was due to soil texture. Higher K in lower depth depicts the leaching of K ions in the sandy texture soils. In addition, an increase in the clay contents in the lower depth of currently studied soils facilitates K retention, compared to surface soil where clay contents were low [27].

3.8. Extractable Boron (B)

The plough layer (0–15 cm) soils had HCl –extractable B ranged 0.19–0.84 mg B/kg, and the subsoil (15–30 and 30–45 cm) contained 0.10 to 0.60 and 0.06 to 0.55 mg B/kg (Table 4). Boron deficiency was noted in 23, 42, and 47 soil samples at 0–15, 15–30, and 30–45 cm-depth soil samples, which accounts for 48, 87 and 98% of total soil samples. Only 25 samples at 0–15 cm depth had medium B contents, while 6 and 1 samples of 15–30 cm and 30–45 cm depth were medium in B contents. According to Rashid [61], a minimum HCl-extractable B content of 0.5 mg kg^{-1} soil is essential for optimum plant growth.

3.9. Extractable Copper (Cu)

Copper contents in the citrus orchard's surface soils (0–15 cm) ranged from 0.20 to 2.06 mg kg^{-1}, while in the subsoil (15–30) ranged from 0.04 to 2.00 mg kg^{-1} (Table 4). The generalized critical level of DTPA-TEA extractable soil Fe recommended for most crops is less than 0.2 mg kg^{-1} [62]. In the present, nutrient indexing in the soils of citrus orchards of Layyah did not show any Cu deficiency in the soil.

3.10. Extractable Iron (Fe)

DTPA-TEA extractable iron contents in the surface soils (0–15 cm) ranged from 0.15 to 6.99 mg $kg^{-1,}$ while in the subsoil (15–30 cm) it ranged from 0.11 to 6.97 mg kg^{-1} (Table 4). The generalized critical level of DTPA-TEA extractable soil Fe recommended for most crops is 4.5 mg kg^{-1} [62]. More than 50% of the surface soils were in the low range in the present nutrient indexing, while 8.3% were high. The low contents of the iron were due to the soil's sandy nature, which facilitates the leaching [27].

3.11. Extractable Manganese (Mn)

The data regarding extractable DTPA-TEA Mn presented in Table 4 indicate that the furrow slice (0–15 cm) of citrus orchards of Layyah district contained Mn contents ranging from 0.1 to 5.03 mg Mn/kg and 0.02 to 5.00 mg Mn/kg in the subsoil (15–30 cm). A minimum of 1.0 mg DTPA-TEA Mn/kg soil is required for better plant growth and development [62]. Thus, the soils of citrus orchards district contained 33% in deficient range and only 12.5% in the acceptable range Mn. This might be due to the district's sandy nature and the fact that micronutrients and organic manures are seldom used [27].

3.12. Extractable Zinc (Zn)

DTPA-TEA extractable Zn contents ranged from 0.55 to 1.55 mg kg^{-1} in the plough layer (0–15 cm) of citrus orchards of Layyah district and 0.55 to 1.25 mg kg^{-1} in subsoil (15–30) (Table 4) the critical level of DTPA-TEA extractable Zn is 0.5 mg kg^{-1} soil [62]. Thus, 50% of samples were found to be deficient in the surface soils of citrus orchards and 79% in subsoils (Table 3). Results showed that Zn concentration in soil was negatively correlated with sand contents and $CaCO_3$ [63].

Table 4. Summary of data showing micronutrients (mg kg^{-1}) status of citrus orchards in Layyah district. There were 48 sites at which sampling was performed. Means are an average of 3 replicates.

