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Soil Characters of the Four Main *Coffea arabica* L. Cultivars in Yemen

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Abstract

Yemen is home to many coffee cultivars due to its unique topography and soil, especially in mountain areas. Soil samples were collected from twelve coffee plantations located in three districts from three governorates. The soil texture of the four coffee cultivars (Bura'ai, Dawairi, Tufahi, and Udaini) ranged from sandy loam to loamy sand. The soil chemical features ranged between 7.08- 8.28 for pH; 3.2 to 4.9% for Nitrogen, 10 to 80 ppm for Sodium, 4 to 6 ppm for Potassium, 21.3 to 33 ppm for Phosphorous, 10.4 to 19.2ppm for Iron, 0.64 to1.93ppm for Manganite, 0.83 to 2.78 ppm for Zinc, 10 to16% for Calcium Carbonate amounts and by employing the Two Way Cluster Analysis, the four main coffee cultivars in Yemen were divided into two categories. The first category included Tufahi while the second category included Bura'ai, Dawairi, and Udaini, this can guide farmers when cultivating new coffee crops.

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1. INTRODUCTION

Coffee (*Coffea* L.) is one of the world's favorite drinks, allowing it to be the second-maximum traded produce after oil [1, 2]. About 400 billion cups of coffee are consumed by half of the world's population each year; most of this coffee is exported from developing countries [2]. Only two species, namely *Coffea arabica* L. (arabica) and *Coffea canephora* Pierre ex A. Froehner (robusta), are under commercial cultivation [2, 3]. Coffee is cultivated in over 80 different countries located in tropical and semi-tropical parts of the world and delivered to over 165 countries, either in the form of green or roasted beans [2, 4]. Since ancient times, Yemen's economy has relied heavily on agriculture. Agriculture in Yemen provides income for approximately 37 % of the country's population [5]. Yemen is home to many coffee (*C. arabica*) cultivars due to its unique topography and soil. Yemeni Coffee cultivars is a well-known cash crop, it is best produced at elevations of 1000–1800m asl but its cultivation sometimes reaches 2600m asl (mountain areas) [6] in Al-Ahjor and Shebam areas, Al- Mahweet governorate [7–9]. It grows in a variety of ecological zones in rain-fed (wadis) and irrigated conditions (wells and springs), where Yemeni coffee farmers still use traditional and /or natural agriculture techniques in growing coffee [7, 10].

Yemen is home of many *C. arabica* varieties/ or cultivars, each of which is identified by its drought tolerance, plant form, and coffee fruit characteristics such as color, size, shape, and flavor. Most of the time, the local names of coffee varieties/ or cultivars relate to the coffee's fruit shape or cultivation area [7]. Researchers have determined different numbers of variants/or cultivars; for instance, 16 *C. arabica* types/ or cultivars have been identified depending on their growing region: Al-Baidani, Al-Bonen, Al-Bura'ai, Al-Dawaeri, Al-Haimi, Al-Hammadi, Al-Jaadi, Al-Matari, Al-Udaini, Al-Shami, Al-Sharki, Al-Tofahi, Al-Yafei, Borai Bonen, Hofaini, and Koubri, but it seems that most of the researchers agree that there are only four main varieties/or cultivars of *C. arabica* in Yemen; Bura'ai, Dawairi, Tufahi and Udaini [6, 10, 11]. The Bura'ai cultivar/or variety is distinguished by its pyramid-shaped leaves and medium-sized round to ovaloid fruits that are produced all year long, while the Dawairi is distinguished by its rounded leaves and large

rounded fruits that are produced all year long; however, the Tufahi is distinguished by its elongated leaves and large apple-shaped fruits that are produced in alternate years, whereas, the Udaini is distinguished by its pendulous leaves and medium-sized round or flat fruits that are produced once a year [10]. Trees that receive insufficient amounts of nutrients from the soil suffer from yellowing leaves, which is a direct result of this deficiency. However, several studies show that appropriate chemical and physical soil conditions are as important for plant development as nutrient availability in the soil [12]. Martunis *et al.* [12], Núñez *et al.* [13], and Maro *et al.* [14] mentioned that some details of soil chemical features may be used as a reference to select the best location for coffee cultivation and to determine the correct quantity of fertilizer depending on the needs of the plant. Moreover, Coffee growth is influenced by the physical and chemical characteristics of the soil [2, 12, 15]. In 2023, Martunis *et al.* [12] conducted a field study and laboratory analysis to determine some of the physical and chemical characteristics of the forestry Coffee plantation soil in West Java, Indonesia. They found that the Coffee soil texture ranged between Silty loam to Silty clay, while pH values ranged from 5.5 to 6.6, the organic carbon content ranged from 1.99 to 4.32%, and the C/N ratio was 11–14. However, the concentration of K_2O and P_2O_5 varies from 461 to 579 ppm and 8 to 13 ppm, respectively. Additionally, soil chemical characteristics play a role in coffee quality; in 2021, Bealu [2] recorded that soil pH scale has an indirect relationship with coffee's flavor and acidity. Furthermore, a negative correlation was noticed between the quantitative measurements of soil Phosphorus, Nitrogen, & Zinc and the quality of coffee. On the other hand, the quality of coffee and soil K, Ca, CEC, and pH are directly correlated [16]. Based on these principles, it's important to conduct a preliminary study on the physical and chemical characteristics of the soil to investigate the physical features of the soil, including soil texture, and to determine the chemical characteristics that support the growth of the four main Yemeni coffee varieties; Bura'ai, Dawairi, Tufahi, and Udaini. Thus, the purpose of this study was to examine the physical characteristics of the soil (soil texture) and to investigate the chemical properties such as soil pH, Calcium Carbonate content, available Iron, Manganese, Nitrogen, Phosphorus, Potassium, Sodium and Zinc that support the growth of the four main Yemeni coffee varieties.

2. MATERIALS AND METHODS

Study area

During the period March 2022 to April 2022, soil samples were collected from twelve coffee plantations (containing natural soil not fertilized) located in three districts—four in the Hufash district, Al-Mahweet governorate, four in the Qafr district, Ibb governorate, and four in the Haraz area, Sana'a governorate—were chosen for analysis. These districts/ areas are known for growing the four primary Yemen coffee cultivars. Of these, in each district/area, the first plantation grows the Bura'ai cultivar, while the second plantation grows the Dawairi cultivar, whereas the third plantation grows the Tufahi cultivar, and the fourth plantation grows the Udaini cultivar (Table 1). Cultivars were recognized and identified with the help of Mr. Ahmed Al-Moalem (Director of the National Coffee Center, AREA) and Dr. Amein Al-Azab at the Agricultural Research and Extinction Authority- Sana'a.

Soil sampling:

The soil was collected for analysis from around 60 sites located over the 12 plantations; five distinct sites from each plantation were selected based on subjective factors such as soil color and slope orientation [17, 18]. Since the top 15 to 16 cm of soil has the highest root activity, soil samples were taken at 0-20 cm depths using a soil drill [19]. Each soil sample was dried in the air, passed through a 2 mm sieve to remove gravel and debris, and then the sample of each plantation (five samples) was thoroughly mixed to obtain a homogeneous sample for analysis and quantification [20]. Then, the mixed soil sample of each plantation was packed in plastic bags individually and sealed carefully until further analysis [17, 18, 20, 21].

Soil analysis:

Soil analysis included Physical analysis, which comprises soil texture consuming mechanical analysis by sieve method using sieves of different sizes (0. 5, 0. 4, 0. 25, 0.125, 0. 09, 0.063, 0.045 and 0.032, mm in diameter) to determine the percentage of the different types of soil particles (sand, silt and clay particles) by calculating the mass of particles retained on each sieve as a percentage of the total dry sample mass [22] then by using particle size class triangle [23] the soil texture of each coffee variety / or cultivar was determined in each coffee plantation. Moreover, to estimate the chemical requirements of each coffee variety / or cultivar, the following chemical analysis was carried out at the General Directorate of Plant Protection Laboratories:

1- Soil reaction (pH):

To measure soil pH, a soil extract (1:5W/V) was prepared from each soil sample individually, and the hydrogen ion concentration of each soil extract was measured [18, 24] using a glass electrode (pH meter).

