Sand minerals, amorphous aluminosilicates, free iron oxides and nutrient status in Wadi Bishah Basin soils

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Abstract: Wadi Bishah basin is one of the important drainage systems in the southwestern region of Saudi Arabia. Characteristics of different soil units were quite variable as a result of the source of parent materials and other factors. This research was carried out to understand the relationship between sand mineralogy, amorphous materials and some plant nutrients in wadi Bishah basin soils. Results indicated that content of free Fe_2O_3, MnO_2 and total amorphous aluminosilicates were higher in residuum soils followed by flood plain and wadi bottom soils. The contents were relatively higher in flood plain soils of the southern parts compared with the northern parts of the wadi. Light minerals constitute between 85.4 – 96.9 % of sand fraction, while heavy minerals constituted from 3.1–14.6 %. Quartz was the dominant mineral > 90 % in light mineral fraction followed by feldspars 1.1– 4.3 % and mica less than 7.7 %. Opaque and non-opaque minerals were higher in residuum soils and flood plain soils in southern part of the wadi. The dominant minerals are amphiboles, pyroxenes and non-opaque minerals. Results indicated also that available Fe, Mn and Cu in flood plain soils range from low in subsurface layers to high or medium in surface layer while available Zn and P were relatively low. Residuum soils have relatively low extractable micronutrient levels compared with flood plain or wadi bottom soils. Correlation coefficients data indicated that free Fe & Mn oxides and amorphous Si & Al components have little or no effects on the availability of nutrients. While mica, pyroxene and amphibole in the sand fraction have positive correlation with the available nutrients with no correlation with available Zn.

Key wards: *Free oxides, sand mineralogy, amorphous materials, nutrients.*

Introduction: Wadi Bishah is one of the main drainage systems in the southwestern region in Saudi Arabia. It starts from the high elevation mountainous areas situated between Sarat Ibeda 2380 m above sea level (asl), Abha 2360 m (asl) and Khamiss Mushait 2112 m (asl). The main attributers of wadi Bishah in the south are Wadi Itwid coming from El-Sahn mountain passing through Khamiss Mushait city, wadi Abha coming from Abha area toward north-east (to the east of 42o 30- Latitude east). Wadi Bishah connected also with other principle branches such as wadi Herjab, wadi Targ and wadi Tabalah and others that come mainly from very large areas in the east and west of wadi Bishah. Geologically, the basin is entirely within the southern Arabian Shield and is underlain by Precambrian crystalline rocks. Igneous and metamorphic rocks are the dominant rocks in mountainous area and consisted mainly from granite, basalt, diorite, gabro, mica-schist and others (Al-Sayari and Zotl, 1978). The main parent materials type in the study area are alluvium mainly in flood plains, terraces and wadi bottoms; residuum in the soils formed the in-situ from the source rock particularly at mountains, and colluvium particularly in slops (Al-Barrak, 1985). Weathering products of basaltic parent material, including saprolite, and transported materials affect greatly both physical and chemical soil properties as well as management practices and land use decisions as reported by (Isotok, 1981). According to Wada and Harward, (1974) amorphous materials in soils are often described as “active” because of their large specific surface area and high chemical reactivity, ability to retain large amounts of organic matter and pH dependent cation and anion exchange capacity. Al-Barrak (1985) found that free iron oxides (Fe_2O_3 %) range from 0.61 – 13.44 % in four soils profiles developed in residuum, alluvium and/or colluvium parent materials in Al-Sawdah, southwestern Saudi Arabia. He refered the high contents of free iron oxides in residuum parent material to the intensive weathering which might take place during the Eocene time. Beside this study there was very limited data available on contents and characteristics of amorphous aluminosilicates and free iron and manganese oxides in wadi soils of southwestern region in Saudi Arabia. Therefore this research was undertaken to study the interrelationships between mineralogical composition of wadi Bishah basin soils and nutrient status in order to understand the effect of these components on some available nutrients in wadi soils.