Nutrients	Units	Soil Depth (cm)	Range	Mean	Low	Medium	High
B		0–15	0.19–0.84	0.50	<0.5 23; 47.91%	0.5–1.0 25; 52.09%	>1.0 0; 0%
		15–30	0.10–0.66	0.35	<0.5 42; 87.50%	0.5–1.0 6; 12.50%	>1.0 0; 0%
		30–45	0.06–0.55	0.26	<0.5 * 47 **; 97.92% ***	0.5–1.0 1; 2.08%	>1.0 0; 0%
Cu		0–15	0.18–0.48	0.28	<0.2 6; 29.17%		>0.2 42; 70.83%
		15–30	0.15–0.32	0.21	<0.2 27; 56.25%		>0.2 21; 43.75%
		30–45	0.06–0.24	0.14	<0.2 43; 89.58%	-	>0.2 5; 10.42%
Fe		0–15	0.33–7.02	4.19	<4.5 27; 56.25%		>4.5 21; 43.75%
	mg kg^{-1}	15–30	0.25–5.78	2.61	<4.5 45; 93.75%		>4.5 3; 6.25%
		30–45	0.04–3.34	1.29	<4.5 48; 100%		>4.5 0; 0%
Mn		0–15	0.15–5.03	1.29	<1.0 16; 33.33%	1.0–2.0 29; 60.42%	>2.0 3; 6.25%
		15–30	0.12–2.12	0.72	<1.0 40; 83.33%	1.0–2.0 7; 14.58%	>2.0 1; 2.09%
		30–45	0.06–1.33	0.42	<1.0 46; 95.33%	1.0–2.0 2; 4.17%	>2.0 0; 0%
Zn		0–15	0.30–1.55	0.78	<0.5 24; 50%	0.5–1.0 19; 39.58%	>2.0 5; 10.42%
		15–30	0.24–1.25	0.48	<0.5 33; 68.75%	0.5–1.0 13; 27.08%	>2.0 2; 4.17%
		30–45	0.11–0.57	0.30	<0.5 45; 93.75%	0.5–1.0 3; 6.25%	>2.0 0; 0%

Source for nutrients ranges and critical levels were assessed according to Martens and Lindsay [62]; Rashid and Memon [64]; Rashid [65].* Critical level, ** number of samples, and *** percentage of samples.

3.13. Leaves Nitrogen, Phosphorus, and Potassium

The critical level of N in citrus leaves is 2.2% [66]. Nitrogen concentration in citrus leaves ranged from 0.50 to 2.30%, with a mean value of 1.20% (Table 5). Notably, 94% of citrus leaves were deficient in N. No samples were found in the low category. There were 2 and 4% leaf samples in adequate and high N contents, respectively. The low N was directly associated with the low N contents of the soil. Poor soil organic matter resulted in less N availability due to high volatilization, and leaching losses due to fertilizer being applied to the soil [67]. Furthermore, sufficient availability of Cu is also a major cause of less N uptake in citrus plants, according to Mulders Chart: Nutrient Interactions. Copper has an antagonistic relationship with N, and both nutrients compete for their uptake in the plants when present in the soil [68]. Phosphorus concentration in citrus leaves ranged from 0.02 to 0.22%, with a mean value of 0.1% (Table 5). Results showed that 27% of leaf samples of citrus were deficient in P. However, 20% were low, 41.5% were adequate, and 23% were high in P. The association of low and deficient P in citrus leaves was with higher Ca contents, high soil pH, and low organic matter. Less organic matter in soil decreased the soil exchange sites, which minimized the exchange of nutrients. Furthermore, Ca-P bonding also restricted P uptake in plants when in calcareous parent material soils. In addition to the above, a significant amount of P is lost after fertilizer application due to the leaching of nutrients when organic residues are minimum [69,70]. Potassium concentration in citrus leaves ranged from 0.03 to 1.36%, with a mean value of 0.6% (Table 5). On average, 60% of citrus leaves were deficient or low in K content, compared to 32% that had an adequate level of K. Only 8% of leaves were high in K content. According to the criterion suggested by Jones and Embleton [71] and Reuter and Robinson [66], 29.5% of the plant samples were categorized as K-deficient (Table 5). The low K in the citrus leaves was associated with the higher Ca contents as described by Mulders Chart: Nutrient Interactions [72]. According to this chart, a higher concentration of Ca decreases the uptake of K in plants due to the antagonistic relationship of Ca with K. Furthermore, low contents of K in sandy nature soils also decrease K uptake in the plants. It has been observed that an increase in organic residues also increases the K uptake [73]. However, in the current study soils, organic matter was also low, which played an important role in citrus leaves' low and deficient K contents [73].

Table 5. Summary of data showing the concentration of macro (%) and micronutrients (mg kg^{-1}) in leaves of citrus trees situated in Layyah district. There were 48 sites at which sampling was performed. Means are an average of 3 replicates.