2- Available Nitrogen:

The available nitrogen was determined by the alkaline permanganate method [25] using Potassium permanganate and Sodium hydroxide to release ammonia, which was titrated with Sulphuric acid (0.02N) till the red-pink color of the indicator (Methyl red) changed into the light yellow. The percentage of nitrogen in the soil sample was calculated from the titer value of Sulphuric acid consumed by ammonia.

Table. 1: Location of Soil Samples.

Coffee varieties /or cultivars	Coffee Plantations	Location		
		Latitude	Longitude	Altitude
Bura'ai	Haraz area (Sana'a Gov.)	15° 1'15.12"N	43°45'28.16"E	2094m asl
	Hufash District (Al-Mahweet Gov.)	15°22'13.29"N	43°21'54.71"E	2183m asl
	Qafr District (Ibb Gov.)	14°18'28.51"N	44° 4'37.34"E	1247 m asl
	Haraz area (Sana'a Gov.)	15° 1'20.76"N	43°45'13.87"E	2213m asl
Dawairi	Hufash District (Al-Mahweet Gov.)	15°22'16.11"N	43°21'48.53"E	2280m asl
	Qafr District (Ibb Gov.)	14°18'34.02"N	44° 4'36.04"E	1248m asl
	Haraz area (Sana'a Gov.)	15° 1'22.38"N	43°45'5.73"E	2324m asl
Tufahi	Hufash District (Al-Mahweet Gov.)	15°22'16.00"N	43°21'55.43"E	2230m asl
	Qafr District (Ibb Gov.)	14°18'24.01"N	44° 4'35.34"E	1247m asl
	Haraz area (Sana'a Gov.)	15° 1'21.79"N	43°44'59.61"E	2380m asl
Udaini	Hufash District (Al-Mahweet Gov.)	15°22'19.77"N	43°21'50.10"E	2312m asl
	Qafr District (Ibb Gov.)	14°18'38.36"N	44° 4'42.56"E	1260m asl

Gov.: Governorate, asl: above sea level.

3- Available Sodium:

To determine the amount of sodium accessible in each soil sample, a soil extract (1:5W/V) was made from each sample separately. Additionally, a calibration curve of Flame Photometer readings at 589 nm wavelength was developed for a series of suitable sodium standards solutions. The sodium (Na) in the soil samples was measured by projecting the flame photometer readings of the sodium soil samples onto the calibration curve of the appropriate sodium standards solution series. The available amount of sodium in the soil samples was calculated and expressed as parts per million (ppm), according to Richard [24].

4- Available Phosphorous:

Soil samples were tested for accessible phosphorus using Olsen's technique [26]. In this procedure, 5 grams of soil sample were mixed with 100 milliliters of 0.5 N sodium bicarbonate (pH 8.5), which transformed all of the phosphorus molecules into orthophosphate. Then, a molybdate solution was added (after pH had been adjusted to 3.0 with 4N HCl), resulting in a blue-colored solution containing a phosphomolybdate complex. A spectrophotometer read the color intensity at 882 nm. In addition, a calibration curve for spectrophotometer readings at 882 nm wavelength was created for a number of appropriate solutions for phosphorus standards. By superimposing the spectrophotometer readings of the phosphorus-containing soil samples onto the calibration curve of the relevant phosphorus standards solution series, the quantity of phosphorus in the soil samples was calculated and expressed as parts per million (ppm) [26].

5- Available Potassium:

The available potassium in soil samples was estimated by the Flame photometric method by mixing 5 g of air-dried soil sample with 25 ml of 1N ammonium acetate, filtered, and then diluted by adding 25 ml of distilled water to 5ml of filtrate soil solution. The diluted extract was atomized to a flame photometer to note the quantity of potassium in soil samples as ppm [27].

6- Available, Zinc, Iron, and Manganese:

The available Zinc, Iron, and Manganese were estimated by mixing 10 g of air-dry soil with 20 ml of DTPA extraction solution, which was composed of 0.005M DTPA (diethylenetriamine pentaacetic acid), 0.01M $CaCl_2$, 0.1M TEA (buffer), and the pH was adjusted to 7.3. The mixture was shaken on a reciprocating shaker for two hours. The suspension was filtered using filter paper, Whatman No. 42. An atomic absorption spectrophotometer was used to measure Zn, Fe, and Mn in the filtrate, then available concentrations of Zinc Iron and Manganese in the soil samples were calculated and reported as ppm [28].

7- Calcium Carbonate:

The calcium carbonate percentage was determined according to Jackson [29] by adding 5 gm of air-dried soil to 1N HCl and stirring vigorously for 1 hour, 6-8 drops of phph indicator was added to 20 ml of the supernatant liquid, then the mixture was titrated against NaOH (1N). Moreover, HCl was titrated against NaOH(1N) to obtain

Table 2: Soil Particles and Soil Texture.

Particles	Location of Plantations	*C. arabica* Cultivars			
		Bura'ai	Dawairi	Tufahi	Udaini
Silt %	Haraz area (Sana'a Gov.)	25	35	17	21
	Hufash District (Al-Mahweet Gov.)	14	19	4	8
	Qafr District (Ibb Gov.)	17	25	7	19
Mean of Silt %		18.7	26.3	9.3	16
Clay%	Haraz area (Sana'a Gov.)	15	8	10	8
	Hufash District (Al-Mahweet Gov.)	11	12	2	5
	Qafr District (Ibb Gov.)	5	9	4	9
The mean of Clay %		10.3	9.7	5.3	7.3
Sand%	Haraz area (Sana'a Gov.)	60	57	73	71
	Hufash District (Al-Mahweet Gov.)	75	69	94	87
	Qafr District (Ibb Gov.)	78	66	89	72
The mean of Sand %		71	64	85.3	76.6
Soil texture	Haraz area (Sana'a Gov.)	Sandy loam	Sandy loam	Sandy loam	Sandy loam
	Hufash District (Al-Mahweet Gov.)	Sandy loam	Sandy loam	Sand	Sandy loam
	Qafr District (Ibb Gov.)	Sandy loam	Sandy loam	Sand	Sandy loam
Soil texture based on the mean percentage		Sandy loam	Sandy loam	Loamy sand	Sandy loam

Gov.: Governorate

the blank titration, which is used to determine the percentage of calcium carbonate. The Soil analysis (Physical and chemical analysis) was made for each homogeneous sample, which represents the soil of each plantation. Then, the mean of each analysis for the three plantations for each variety/ or cultivar was taken to represent the physical and chemical properties of each variety/ or cultivar.

Statistical Analysis:

The collected data was statistically analyzed using PC-ORD Windows version 7.09 (Two Way Cluster Analysis (TWCA)) using the Least Significant Difference (LSD) at P- value = 0.05 to compare the significant differences among the Physical and chemical quantitative properties of each coffee variety/ or cultivar [30, 31].

3. RESULTS AND DISCUSSION

Based on Table 2 and Figures 1, 2 & 3, the percentage of silt and clay particles in the plantation soil of the Bura'ai cultivar ranged from 14% to 25% (with a mean of 18.7%) and 5% to 15% (with a mean of 10.3%), respectively, while the percentage of sand particles in ranges of 60% to 78% (with a mean of 71%). However, the percentage of Silt particles in the plantation soil of the Dawairi cultivar varied from 19% to 35% (mean of 26.3%), whereas the percentage of clay and Sand ranged from 8% to 12% (with a mean of 9.7 %) and 57% to 69% (with a mean of 64%), correspondingly (Table 2 and Figures 1, 2 & 3).