Materials & Methods

Nine soil profiles representing the dominant geomorphologic units along wadi Bishah basin were selected and morphologically described according to Soil Survey Manual (1993), then soil profiles were classified according to Soil Survey Staff (1994). The selected units are flood plain, present wadi channel (wadi bottom) and the high elevation mountainous areas. Thirty-six (36) soil samples representing the subsequent profile layers were collected, then prepared for analysis. Representative sub-samples were extracted by DTPA (Di Tetra Penta Amine Acetic Acid) according to Lindsay & Norvell (1978) for available micronutrient determinations. Extractable Fe, Mn, Zn and Cu were measured using atomic absorption spectrometry (AAS) according to Barker & Suthr (1982). Available phosphorus was detemined by the modified $NaHCO_3$ method using ascorbic acid as a reducing agent, (Olsen and Sommers, 1982). Sub-samples were subjected to amorphous Si and Al determinations using the selective dissolution method, (Jackson et.al, 1986). Briefly, soil sample was boiled for 2.5 minutes in 0.5 N NaOH to dissolve the amorphous aluminosilicates, and then dissolved Si and Al were measured immediately in the extracts using AAS according to (Barker & Suthr, 1982). Free iron and manganese oxides were extracted from representative sub-samples using sodium bicarbonate-citrate-dithionite mixture (Na-CBD) according to (Mehra & Jackson, 1960), then Fe and Mn were measured in the extract using AAS. Separation of sand fraction for sand mineralogical analysis was conducted after the appropriate pretreatment on selected samples as outlined by (Jackson, 1979). Soil samples were treated with 1N sodium acetate buffered at pH 5 for carbonate removal, 30 % H_2O_2 for organic matter removal and sodium bicarbonate-citrate-dithionite mixture (Na-CBD) for free iron oxides removal followed by several washings by distilled water for the removal of dissolved salts. The sand fraction 0.063-0.125 mm was separated by sieves after the decantation of silt and clay, then washed by distilled water and dried. Separation of heavy and light minerals was carried following the procedure outlined by (Brewer, 1976), where the separatory funnel containing bromoform (sp.gr. 2.85) as a heavy liquid was adopted. After separation, heavy (sp.gr. > 2.85) and light (sp.gr. < 2.85) mineral samples were washed with alcohol, dried, weighed and reported as percentage of the total. Representative samples were mounted on glass slides using canada balsam (R.I. 1.538). Slides were examined for light and heavy mineral identifications using polarizing microscope according to (Brewer, 1976 & Cady et. al. 1986).

Results & Discussions

Some morphological, chemical and physical properties of the studied soils are presented in (Table 1). In brief, flood plain soils; represented by profile (1- 6), shows almost flat surface with no diagnostic surface or subsurface horizons. There are differences in morphological features of soil profiles representing southern part (profile 5 and 6) and northern part (profile 1,2,3 and 4) of the wadi. Soil profiles in southern parts are relatively dark, relatively high in organic matter and have thick surface layer compared with soil profiles in northern parts. Present wadi channel soil unit (profile 7) was characterized by recent coarse sandy to gravelly or bouldary surface where it was dry most of the year and dominated by natural vegetation (Citrullus Coloynthins). Profile 7 show variations in texture, structure and layer thickness reflecting the depositional pattern from which it was formed. Residuum soils at mountainous areas were formed in-situ under the prevailed semiarid conditions where the dominant rocks are igneous such as basalt as in profile (9) and metamorphic such as chlorite-schist as in profile (8).