Nutrients	Units	Range	Mean	Deficient	Low	Adequate	High
N	%	0.50–2.30	1.2	<2.2 * / 182 **; 94% ***	2.2–2.3 / 0; 0%	2.3–2.6 / 4; 2%	2.6–2.95 / 7; 4%
P		0.02–0.22	0.1	<0.09 / 52; 26.94%	0.09–0.11 / 38; 19.68%	0.11–0.16 / 80; 41.50%	0.16–0.29 / 23; 11.91%
K		0.03–1.36	0.6	<0.40 / 58; 29.53%	0.40–0.69 / 57; 29.53%	0.69–1.09 / 62; 32.12%	1.09–2 / 16; 8.29%
Zn	mg kg^{-1}	1.33–33.0	13.9	<16 / 129; 67%	16–24 / 44; 23%	24–200 / 20; 10%	–
Fe		1.33–57.9	28.5	<36 / 147; 76%	36–59 / 29; 15%	59–120 / 17; 9%	>120 / 0; 0%
Cu		1.00–14.9	6.65	<3.6 / 25; 12.9%	3.6–4.9 / 5; 2.65%	4.9–16 / 163; 84.5%	–
Mn		1.75–41.5	23.1	<16 / 34; 18%	16–24 / 71; 37%	24–200 / 88; 46%	–
B		2.20–33.14	16.27	<21 / 130; 67.36%	21–30 / 50; 36.90%	30–100 / 13; 6.73%	–

Source for nutrients ranges and critical levels were assessed according to Jones and Embleton [71] and Reuter and Robinson [66]. * Critical level, ** Number of samples, *** Percentage of samples.

3.14. Leaves Zinc, Iron, Copper, Manganese, and Boron

Zinc concentration in citrus leaves ranged from 1.33 to 33 mg kg^{-1}. The mean value was 13.9 mg kg^{-1} (Table 5). It was observed that 67% of citrus leaves were deficient in Zn. However, 23% of leaf samples were low in this category. Only 10% of citrus leaves were adequate in Zn concentration. Furthermore, no citrus leaves were observed in high concentrations. Total Fe concentration in citrus leaves ranged from 1.33–57.9 mg kg^{-1} (Table 5). Using the criteria of Jones and Embleton [71] and Reuter and Robinson [66] for citrus leaves, 76% of all the sampled orchards contained a low concentration of Fe (less than 36 mg kg^{-1}) or an adequate level of Fe (Table 5). Copper concentration in ranged leaves ranged from 1.0 to 14.9 mg kg^{-1} (Table 5). By using the criteria for citrus leaves as described by Jones and Embleton [71] and Reuter and Robinson [66], more than 80% of samples of citrus orchards in the district contained adequate Cu (Table 5). The manganese content in citrus leaves ranged from 1.75 to 41.5 mg kg^{-1} (Table 5). According to the criteria suggested by Jones and Embleton [71] and Reuter and Robinson [66], almost all the plant samples contained adequate Mn (Table 5). Soil analysis also revealed a similar situation (Table 5). Manganese deficiency was found in up to 33% of citrus grown in Layyah. The concentration of boron in citrus leaves ranged from 2.20 to 33.14 mg kg^{-1} (Table 5). More than 60% of leaf samples were found to be boron-deficient, and 25.9 were also categorized as low according to the criterion suggested by Jones and Embleton [71] and Reuter and Robinson [66]. The critical Zn level in citrus is 16 mg kg^{-1} [66,71]. Mulders Chart: Nutrient Interactions showed that the presence of higher Ca also minimizes Zn uptake in the plants due to an antagonistic relationship. Similar opposite interaction of Mn and Fe also exists with Cu [72]. As the soil of citrus orchards in Layyah district is also deficient in Zn and B, it is one of the major causes of less Zn uptake in the leaves. The optimum proliferation of arbuscular mycorrhizae and beneficial rhizobacteria improves the plants' Zn bioavailability through symbiosis [74]. The microbiome and proliferation of microbes are directly associated with the organic contents of the soil. These microbes solubilize the immobilized and mineralized organic fractions to release micronutrients in the soil [75,76]. As soil organic matter was low in current study soils, this was a major cause of disturbance to the microbial diversity and microbiome, which were unable to regulate the optimum micronutrients uptake in the citrus leaves [76].