Moreover, the percentage of Silt particles in the plantation soil of the Tufahi cultivar (Table 2 and Figures 1, 2 & 3) ranges between 7% - 17% (with a mean of 9.3%), while the Clay particles vary from 2% to 10% (with a mean of 5.3%), whereas the percentage of Sand ranged between 73% to 94% (with mean of 85.3%). Furthermore, Table 2 and Figures 1, 2 & 3 illustrate that the percentage of Silt particles varied in the plantation soil of the Udaini cultivar from 8% to 21% (with a mean of 16%), whereas the clay and the sand particles ranged between 5 to 9% (with a mean of 7.3%) and 71 to 87% (with a mean of 76.6%) sequentially. On the other hand, Table 2 and Figures 1 & 13 indicate that the Dawairi cultivar plantation soil has the highest mean percentage of silt particles (26.3), followed by the soils of the Bura'ai (18.7), Udaini (16.3), and Tufahi (9.3) cultivars. Moreover, Table 2 and Figures 2 & 13 illustrate that the Bura'ai cultivar plantation soil has the highest mean percentage of clay particles (10.3), followed by the plantation soil of the Dawairi, Udaini, and Tufahi, with a mean percentage of clay particles; 9.7, 7.3 and 5.3 serially. Furthermore, Table 2 and Figures 3 & 13 exhibit that the Tufahi cultivar plantation soil has the highest mean percentage of sand particles (85.3), followed by Udaini (76.6), Bura'ai (71), while Dawairi has the lowest percentage of sand particles (64). In addition, Table 2 shows that the plantation soil texture of the four *C. arabica* cultivars ranges from sandy loam to loamy sand, and this result is compatible with the findings of Marbun *et al.* [32] where they studied the relationship between soil profile fertility and *C. arabica* production in the northern region of Sumatra and they noted that *C. arabica* grows on four types of soil texture including sandy loam to loamy sand. According to Table 3 and Figures 4 & 5, the plantation soil pH of the Bura'ai cultivar ranges between 8.1 to 8.24 (with a mean of 8.15), while the Nitrogen percentage varied from 3.3 to 3.8 (with a

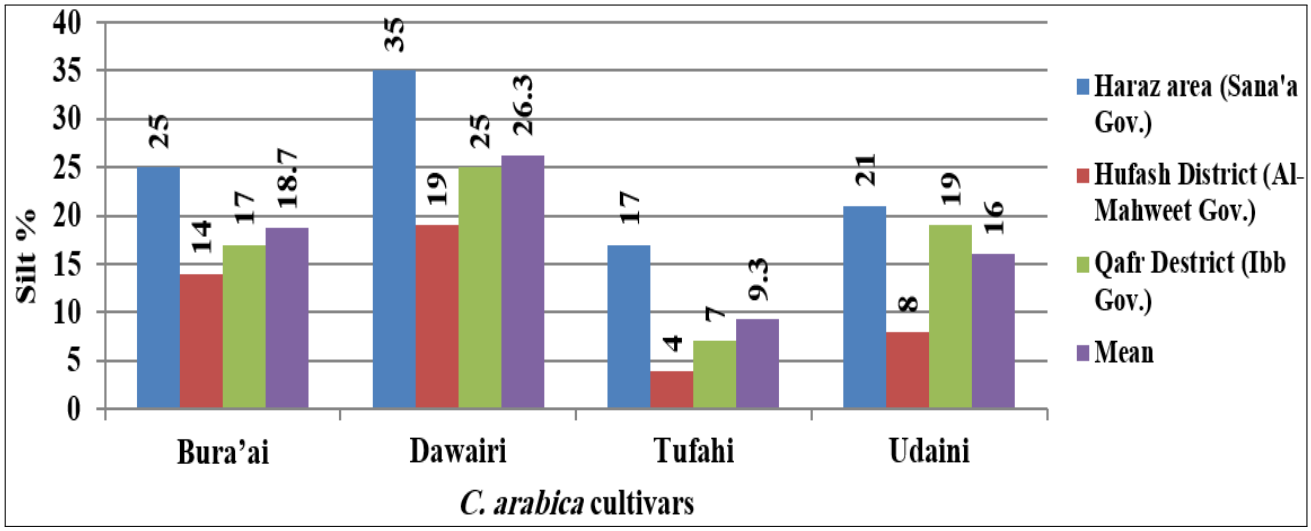

Figure 1. Percentage of Silt particles in the plantation soil of the four *C. arabica* cultivars.

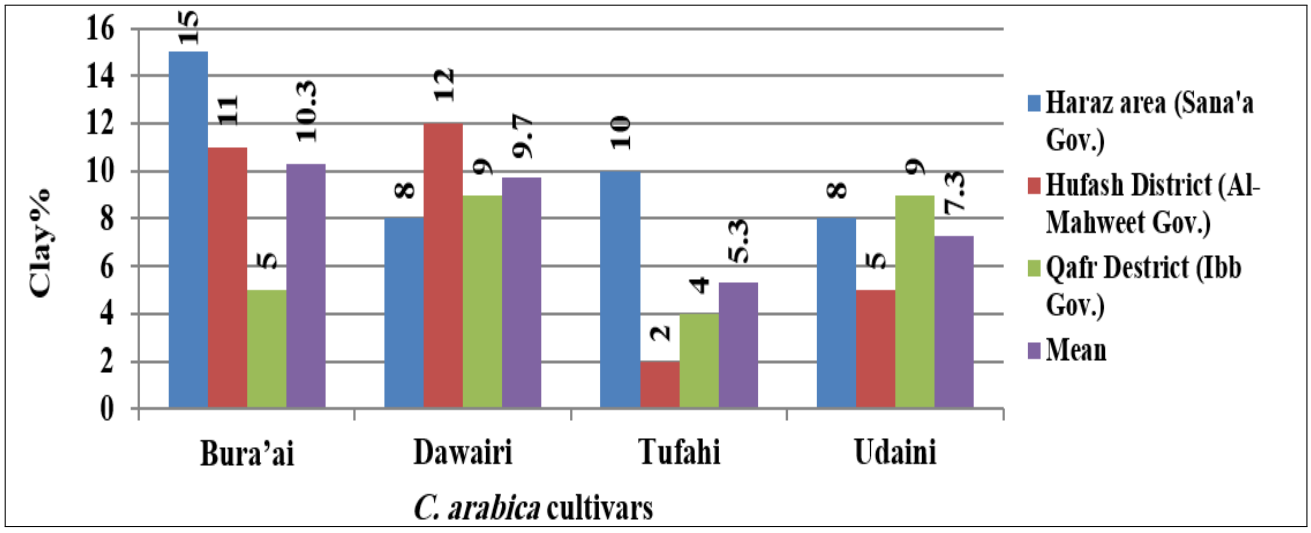

Figure 2. Percentage of Clay particles in the plantation soil of the four *C. arabica* cultivars.

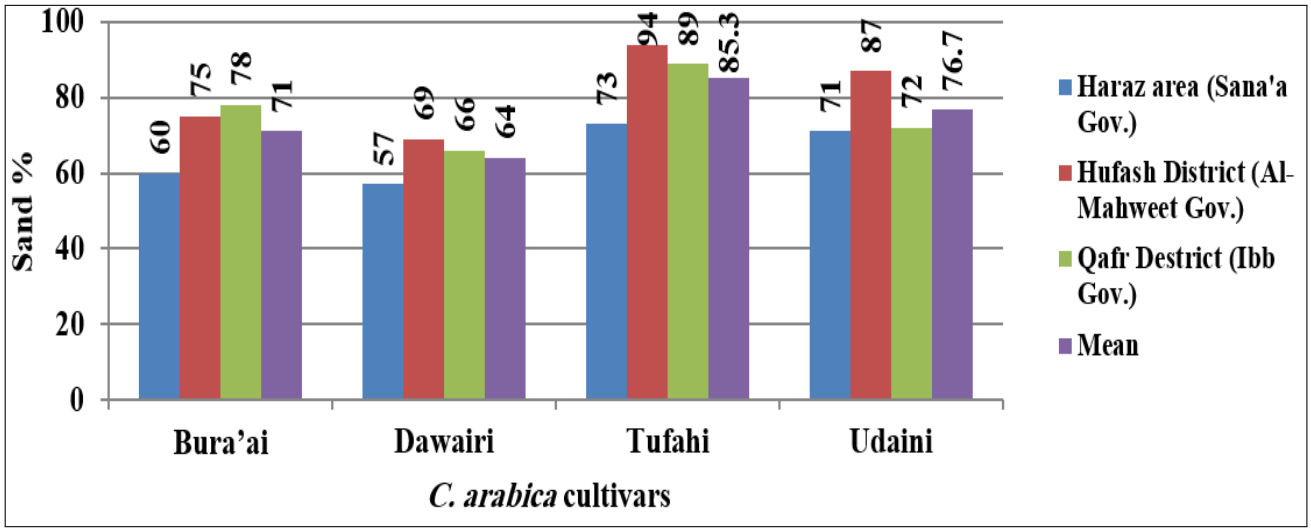

Figure 3. Percentage of Sand particles in the plantation soil of the four *C. arabica* cultivars.