Data of amorphous and poorly crystalline Si and Al (Table 2) are relatively higher in residuum soil profiles (8 and 9) compared with flood plain (profiles 1-6) or wadi bottom (profile 7). Amorphous Si was generally higher than Al in the studied soils, while Fe dissolved by boiled NaOH was very low compared with either Si or Al. Amorphous Si and Al was higher in flood plain soil profiles in southern part (5 and 6) of the wadi compared with northern part (profile 1-4). The obtained variations could be attributed to sedimentation pattern of alluvium materials as well as to the intensity of chemical weathering of parent rock from which these materials were formed. The southern part of wadi Bishah is located within Al-Sarrawat high elevation mountains as reported by (Al-Sayari and Zotl, 1978). Under these conditions intensity of chemical weathering on the dominant igneous and metamorphic rocks was relatively high leading to the formation of weathering products rich in amorphous and or poorly crystalline Si and Al materials particularly in the residuum soil profiles. In that respect, Boettinger and Southard, (1995) studied the distribution of minerals and amorphous materials in soils formed from weathered granitic rocks. They reported that excess silica in weathering environment may react as binding materials for soil particles or it may precipitate as amorphous silica compounds in the soil. On the other hand, the northern part of wadi Bishah receive sediments from many attributers and principle branches such as wadi Targ and wadi Tabalah that have quite different weathering conditions and rock structure. These conditions lead to the formation of quite different weathering products and hence different composition and amorphous Si and Al in the parent material and consequently in the formed soils. Also, data of the contents and distributions of free iron & manganese oxides (Table 2) indicated that residuum soils have the highest free iron & manganese oxides content as in profile 8 and 9, while wadi bottom soils (profile 7) have the lowest. Flood plain soils contain relatively high contents of free iron oxides particularly in the soils of southern part of the wadi (profile 6). The distribution of these conistituents indicated that free Fe oxides increased dramatically in the Bt horizon of residuum soils (profile 8 and 9) while other profiles showed no clear distribution trend with depth. The amounts and distributions of free Fe & Mn oxides in residuum soils are true reflection of both parent material type and intensity of soil forming processes encountered during soil formation. For example, profile 8 was formed under weathered different chlorite schist, diorite and other rocks under semi arid climatic conditions. The relatively high content of free Fe oxides in Bt horizon may result from accumulation of Fe oxides as in-situ weathering products or it may be translocated with other soil materials such as clays and organic matter during soil formation. Similar finding was reported by Al-Barrak (1985) in Al-Sawdah area. He indicated that the presence of high quantities of free Fe oxides in residuum soils was related mainly to high intensive weathering, typical of the warm humid tropics which presumably dominated in the past. He also found geothite mineral in some Bt horizons in the area. On the other hand, profile 9 formed under weathered basaltic rock under active weathering conditions that lead to the release and oxidation of Fe and Mn forming relatively high quantities particularly in the Bt horizon. Data of Al oxides released by the CBD method show generally high contents particularly in residuum and flood plain soil profiles in southern part of the wadi. This may be due to presence of some Al incorporated in the structure of free iron oxides including crystalline and poorly crystalline Fe oxides. The finding of Blume & Schwertmann, (1969) and Tokashiki & Wada, (1972) supported this conclusion; they reported partial substitution of Al in hematite and geothite minerals. Data also indicated high content of Al in the Bt horizon of profile 9, low content in the Bt horizon of profile 8 and no depth-wise distributions in other profiles, that could be related to the type of parent materials.

Data of mineralogical analysis of sand fraction (Table 3) indicated that sand fraction was dominated mainly by light minerals (85.4 – 96.9 %) in comparison with heavy minerals which constituted only from (3.1 – 14.6 %). Index figure data was relatively higher in residuum soils (profile 9) and flood plain soils (profile 6) in southern part. While it was relatively low in flood plain soils of northern part (profile 1 & 3). Such finding clearly reflects the existing variations in mineralogical composition of the alluvium parent material of flood plain soils in northern and southern parts of wadi Bishah. Quartz was the dominant mineral in light mineral fraction (> 90 %) whereas other light minerals such as feldspar and mica were quite low. In wadi bottom soils there was drastically decrease in the percentage of light minerals percentage in the deep layer (profile 7). Data also indicated that heavy minerals fraction was relatively higher in residuum soils when compared with those in flood plain soils of northern and southern wadi parts (low to high respectively). The wadi bottom soil has relatively higher percentage of heavy minerals in the deep layer compared with the upper layers. Such distribution reflects the presence of discontinuity in the composition of the parent material from which the profile was formed. Amphiboles and pyroxenes dominated the heavy minerals while opaque minerals were intermediate between amphiboles and pyroxenes. Presence of sensitive weathering minerals, such as amphiboles and pyroxenes, in the profile layers prove that the soils are quite recent and geogenic processes dominated over pedogenic processes in the development of soil profiles.

