MORPHOLOGICAL, PHYSICAL AND CHEMICAL CHARACTERIZATION OF SOME SOILS REPRESENTING THE NORTHERN STATES OF THE SUDAN

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ABSTRACT

Sixty six soil samples of soils from the Northern states of Sudan were selected from three different locations namely, Elkhalag, Ed Debba, and Merowe to represent the Abu Gidian, Wadi Sherife, Muckabra and El-Eammer soils. The objectives of this study were to characterize these soils' morphological, physical and chemical properties. Physical and chemical properties were analyzed according to standard procedures, used at the laboratory of Land and Water Research Centre, Agricultural Research Corporation Wad Medani, Sudan. Results showed that all the soils were characterized by a coarse texture (48% to 61%, sand fraction). Abu Gidian; Wadi Sheriff Soil occupies flat to nearly flat land (slope $\leq$ 1%) with sandy and gravelly material on the surface. They are deep and excessively drained having strong brown 7.5 YR5/6, to reddish color 7.5YR6/6 colour. Muckabrab soil occupies gently sloping to undulating ridges, covered with gravels, calcium carbonate concretion, and stone. Muckabrab soil is moderately deep to shallow and having yellowish colour 10YR5/6 to light yellowish brown color while El-Dammer soil occupies flat to nearly desert plains and has gravel surface. El-Dammer soil is deep and has dark yellowish brown 10YR4/4 to olive colour 2.5Y4/4. The soil is described as light and falls under sandy loam and sandy clay loam. The bulk density (1.3 to 1.5 $Mg{\cdot}m^{-3}$), low organic-C content (0.08% to 0.25%), Alkalinity soil reaction (varied from 7.7 to 8.8). The cation exchange capacity values ranged from 15 to 31 cmol kg^{-1}. The total nitrogen and available phosphorus are low ranged from 0.02 to 0.07% and 2.3 to 3.0 mg kg^{-1} soil respectively.

Keywords: Soil Morphological; Physico-chemical Properties; Soils; Northern states; Sudan.

1. INTRODUCTION

The Northern States of Sudan's main geological formation according to Whitman (1971) consists of basement complex and Nubain sandstone with the surface gently undulating and sloping toward the Nile. The main geomorphic features belong to the following units namely, Dissected ridges, hills, flat desert plains, undulating desert plains, broad flat valleys and in filled valleys. The land is generally bare except for sparse bushes on valley beds. According to Harrison, and Jackson (1958) the area lies within the desert zone of which the vegetation is characterized by *Acacia torilla*, *Maerus crassifolia*, *Acacia ehrenbergiana*, shrubs and desert grasses such as *Aristida* spp. The soils of the Northern Sudan vary depending on their location along the river Nile, as Nile alluvial levees, back swamps, high or low terraces or aeolian or colluvial and alluvial deposits. It is generally accepted that earth materials (fine earth) < 2mm effective diameter are known as soils. The sand fraction (2 - 0.02 mm) is usually composed of primary minerals; the silt fraction (0.02 to 0.002 mm) is mostly primary minerals whereas the clay fraction (<0.002 mm) is secondary minerals except for rare cases of weakly weathered soils (Bohn *et al.,* (1979). The knowledge of the soils in respect of its origin and formation, nature and properties and distribution becomes imperative in this connection. Such information is not only useful in agriculture but are equally important for foresters, geologists and engineers for land use planning and soil management. Knowledge of the kinds and properties of soils is critical for decision making with respect to crop production and other land use types. In order to evaluate the quality of our natural resources and their potential to produce food, fodder, fiber, and fuel for present and future generations, detailed information on soil properties is required. Soil characterization is required to classify soil and determine chemical and physical properties not visible in field examination (Blum *et al.,* 2003). The current study was therefore, initiated to characterize the soils of the Northern states of Sudan based on their Morphological, physical and chemical properties so as to provide the needed basic information of these soils.

2. MATERIALS AND METHODS

2.1. Location

The soils used in this study were collected from three locations in the Northern states of Sudan on the left bank of the River Nile. The area is T shaped and confined between Elkhalag, Ed Debba, and Merawe which lie approximately at Longitudes $31^{0\circ}$ 34‘E and 31^0 40‘E and latitudes 18^0 00‘ and $18^0$11‘ N. The soils were selected to represent the Abu Gidian, Wadi Sherife, Muckabra and El-Eammer soils.