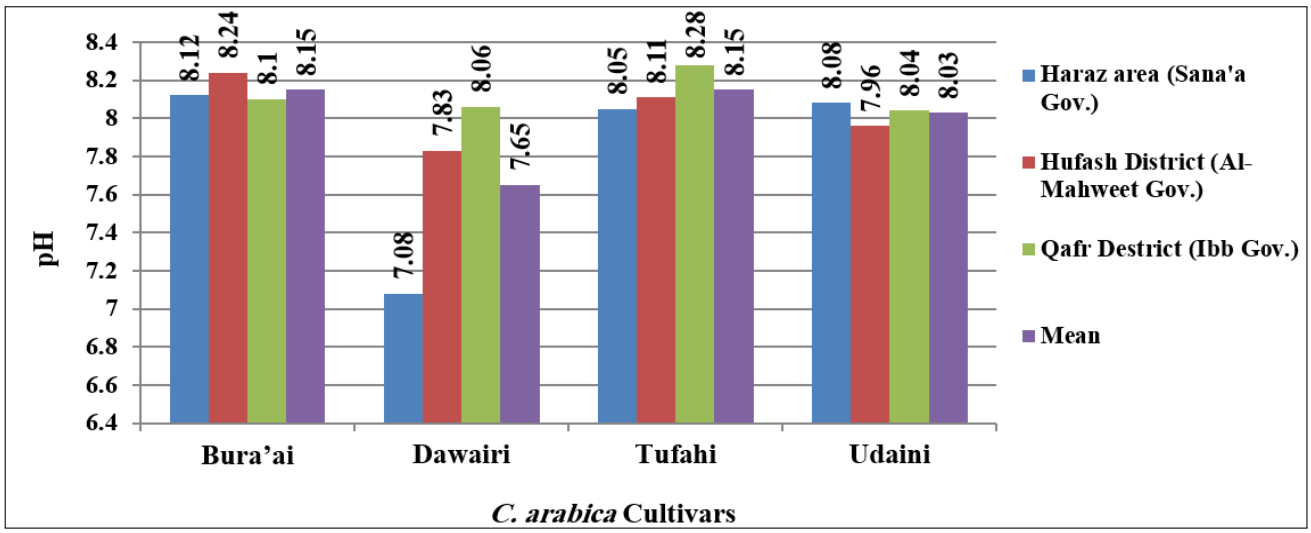

Figure 4. pH of the four *C. arabica* cultivars plantation soil.

mean percentage of 3.5), whereas; the percentage of Calcium Carbonate (Table 3 and Figure 6) in the Bura'ai cultivar plantation soil ranged from 10 to 15 (with a mean of 13.3). Moreover, the amount of Sodium Phosphorus; Iron, Manganite, and Zinc in the Bura'ai cultivar plantation soil ranged between 10-30ppm (with a mean of 20 ppm), 27-29 ppm (with a mean of 28 ppm), 11.1-15.7 ppm (with a mean of 12.7 ppm); 0.9-1.63 ppm (with a mean of 20 ppm) and 0.83-1.87 ppm (with a mean of 1.2 ppm) respectively (Table 3 and Figures 7, 9, 10, 11 & 12), while, the quantity of Potassium was 5 ppm (Table 3 and Figure 8). However, the Dawairi cultivar plantation soil pH (Table 3 and Figure 4) varied from 7.08 to 8.06 (with a mean of 7.65), while the Nitrogen percentage (Table 3 and Figure 5) ranged from 3.2 to 4.7 (with a mean percentage of 4.2), whereas the percentage of Calcium Carbonate (Table 3 and Figure 6) in the Dawairi cultivar plantation soil ranged from 13 to 15 (with a mean of 14). Moreover, the amount of Sodium and Potassium in the Dawairi cultivar plantation soil ranged from 30 - 40ppm (with a mean of 33.3ppm) and 4-5 ppm (with a mean of 4.7 ppm) consecutively; while the quantity of Phosphorus and Iron ranged between 21.3-30ppm (with a mean of 25.8ppm) and 10.7-14.7ppm (with a mean of 13 ppm) accordingly; whereas the amount of Manganite and Zinc ranged from 0.67 to 1.93 ppm (with a mean of 1.2 ppm) and 1.67-2.52ppm (with a mean of 2.06 ppm) correspondingly (Table 3 and Figures 7, 8, 9, 10, 11 & 12). Moreover, the pH of the Tufahi cultivar plantation soil (Table 3 and Figure 4) ranges between 8.05 to 8.28 (with a mean of 8.15), while the Nitrogen percentage (Table 3 and Figure 5) varied from 3.6 to 4.4 (with a mean percentage of 3.9), however; the percentage of Calcium Carbonate (Table 3 and Figure 6) ranged from 13 to 15 (with a mean of 14).

In addition, the quantity of Sodium, Phosphorus; Iron, Manganite and Zinc in the plantation soil of the Tufahi cultivar ranged from 30-80 ppm (with a mean of 53.3ppm), 30-80 ppm (with a mean of 53.3 ppm); 17-25 ppm (with a mean of 21.9 ppm); 11.6-19.2 ppm (with a mean of 14.3 ppm); 1.04-1.45 ppm (with a mean of 1.27 ppm) and 1.56- 2.53 ppm (with a mean of 1.94 ppm) sequentially (Table 3 and Figures 7, 9, 10, 11 & 12), while the amount of Potassium in the Tufahi cultivar plantation soil was 5ppm in all Tufahi cultivar plantation (Table 3 and Figure 8). Additionally, the Udaini cultivar plantation soil pH (Table 3 and Figure 4) varied from 7.96 to 8.08 (with a mean of 8.03), whereas the Nitrogen percentage (Table 3 and Figure 5) ranged from 4.2 to 4.9 (with a mean percentage of 4.5), however; the percentage of Calcium Carbonate (Table 3 and Figure 6) in the soil of the Udaini cultivar ranged from 14 to 16 (with a mean of 15). Moreover, the amount of Sodium and Potassium in the Udaini cultivar plantation soil ranged from 20- 70 ppm (with a mean of 40 ppm) and 5-6 ppm (with a mean of 5.3 ppm) consecutively, while the quantity of Phosphorus and Iron ranged between 23-33 ppm (with a mean of 27.3ppm) and 10.4-17.2ppm (with a mean of 14.6 ppm) accordingly; whereas the amount of Manganite and Zinc ranged from 0.64 to 1.12 ppm (with a mean of 0.83ppm) and 1.79 - 2.78ppm (with a mean of 2.44 ppm) correspondingly (Table 3 and Figures 7, 8, 9, 10, 11 & 12). On the other hand, Table 3 and Figures 4 & 13 indicate that the Bura'ai and Tufahi cultivars plantation soil has the highest mean of pH (8.15) followed by the Udaini cultivar (8.03) and Dawairi cultivar (7.65) plantation soils. Moreover, the Udaini cultivar plantation soil showed the highest mean Nitrogen percentage (4.5), followed by the plantation soil of the Dawairi cultivar, Tufahi cultivar and Bura'ai cultivar with a mean Nitrogen percentage of 4.2; 3.9, and 3.5 respectively (Table 3 and Figures 5 & 13); whereas, the Udaini cultivar plantation soil (Table 3 and Figures 6 & 13) illustrates the highest Calcium Carbonate mean percentage (15) when compared with the plantation soil of Dawairi (14); Bura'ai and Tufahi (13.3) cultivars plan-

Table. 3: Soil Chemical Properties.