Nutrient levels: Amounts of available P extracted by $NaHCO_3$ (Table 4) varied from 0.30 – 32.0 mg kg-1 in the studied soil units. The highest amount was in the surface layer of the flood plain soil (profile 6) located in the southern part of wadi Bishah. All other soil profiles have low to very low available P with no specific distribution trend with depth. It appears that cultivated soils have relatively high available P in the surface layer while the subsequent layers have low values. Bowman et. al., (1978) reported that 12 mg P kg^{-1} soil to be as a critical level for available P in soils. Similar data was reported by Al-Mustafa et al., (1995) in the soils of Saudi Arabia. Therefore, it appears that most of the studied soils are quite low in available P particularly the residuum soils at mountains while floodplain soils have relatively higher amounts particularly at surface layers of some soil profiles which was affected mostly by agricultural practices. These finding are explained by the dominance of igneous and metamorphic rocks from which parent materials of residuum, flood plain or wadi bottom soils have been formed. Also, anthropogenic effects including addition of manure, farm residue and fertilizers seems to have the major impact on increasing available P in surface layers of the cultivated soils. DTPA extractable Fe was low to very high (Herrera, 2000) in flood plain soils (2.2 to 56.0 mg Fe kg-1). Wadi bottom soils show relatively high extractable Fe (6.3 to 10 mg Fe kg-1 soil), whereas residuum soils indicate low to high values (1.4 – 14 mg Fe kg-1 soil). Extractable Mn and Cu were quite high in all the studied soil units and range from medium to high as reported by Herrera, (2000). On the other hand, extractable Zn was low in most of the studied profiles except few surface layers that have moderate to high extractable Zn. In general, it appears that residuum soils have relatively low extractable micronutrient levels compared with flood plain or wadi bottom soils. Such finding may reflect the importance of processes involved in transporting weathering products and the subsequent management practices in increasing available micronutrients of the cultivated soils. Correlation coefficient was carried out between soil properties, sand mineralogy and nutrient levels to shed more light on the properties affecting available nutrients. Data in table (5) indicated that no significant positive correlation was obtained between P level and contents of amorphous Si&Al, free Fe&Mn oxides and amphibole or pyroxene minerals. Available Fe showed significant positive correlation (at 5%) with mica minerals and negative correlation with quartz and feldspar minerals. No significant correlation was obtained between available Fe and contents of amorphous Si & Al and or other soil constituents. Available Mn levels indicated significant correlation with amphibole content while other properties and mineral contents were not significant. No significant correlation coefficients were obtained between Zn contents and either amorphous Si&Al , free Fe&Mn oxides or mineral contents in sand fraction. Therefore, it seems that free Fe & Mn oxides and amorphous Si & Al components have little or no effects on the availability of the studied nutrients under the prevailing wadi soils conditions. While mica, pyroxene and amphibole minerals in the sand fraction have significant role in the availability of

P, Fe, Mn and Cu. The studied soil constituents and mineralogy of sand fraction have no effect on the availability of Zn under the studied wadi soil conditions.

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معادن الرمل , سيليكات الألومنيوم غير المتبلورة , أكاسيد الحديد الحرة ومستوى المغذيات فى ترب حوض وادى بيشة