3.15. Pearson Correlation of Soil and Plant Attributes

Pearson correlation showed that depth of soil was negatively associated with the sand, silt EC, OM, $CaCO_3$, Fe, Mn, B, and N contents of the soil. A positive correlation existed between the soil's Fe, Mn, B, N, and P contents. An increase in pH was negatively linked with micronutrients Zn, Fe, Mn, and Cu. Similarly, an increase in soil pH and sand was also negative compared to the K of soil. Data showed that the association of P was also negative compared with the EC and silt and positive compared with clay. In leaves, N, K, and Fe were negatively correlated with Cu. Potassium and B were positively correlated with N and P (Table 6). Principal component analysis showed that variables explained 32.3% of the variation in the first two axes (Table 7; Figure 2), which is why 18.40% and 13.90% variances were accounted for the first and second principal components, respectively. The first principal component (PC1) captured more attributes than the second (PC2). OM and N were closely linked to each other. Mn and B were more responsive towards pH, EC, and $CaCO_3$. Zinc and copper were interlinked with K. However, sand was more closely associated with P and Fe.

Table 6. Pearson correlation of studied soil and plant attributes.

							Soil								
Attributes	**Depth**	**Sand**	**Silt**	**Clay**	**pH**	**EC**	**OM**	**$CaCO_3$**	**Zn**	**Fe**	**Mn**	**Cu**	**B**	**N**	**P**
Sand	−0.2015														
Silt	−0.1112	−0.8327													
Clay	0.5189	−0.0829	−0.4827												
pH	0.0321	−0.0089	−0.0025	0.0185											
EC	−0.0138	0.0321	−0.0073	−0.0376	0.2787										
OM	−0.5566	0.0475	0.1031	−0.2607	0.2386	0.0828									
$CaCO_3$	−0.3611	−0.0585	0.0765	−0.0451	−0.0024	0.1191	0.2862								
Zn	0.2072	−0.0492	−0.0001	0.0780	−0.0306	0.0993	−0.0131	0.0531							
Fe	−0.2756	0.2646	−0.1615	−0.1278	−0.1371	−0.0639	0.0948	0.1173	−0.0313						
Mn	−0.3649	0.0856	−0.0133	−0.1115	−0.0262	0.0593	0.2562	0.1523	−0.1542	0.1107					
Cu	0.3103	−0.0443	0.0425	−0.0065	−0.1075	−0.0288	−0.1571	−0.0149	0.0963	−0.0253	−0.0493				
B	−0.2853	0.0169	0.0824	−0.1750	0.0975	0.0905	0.3065	0.0785	0.0320	0.0949	0.2165	−0.0236			
N	−0.5526	0.0435	0.1043	−0.2567	0.2410	0.0819	0.9997	0.2843	−0.0161	0.0900	0.2561	−0.1556	0.3073		
P	0.0956	0.1504	−0.1537	0.0387	0.0732	−0.0505	0.0619	0.0605	0.0655	0.1750	0.0114	0.0991	0.0829	0.0620	
K	0.3218	−0.1952	0.0568	0.2065	−0.0051	0.0884	−0.1096	−0.0110	0.2074	−0.1558	−0.1785	0.0579	−0.0408	−0.1086	0.0365
Plant															
Attributes	**N**	**P**	**K**	**Mn**	**Fe**	**Zn**	**Cu**								
P	−0.0515														
K	0.1142	0.0137													
Mn	−0.0224	0.1007	−0.0266												
Fe	0.0912	−0.0747	0.0670	−0.0429											
Zn	−0.0208	0.0146	0.0096	−0.0654	0.0198										
Cu	−0.0098	0.0426	−0.0919	0.0368	−0.0141	0.0134									
B	0.0353	0.0978	−0.0683	0.0710	−0.0831	0.0571	0.0170								

Table 7. Eigenvalues of soil studied PCA attributes.

Principal Component Name	PC1	PC2	Eigenvalue	Percentage of Variance (%)	Cumulative (%)
	Loadings				
EC	0.11039	−0.03655	2.76299	18.41996	18.41996
pH	0.17578	−0.02994	2.09231	13.94876	32.36872
OM	0.54404	−0.00228	1.52309	10.15394	42.52266
$CaCO_3$	0.24058	−0.03169	1.29373	8.62489	51.14754
Zn	−0.05452	−0.07174	1.05737	7.04912	58.19666
Fe	0.12402	0.30105	1.00438	6.69589	64.89255
Mn	0.26602	0.10773	0.94669	6.31126	71.20381
Cu	−0.12618	−0.05415	0.89797	5.98646	77.19028
B	0.29453	−0.00369	0.8619	5.74597	82.93624
K	−0.15047	−0.18534	0.72676	4.84504	87.78128
P	0.05317	0.21096	0.6767	4.51137	92.29265
N	0.54338	−0.00423	0.63379	4.22524	96.51788
Sand	0.03839	0.61922	0.52204	3.48025	99.99813
Silt	0.11845	−0.63184	2.80154×10^{-4}	0.00187	100
Clay	−0.27392	0.15779	1.02939×10^{-31}	6.86263×10^{-31}	100