Chemical Characters	Location of Plantations	*C. arabica* Cultivars			
		Bura'ai	Dawairi	Tufahi	Udaini
pH	Haraz area (Sana'a Gov.)	8.12	7.08	8.05	8.08
	Hufash District (Al-Mahweet Gov.)	8.24	7.83	8.11	7.96
	Qafr District (Ibb Gov.)	8.1	8.06	8.28	8.04
Mean of pH		8.15	7.65	8.15	8.03
%N	Haraz area (Sana'a Gov.)	3.3	3.2	3.7	4.5
	Hufash District (Al-Mahweet Gov.)	3.8	4.7	3.6	4.2
	Qafr District (Ibb Gov.)	3.4	4.6	4.4	4.9
Mean of % N		3.5	4.2	3.9	4.5
% Calcium (CaCO3)	Haraz area (Sana'a Gov.)	15	13	11	14
	Hufash District (Al-Mahweet Gov.)	10	15	14	15
	Qafr District (Ibb Gov.)	15	14	15	16
Mean of % $CaCO_3$		13.3	14	13.3	15
Na (ppm)	Haraz area (Sana'a Gov.)	10	30	50	70
	Hufash District (Al-Mahweet Gov.)	30	40	80	30
	Qafr District (Ibb Gov.)	20	30	30	20
Mean of Na amount		20	33.3	53.3	40
K (ppm)	Haraz area (Sana'a Gov.)	5	4	5	5
	Hufash District (Al-Mahweet Gov.)	5	5	5	6
	Qafr District (Ibb Gov.)	5	5	5	5
Mean of K amount		5	4.7	5	5.3
P (ppm)	Haraz area (Sana'a Gov.)	29	26	25	26
	Hufash District (Al-Mahweet Gov.)	27	21.3	23.8	33
	Qafr District (Ibb Gov.)	28	30	17	23
Mean of P amount		28	25.8	21.9	27.3
Fe (ppm)	Haraz area (Sana'a Gov.)	15.7	14.7	19.2	10.4
	Hufash District (Al-Mahweet Gov.)	11.1	10.7	11.6	16.2
	Qafr District(Ibb Gov.)	11.3	13.6	12.1	17.2
Mean of Fe amount		12.7	13	14.3	14.6
Mn (ppm)	Haraz area (Sana'a Gov.)	1	1	1.45	0.73
	Hufash District (Al-Mahweet Gov.)	1.63	0.67	1.04	1.12
	Qafr District (Ibb Gov.)	0.93	1.93	1.33	0.64
Mean of Mn amount		1.19	1.2	1.27	0.83
Zn (ppm)	Haraz area (Sana'a Gov.)	0.91	2	1.72	2.75
	Hufash District (Al-Mahweet Gov.)	0.83	2.52	2.53	1.79
	Qafr District (Ibb Gov.)	1.87	1.67	1.56	2.78
Mean of Zn amount		1.2	2.06	1.94	2.44

Gov.: Governorate, ppm: parts per million.

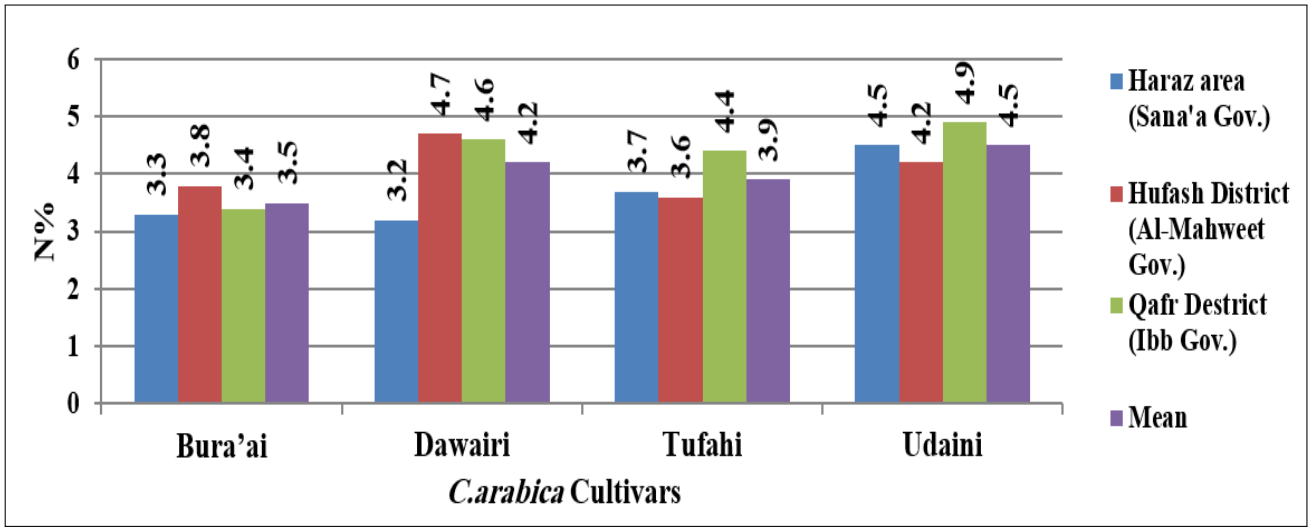

Figure 5. Percentage of Nitrogen in the four *C. arabica* cultivars plantation soil.

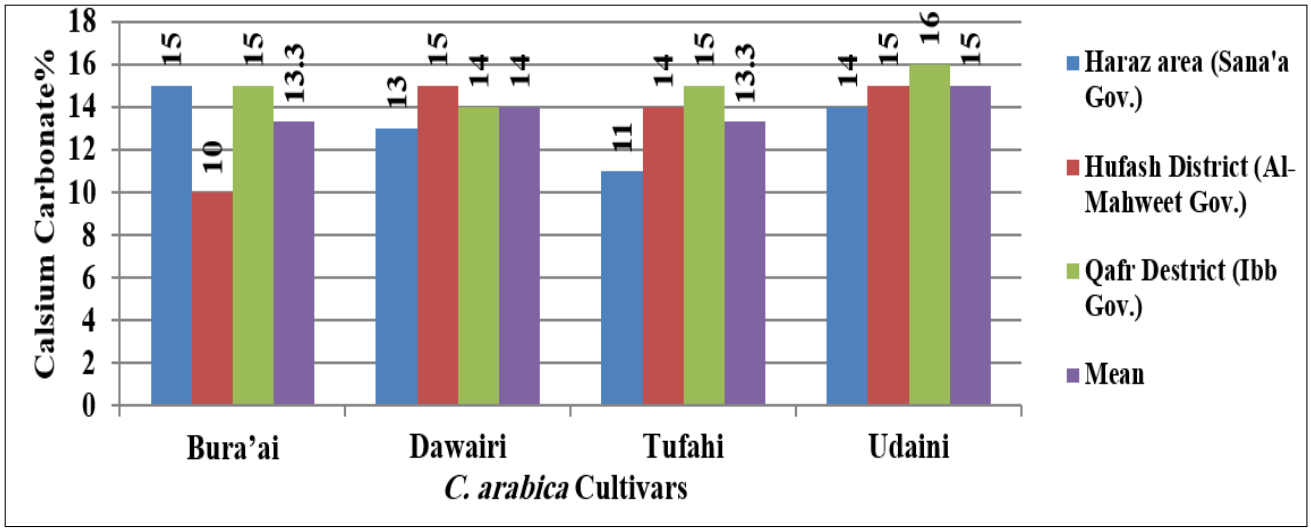

Figure 6. Percentage of Calcium Carbonate in the four *C. arabica* cultivars plantation soil.