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الملخص العربي: يعتبر حوض وادي بيشة من أهم نظم الصرف في المنطقة الجنوبية الغربية بالمملكة العربيـــة السعودية وتختلف فيه خواص ترب الوحدات الأرضية كنتيجة لتنوع مصادر مادة الأصل وعوامل أخرى . هذا ويهدف البحث إلى فهم العلاقة بين التركيب المعدني لمكون الرمل في ترب الوادي ومحتواها من المـــواد غـــير المتبلورة وأكاسيد الحديد والمنجنيز الحرة والصورة الميسرة لبعض العناصر الغذائية في التربة . أوضحت النتائج أن الترب المحلية لحوض وادي بيشة تكون مرتفعة فى محتواها من أكاسيد الحديد والمنجنيز الحرة والمواد الغـــير متبلورة يليها ترب السهول الفيضية وترب مجرى الوادى. يكون المحتوى مرتفعآ في ترب الأجزاء الجنوبية من الوادي بالمقارنة بترب الأجزاء الشمالية منه. نسبة المعادن الخفيفة والمعادن الثقيلة لمكون الرمل تراوحت بـــين **85.4 – 96.9**% و **3.1 – 14.6**% على التوالي . معدن الكوارتز هو السائد في المعادن الخفيفة (أكثر من **90**%) يليه معادن الفلسبارات (**1,1 – 4.3**%) والميكا (أقل من **7,7**%) . المعادن المعتمة والغير معتمـــة كانت مرتفعة نسبيا في التربة المحلية بالمرتفعات وفي ترب السهول الفيضية بالجزء الجنوبي من الوادي مع سيادة معادن الأمفيبول والبيروكسين والمعادن الغير معتمة . أوضحت النتائج أيضا أن مستوى **Fe ,Mn** والـــ **Cu** الميسر يتراوح بين متوسط إلى مرتفع في ترب السهول الفيضية خاصة الطبقة السطحية بينما الزنك والفوسفور الميسر منخفض نسبيا . الترب المحلية تحتوى على مستويات قليلة نسبيا من هذه العناصر الغذائية مقارنة بترب السهول الفيضية أو ترب مجرى الوادي . بيانات معاملات الارتباط تدل على أن أكاسيد الحديد والمنجنيـــز الحرة والمواد الغير متبلورة لا ترتبط بشكل عام مع الصورة الميسرة من العناصر الغذائيـــة . معـــادن الميكـــا والبيروكسين والأمفيبول في جزء الرمل له علاقة موجبة مع جميع العناصر المدروسة ما عدا الزنك وكانت هذه العلاقة معنوية بين كلاً من الميكا والحديد والأمفيبول والمنجنيز .

Table 1. Field description of the studied soil profiles.

Classification	Profile No.	Horizon	Depth cm	Colour Moist	Texture	Structure[a]	Condistence[b] Dry	Wet St.	Wet Pt.	Boundary[c]	Landform/ Parent materials	Location
Typic Torrifluvents	1	Ap_1	0-35	2.5Y4/2	SL	w.f.sb.b.	sh	s.st	s.pl	a.sm	Flood plain	19° 56' N,
		Ap_2	35-70	10YR4/2	LS	w.f.sb.b.	sh	s.st	n.pl	c.sm	Alluvium	42° 32' 49" E
		C_1	70-100	2.5Y4/2	SL	w.f.sb.b.	sh	s.st	s.pl	d.sm		
		C_2	100-150	2.5Y4/2	SL	w.f.sb.b.	h	s.st	s.pl	-		
Typic Torriorthents	2	A	0-8	2.5Y4/4	CL	w.f.sb.b.	so	v.st	v.pl	c.sm	Flood plain	20° 4' 59" N,
		C_1	8-45	2.5Y4/4	SL	w.f.sb.b.	h	s.st	s.pl	a.sm	Alluvium	42° 36' 31" E
		$2C_2$	45-85	2.5Y5/2	S	s.g	l	n.st	n.pl	c.sm		
		$2C_3$	85-140	10YR3/3	S	s.g	l	n.st	n.pl	-		
Typic Torrifluvents	3	Ap_z	0-3	10YR4/6	LS	ma	so	s.st	n.pl	c.sm	Flood plain	20° 19' 30" N,
		Ap	3-40	10YR4/6	LS	w.f.sb.b.	sh	s.st	n.pl	c.sm	Alluvium	42° 49' 49" E
		C_1	40-60	2.2Y5/4	SL	w.f.sb.b.	sh	s.st	s.pl	c.sm		
		C_2	60-85	10YR4/4	SCL	w.f.sb.b.	h	st	pl	c.sm		
		C_3	85-110	10YR4/4	SCL	w.f.sb.b.	h	st	pl	-		
Typic Torriorthents	4	Ap	0-35	10YR5/3	LS	w.f.sb.b.	so	s.st	n.pl	a.sm	Flood plain	20° 10' 3" N,
		C_1	35-80	5Y5/3	CL	w.f.sb.b.	sh	st	pl	c.sm	Alluvium	42° 39' 38" E
		C_2	80-150	2.5Y5/4	CL	w.f.sb.b.	vh	st	pl	-		

Table 1. cont.