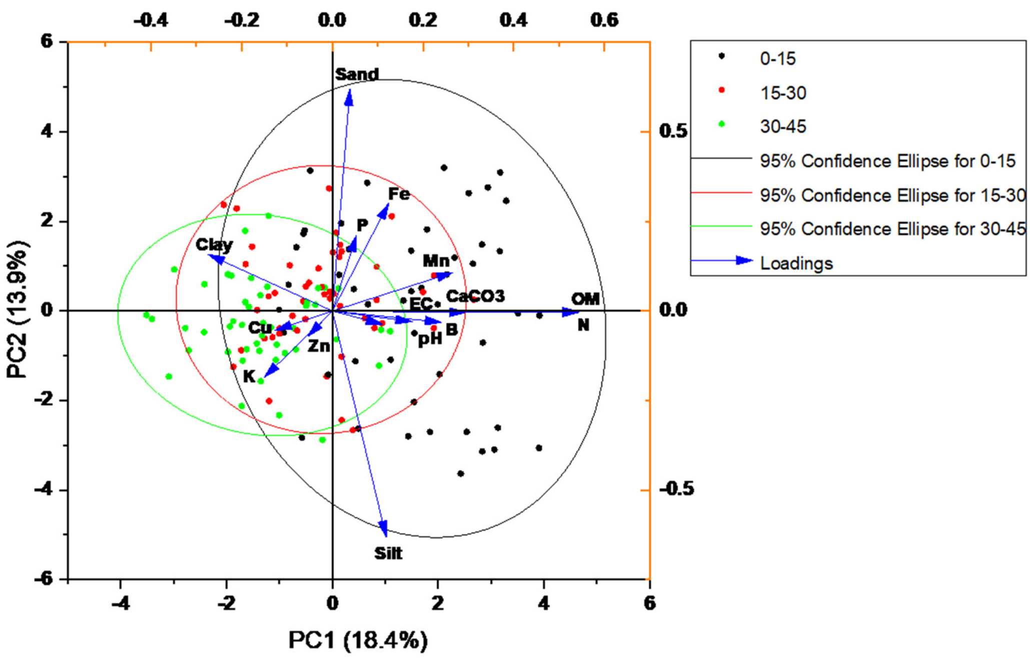

Figure 2. Principal component analysis for studied soil attributes.

4. Conclusions

Soil fertilization could not prove better because of the high sand particles, pH, and calcareous soil conditions in this region. These factors hindered the availability of basal applied micronutrients. Nitrogen, P, Zn, and B were deficient in the citrus orchard soils of Layyah district. Furthermore, citrus leaves also were deficient in Zn, Fe, and B. Foliar application of micronutrients through the foliage could be more efficient than soil fertilization to manage micronutrients in the soil. The amount of organic matter present was also found to be very small. The application of organic matter in soil, along with inorganic fertilizers, is a major requirement for the sustainable management of Layyah district's soil fertility status and for its improvement in terms of citrus nutritional contents.

5. Future Recommendation

It is time to highlight the importance of soil and leaf analyses among citrus growers. This practice should be followed regularly after subsequent years for the balanced use of fertilizers. Balanced nutrition regarding N:P:K recommended 1:0.5:0.5 for better citrus production. Citrus growers should be aware of the importance of combining farmyard manure and chemical fertilizers for good produce that has superior quality from the human health point of view. A regular fertilizer schedule (farming practice) must be included for micronutrient (Zn, B, Cu, Mn, and Fe) fertilization among citrus growers. Generally, citrus growers do not apply organic manures to their citrus groves as recommended by extension workers. Farmers should be convinced to include the use of manures in their regular fertilizer schedules. Citrus fruit yield can be enhanced by providing essential commodities such as fertilizers, fungicides, and pesticides to growers at lower rates and of good quality. Electro-print media and extension experts should provide training facilities to the citrus growers on the effective application of fungicides, organic manures, inorganic fertilizers, and pesticides. Regular short courses for clean cultivation and better pruning should be arranged for citrus. Incentives in the form of free implements and gadgets for small citrus growers (those farming 2 to 5 acres) should be supported by provincial governments.

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