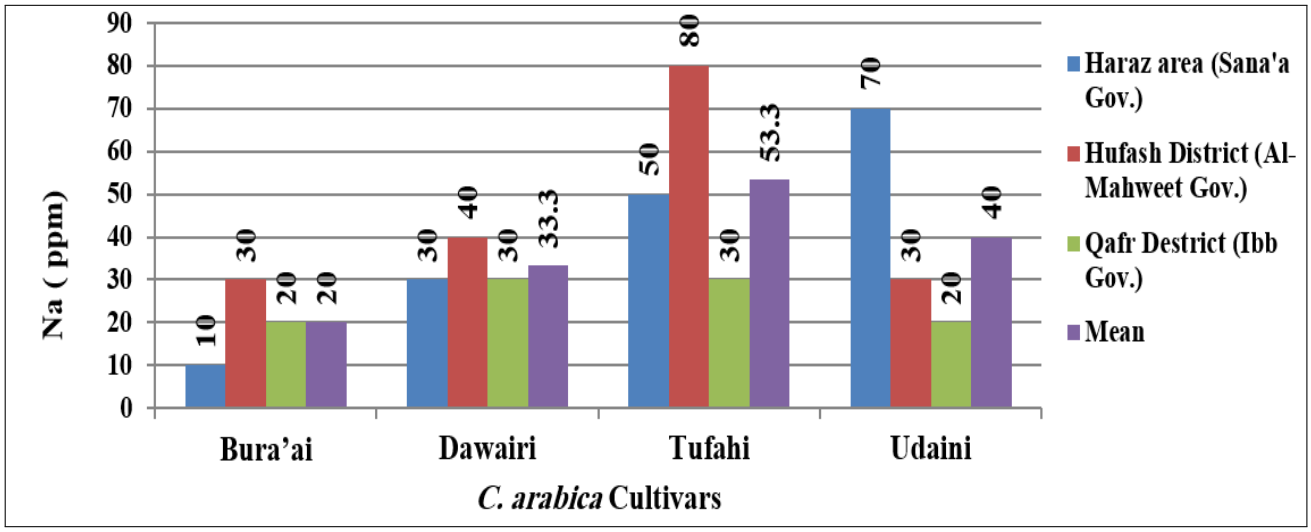

Figure 7. Amount of Sodium in the four *C. arabica* cultivars plantation soil.

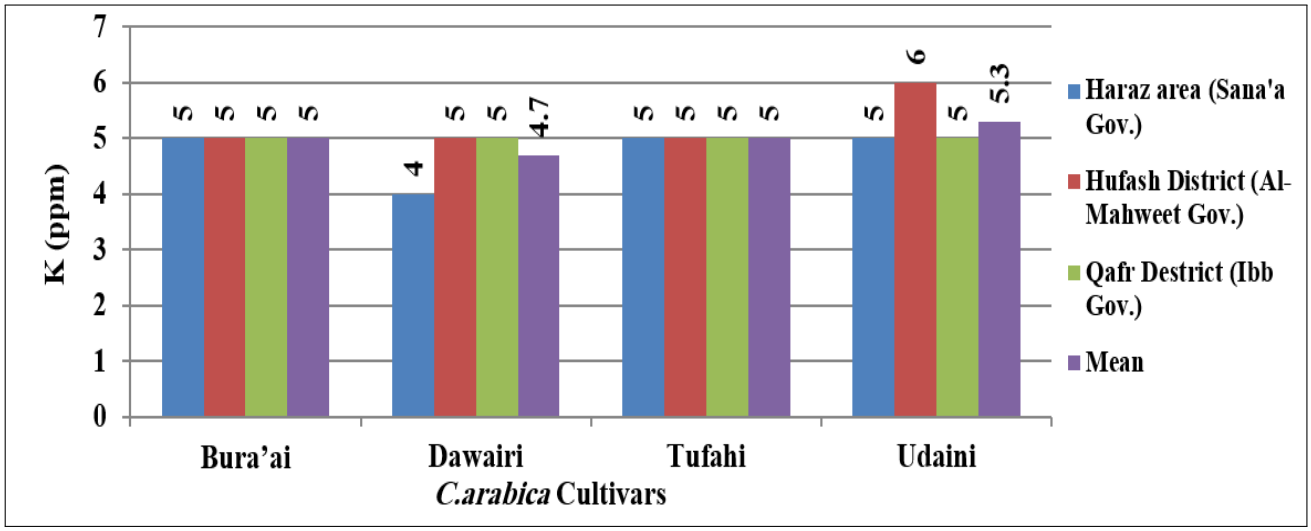

Figure 8. Amount of Potassium in the four *C. arabica* cultivars plantation soil.

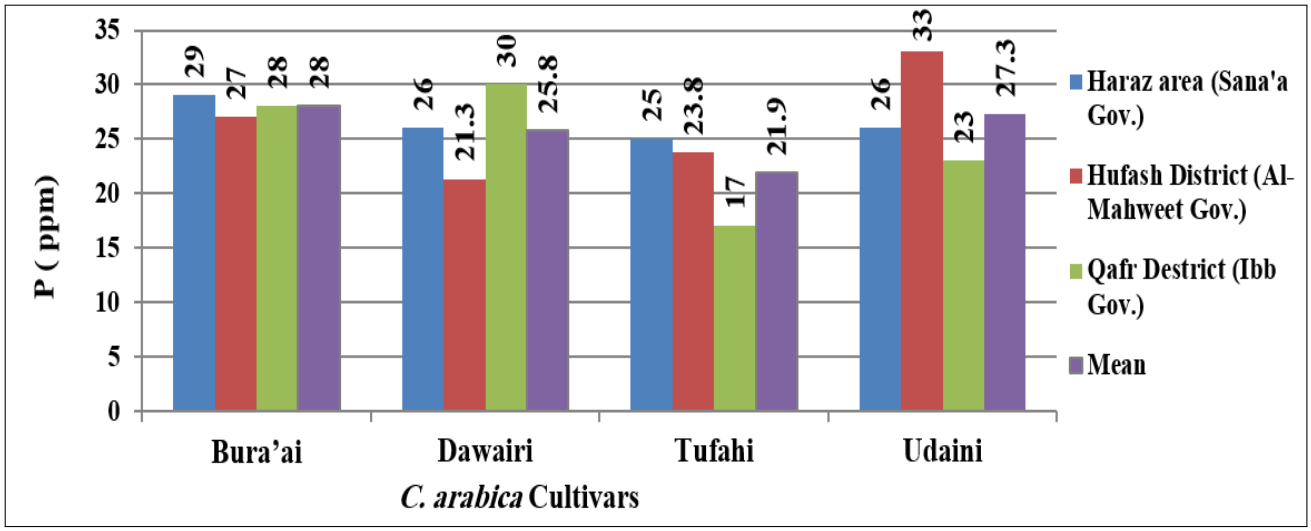

Figure 9. Amount of Phosphorous in the four *C. arabica* cultivars plantation soil.