Classification	Profile No.	Horizon	Depth cm	Colour Moist	Texture	Structure[a]	Condistence[b] Dry	Wet St.	Wet Pt.	Boundary[c]	Landform/ Parent materials	Location
Typic Torriorthents	5	Ap_1	0-20	10YR3/3	SL	w.f.sb.b.	sh	s.st	s.pl	c.wa	Flood plain Alluvium	18° 46' 57" N, 42° 52' 30" E
		Ap_2	20-35	10YR3/2	SL	w.f.sb.b.	sh	s.st	s.pl	c.sm		
		C_1	35-70	10YR2/2	LS	ma	h	s.st	n.pl	c.sm		
		C_2	70-110	10YR3/2	LS	ma	h	s.st	n.pl	-		
Mollic Ustifluvents	6	Ap_1	0-8	10YR3/2	SCL	w.f.a.sb.b	so	st	pl	c.sm	Flood plain Alluvium	18° 17' 3" N, 42° 44' 25" E
		Ap_2	8-45	10YR3/2	CL	m.m.a,sb.b	sh	st	pl	c.sm		
		C_1	45-75	10YR3/2	CL	m.m.a,sb.b	vh	v.st	v.pl	a.sm		
		$2C_2$	75-110	10YR3/2	SL	w.f.a.sb.b	vh	s.st	s.pl	c.sm		
		$2C_3$	110-140	10YR3/2	SL	w.f.a.sb.b	vh	s.st	s.pl	-		
Typic Torriorthents	7	C_1	0-20	2.5Y4/2	LS	s.g	l	st	n.pl	c.sm	Present channel Alluvium	19° 56' 10" N, 42° 33' 13" E
		C_2	20-30	2.5Y4/2	SCL	w.f.sb.b.	sh	st	pl	a.sm		
		$2C_3$	30-85	2.5Y4/2	S	s.g	l	n.st	n.pl	d.sm		
		$2C_4$	85-150	2.5Y5/2	S	s.g	l	n.st	n.pl	-		

Table 1. cont.

Classification	Profile No.	Horizon	Depth cm	Colour Moist	Texture	Structure[a]	Condistence[b] Dry	Wet St.	Wet Pt.	Boundary[c]	Landform/Parent materials	Location
Pachic Argiustolls	8	A	0-40	7.5YR3/2	CL	g	so	v.st	v.pl	c.sm	Mountain area	18° 16' N,
		Bt	40-90	2.5YR4/6	C	m.f.a,b	sh	v.st	v.pl	d.sm	Residuum	42° 20' E
		C	90-140	2.5YR4/6	CL	m.f.a,b	h	v.st	v.pl	-		
Typic Paleustolls	9	A	0-20	7.5YR3/4	CL	g	so	v.st	v.pl	c.wa	Mountain area	18° 3' N,
		B_t	20-45	5YR3/4	C	m.f.sb.b	sh	v.st	v.pl	c.wa	Residuum	43° 15' E
		B_{tk}	45-75	10YR3/1	C	m.f.sb.b	h	v.st	v.pl	a.sm		
		B_k	75-150	5Y5/1	CL	ma	vh	s.st	s.pl			

[a]ma: massive, s.g: single grain, w.f.sb.b.: weak fine subangular blocky, a.: angular, m.: moderately, m.m.: moderatly medium , g: granular

[b]l: loose, so: soft, h: hard, sh: slightly hard, vh: very hard, st: sticky, n.: non, s.: slightly, v.: very, pl: plastic

[c] a.: abrupt, sm.: smooth, c.: clear, wa: wavy, d.: diffuse

Table (4) Amounts of available P and micronutrients (Fe, Mn, Cu and Zn) in the studied soil profiles (mg Kg^{-1} soil).