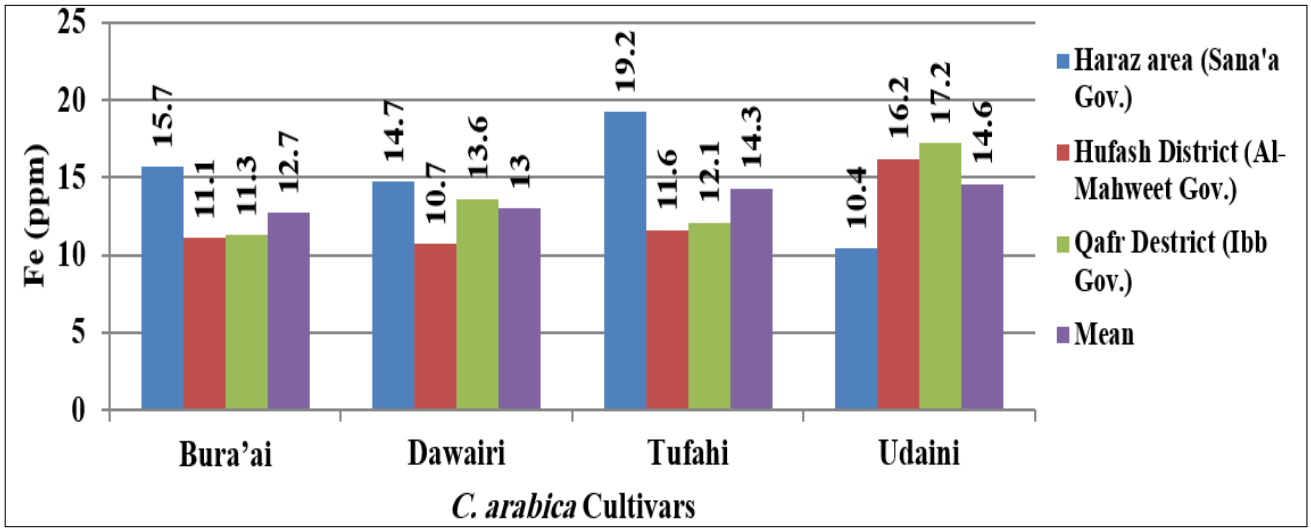

Figure 10. Amount of Iron in the four *C. arabica* cultivars plantation soil.

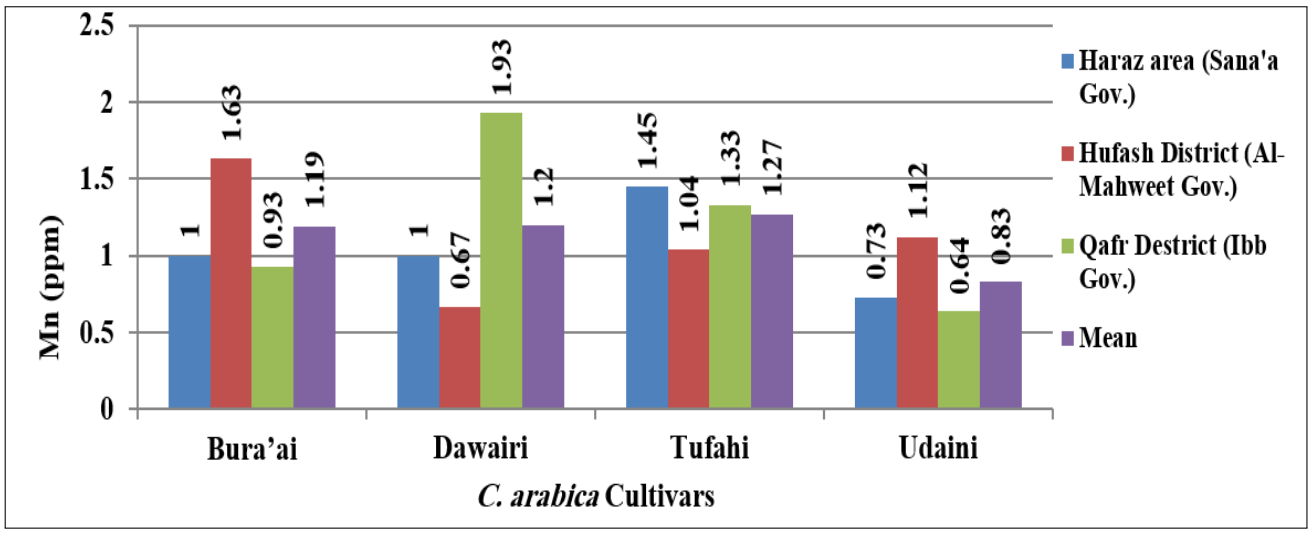

Figure 11. Amount Manganite in the four *C. arabica* cultivars plantation soil.

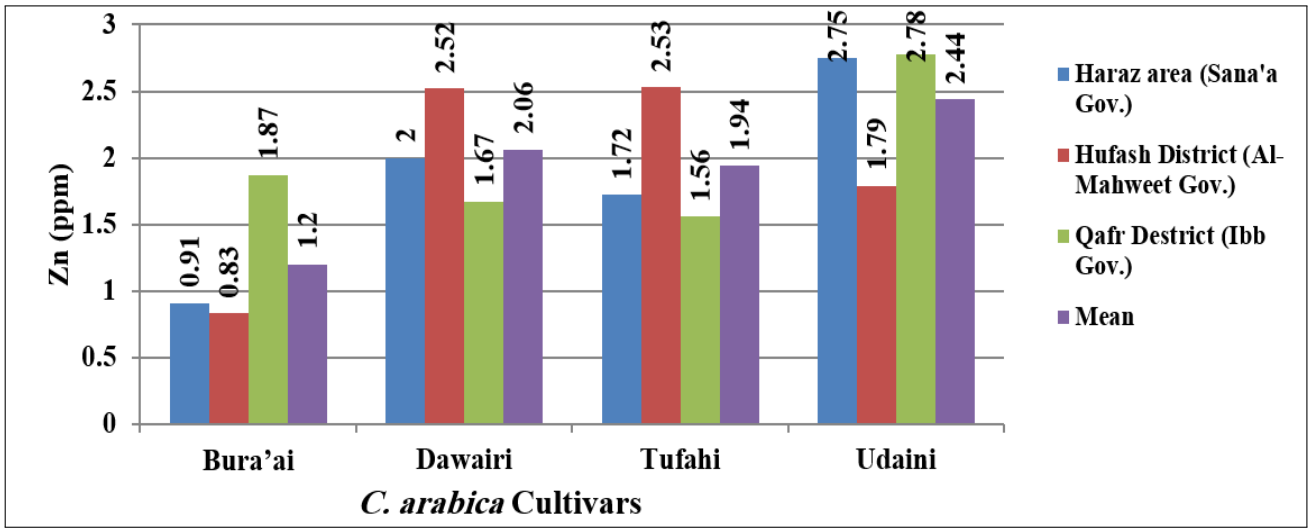

Figure 12. Amount of Zinc in the four *C. arabica* cultivars plantation soil.

tation soil. However, the Tufahi cultivar plantation soil (Table 3 and Figures 7 & 13) exhibited the highest mean Sodium amount (53.3 ppm), trailed by the plantation soil of the Udaini cultivar (40 ppm), Dawairi cultivar (33.3 ppm) and Bura'ai cultivar (20 ppm); while; the plantation soil of the Udaini cultivar (Table 3 and Figures 8 & 13) showed the highest mean of potassium amount (5.3 ppm) followed by Bura'ai and Tufahi cultivars plantation soil (5 ppm) while the plantation soil of the Dawairi cultivar exhibited the lowest mean of potassium amount (4.7 ppm). Furthermore, the Bura'ai cultivar plantation soil displayed the highest mean Phosphorus quantity (28 ppm) trailed by the plantation soil of the Udaini cultivar, Dawairi cultivar, and Tufahi cultivar, with a mean amount of 27.3, 25.8, and 21.9 ppm sequentially (Table 3 and Figures 9 & 13); whereas; the Udaini cultivar plantation soil exhibited the highest mean of Iron amount (14.6 ppm), followed by Tufahi cultivar (14.3ppm), Dawairi cultivar (13 ppm) and Bura'ai cultivar (12.7 ppm) plantation soils (Table 3 and Figures 10 & 13). In addition, the Tufahi cultivar plantation soil illustrates the highest mean of Manganite quantity (1.27 ppm) trailed by Dawairi cultivar, Bura'ai cultivar and Udaini cultivar plantation soils, with a mean of 1.2, 1.19, and 0.83 ppm accordingly (Table 3 and Figures 11 & 13) whilst; the plantation soil of Udaini cultivar displayed the highest amount of Zinc when compared with the soil of Dawairi (2.06 ppm), Tufahi (1.94 ppm) and Bura'ai cultivars (1.2 ppm) (Table 3 and Figures 12 & 13). Based on Table 3 and Figure 4, the soil pH of the four *C. arabica* cultivars, which were collected from different locations ranging from 7.08 - 8.28, indicates that the soil is alkaline. This result agrees with Al-Najjar *et al.* [5] where reported that Yemeni soil has a high pH. Moreover, the Nitrogen percentage of the four *C. arabica* cultivars plantation soil ranging from 3.2 to 4.9 % (Table 3 and Figure 5), which is close to the findings of Martunis *et al.* [12], where they reported that *C. arabica* could grow in soil with a Nitrogen content ranging from 1.99 to 4.32%.

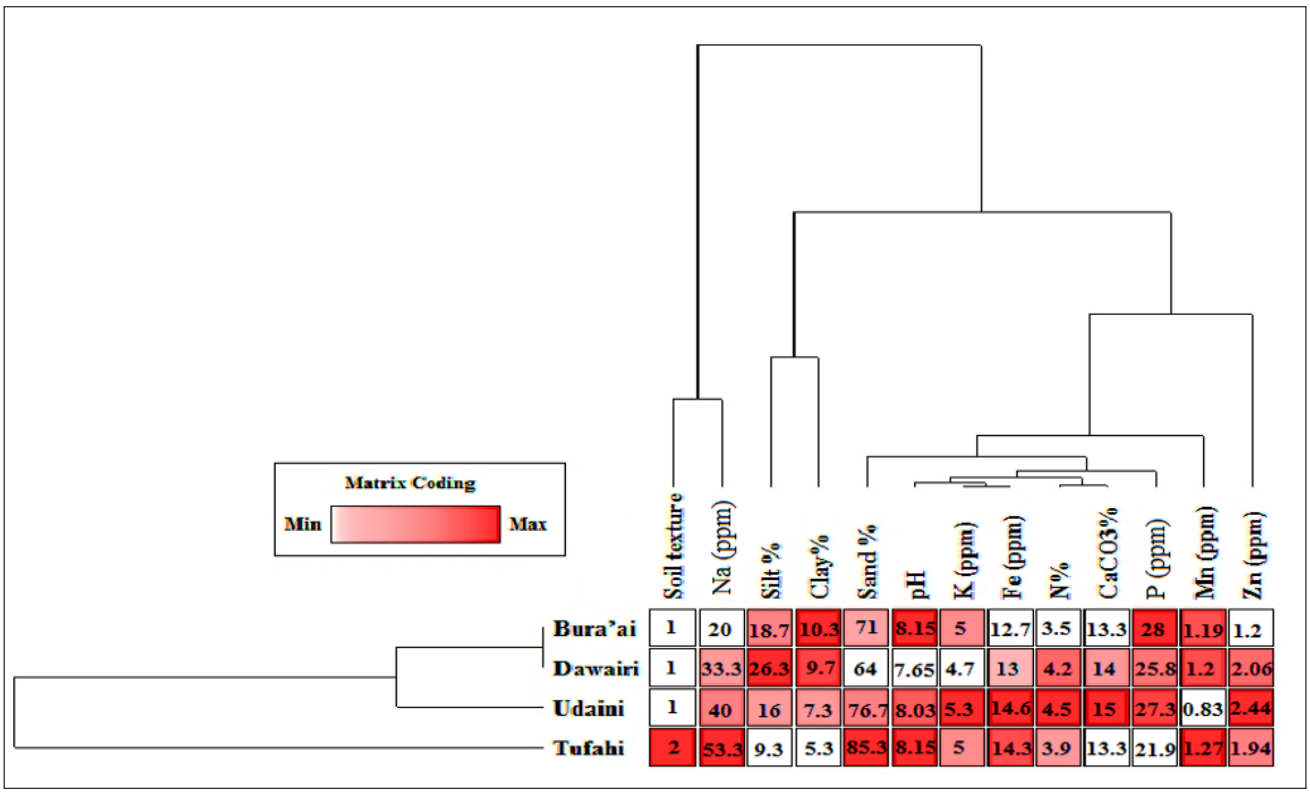

Figure 13. Cluster analysis illustrates the relationship among the four *C. arabica* L. cultivars based on 13 plantation soil characters (4 Physical and 11 chemical characters) by using the Two-Way Cluster Analysis (TWCA) - Group average linkage method.

In addition, the amount of Calcium Carbonate in the four *C. arabica* cultivars plantation soil (Table 3 and Figure 6) varying between 10 to 16% this outcome is in line with the finding of Almosawa & Almaghrebi [33] where they reported that the Calcium Carbonate amount reaches 16% in the soil of Yemeni High mountain. Furthermore, the Sodium and Potassium amounts in the plantation soil of the four *C. arabica* cultivars varying from 10 to 80 ppm and 4 to 6 ppm, respectively (Table 3 and Figures 7 & 8) those outcomes are in line with the findings of Assa *et al.* [21] where they mentioned that *C. arabica* tree can grow in soil containing 48.94-101.11 ppm of Sodium and 3.11-11.28 ppm of Potassium. Additionally, based on (Table 3 and Figures 9, 10 & 11) the Phosphorous, Iron, and Manganite quantities in the plantation soil of the four *C. arabica* cultivars ranging from; 21.3 to 33 ppm, 10.4 to 19.2ppm and 0.64 to 1.93ppm correspondingly are in approximately with Núñez *et al.* [13] findings where they reported that *C. arabica* in Barahona area in Dominican at Central America grows in soil that contains phosphorus, iron, and manganite with quantities ranging from 4.5 – 40.31ppm; 7.42-768 ppm and 1,20-9.36 ppm sequentially. However; (Table 3 and Figure 12), exhibit that the plantation soil of the four *C. arabica* cultivars contains Zinc with an amount ranging from 0.83 to 2.78 ppm, and this agrees with Melke & Ittana [34] where they made a review study on the soil's nutritional requirement for coffee trees in Ethiopia and they illustrated that *C. arabica* can grow in soil that contains 0.34- 5.5 ppm of Zinc. Relatively, based on the Two-way cluster analysis (TWCA) in Figure 13, the four coffee cultivars (Bura'ai, Dawairi, Tufahi, and Udaini) were divided into two main groups (I & II) at a distance level of 92.84 based on 13 plantation soil characters (4 Physical and 9 Chemical characters). Group I includes the Tufahi cultivar, while Group II comprises the other three remaining *C. arabica* cultivars (Bura'ai, Dawairi, and Udaini); this indicates that there is a link between the Bura'ai, Dawairi, and Udaini cultivars. These results are in close agreement with the Dendrogram produced by Hussein *et al.* [35], which exhibited the genetic relationship between the Bura'ai cultivar and five genotypes of the Udaini cultivar from one side, and between the Dawairi cultivar and one genotype of the Udaini cultivar from the other side.

4. CONCLUSION

According to the previous results, the soil texture of the four *C. arabica* cultivars plantations ranged from sandy loam to loamy sand. On the other hand, the former results revealed that the soil pH of the four *C. arabica* cultivars ranged from 7.08- 8.28, while the Nitrogen percentage in plantation soil of the four *C. arabica* cultivars varied from 3.2 to 4.9 %, whereas the Sodium and Potassium quantity in the plantation soil of the four *C. arabica* cultivars varied from 10 to 80 ppm and 4 to 6 ppm consecutively; whilst the Phosphorous; Iron and Manganite amounts in the plantation soil of the four *C. arabica* cul-

tivars plantation ranged from; 21.3 to 33 ppm; 10.4 to 19.2ppm and 0.64 to 1.93ppm accordingly. Finally, the preceding results exhibited that the plantation soil of the four *C. arabica* cultivars contains Zinc with an amount ranging from 0.83 to 2.78 ppm, while the amount of Calcium Carbonate in the four *C. arabica* cultivars plantation soil varied between 10 to 16 percent. Moreover, based on the soil characteristics (Physical and chemical properties), the four main coffee cultivars in Yemen were divided into two categories: the first category included Tufahi cultivar while the second category included the three remaining cultivars (Bura'ai, Dawairi, and Udaini), this can guide farmers when cultivating new coffee crops.

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