Profile	Horizon	Depth/cm	P	Fe	Mn	Cu	Zn
1	Ap_1	0-35	2.1	6.9	6.1	1.3	0.3
	Ap_2	35-70	1.3	5.8	3.0	0.8	0.2
	C_1	70-100	0.8	4.7	4.2	1.1	0.2
	C_2	100-150	2.5	5.7	5.5	1.7	0.3
2	A	0-8	7.8	56	29	8.1	1.8
	C_1	8-45	0.8	4.3	3.5	1.7	0.24
	$2C_2$	45-85	0.6	9.5	2.2	0.8	0.28
	$2C_3$	85-140	0.5	9.0	2.3	0.6	0.2
3	Ap_z	0-3	2.2	3.2	5.5	1.7	0.5
	Ap	3-40	1.4	3.0	1.8	0.7	0.2
	C_1	40-60	3.4	2.2	2.2	1.2	0.4
	C_2	60-85	2.0	2.2	1.8	1.0	0.3
	C_3	85-110	0.3	2.5	1.1	1.5	0.3
4	Ap	0-35	0.3	7.5	1.7	1.2	0.2
	C_1	35-80	0.3	6.7	2.2	1.9	0.3
	C_2	80-150	2.1	12.0	3.3	1.7	0.3
5	Ap_1	0-20	32	3.4	7.7	4.5	1.7
	Ap_2	20-35	14	3.4	3.2	3.2	0.7
	C_1	35-70	6.4	2.8	1.4	2.3	0.3
	C_2	70-110	6.6	3.6	1.4	1.8	0.2

Table (4) cont.

Profile	Horizon	Depth/cm	P	Fe	Mn	Cu	Zn
6	Ap_1	0-8	11	9.0	5.6	3.8	0.8
	Ap_2	8-45	3.0	6.3	4.0	3.0	0.4
	C_1	45-75	2.0	10	3.4	4.3	0.3
	$2C_2$	75-110	2.0	7.4	26	2.8	0.2
	$2C_3$	110-140	6.0	6.7	3.4	2.7	0.2
7	C_1	0-20	1.4	11	4.0	1.3	0.21
	C_2	20-30	10.8	22	8.3	3.8	0.7
	$2C_3$	30-85	0.8	10	2.7	0.9	0.3
	$2C_4$	85-150	1.7	10	2.2	0.6	0.2
8	A	040	2.8	14	11	3.3	0.3
	Bt	40-90	1.0	3.7	13	0.8	0.2
	C	90-140	2.0	1.4	3.2	0.2	0.1
9	A	0-20	2.5	5.6	4.5	1.2	0.1
	B_t	20-45	1.9	6.0	2.5	1.6	0.4
	B_{tk}	45-75	1.0	10	1.6	1.5	0.3
	B_k	75-150	1.4	4.9	2.7	1.2	0.3

Table (5): Simple correlation coefficient between available nutrients and some soil constituents and sand mineralogy.

	P	*Fe*	*Mn*	*Cu*	*Zn*
MnO_2d	-0.077	-0.029	0.175	-0.085	-0.062
Al_2O_3d	-0.095	0.084	0.185	0.077	-0.050
Fe_2O_3d	-0.104	0.013	0.271	-0.009	-0.061
Fe_2O_3a	-0.188	-0.179	0.060	0.113	-0.265
Al_2O_3a	-0.128	-0.004	0.249	-0.040	-0.113
SiO_2a	-0.085	-0.036	0.246	-0.008	-0.084
$SiO_2+Al_2O_3$	-0.110	-0.023	0.244	-0.032	-0.103
Quartz	-0.425	-0.531*	-0.216	-0.279	-0.030
Feldspare	-0.042	-0.430	-0.287	-0.114	-0.431
Mica	0.422	0.644**	0.296	0.303	0.164
Pyroxene	0.192	0.337	0.392	0.324	0.007
Amphibole	0.384	0.312	0.587*	0.351	0.207

* Significant at 5%

** significant at 1%