2.2 Climate

The present study included soil samples from aridic moisture regimes. According to Kevie (1976) the area lies within desert zone. The annual mean temperature is 29^0C with a mean maximum of 37^0C and mean minimum of 21^0C. The long term, 30 years average, annual rainfall is 20.7 mm and annual potential evapotranspiration is 1855 mm, which generally decreases when rainfall increases. This results in an annual evapotranspiration of 86% and mean annual relative humidity of 23% with the lowest value in May, and highest in

December. The winds are moderate throughout the year with a monthly average value of 4.4 meter per second. The prevailing wind blows from the north direction in all seasons.

2.3 Field Methods

Soil samples site representative of the major soils of Northern state of Sudan was identified and described according to the FAO Guidelines for Soil Description, FAO, (1975). Soil samples were taken from two depths for physical and chemical analysis in the laboratory.

2.4 Soil Sampling

Soil samples were collected at two depths (0-30 and 30-60 cm). The soil samples collected were air-dried, ground using a wooden mortar and pestle and sieved to pass 2.0 mm sieve. The samples were then kept at room temperature for routine analyses. Physical and chemical properties were analyzed according to standard procedures, used at laboratory of Land and Water Research Centre, Agricultural Research Corporation Wad Medani, Sudan.

2.5 Physical and chemical analyses

The particle size distribution was determined following the pipette methods of Jackson (1958), and hydraulic conductivity of saturated soil sample was obtained as outlined by the US Salinity Laboratory Staff (1954); and, the soil moisture retained was determined by using the pressure membrane apparatus described by Klute (1986). Electrical conductivity was determined as outlined by US Salinity Laboratory Staff, (1954). Organic carbon was determined by Walkley - Black procedure Jackson (1958) and converted to organic matter (OM) by multiplying by a factor of 1.724. Soil pH was measured according to the methods of McLean, (1982) Total nitrogen was determined by micro - Kjeldahl procedure as indicated by Jackson (1958). Available phosphorus was extracted from soil sample by 0.5 N sodium bicarbonate solution at pH 8.5 (Olsen *et. al.*, 1954) Cation exchange capacity was determined by the sodium saturation method Chapman (1965). The extracted sodium was determined by the flame photometer (Richards, 1954). Exchangeable sodium (Na), and potassium (K) were extracted with IN ammonium acetate (pH=7.0) and determined by flame-photometer. Soluble cations and anions included were determined in the saturated extract of soil paste and expressed in mel-1. Soluble Na and K, were determined in the saturation extract by flame-photometer; Ca and Mg were determined by titration with ethylenediaminetetraaceticacid (EDTA). Calcium carbonate was determined by back titration with standard 1N NaOH and phenolphthalein indicator, after treating a known weight of soil with a known volume of standard HCl. Exchangeable Sodium Percentage (ESP) and Sodium Adsorption Ratio (SAR) was calculated using the following equation.

The ESP was calculated using the following equation**:**

$$ESP = \frac{\text{Exchangeable Na}}{\text{CEC}} \times 100$$

The SAR was calculated from the soluble cations by the following equation:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

All determinations were carried out at the laboratory of Land and Water Research Centre, (LWRC) Agricultural Research Corporation (ARC) Wad Medani, Sudan.

3. RESULTS AND DISCUSSION

3.1 Morphological characteristics

The parent materials are believed to be formed by natural processes of weathering of the basement complex, Nubian sandstone, rocks and sediments. The weatherable materials at different modes of formation consisted of variable materials of sandy aeolian deposits, alluvial and colluvial deposits as well as reddish gravelly materials. Abu Gidian Soil occupies flat to nearly flat land (slope $\leq$ 1%) with sandy and gravelly material on the surface. The soil is deep and excessively drained having strong brown 7.5 YR5/6, non calcareous, and mildly alkaline. Wadi Sherif soil occupies flat to nearly flat land (slope $\leq$ 1%) with sandy material on the surface, the soil is deep and having reddish colour 7.5YR6/6. Muckabrab soil occupies gently sloping to undulating ridges, covered with gravels, calcium carbonate concretion, and stone. The soil is moderately deep to shallow and having yellowish colour10YR5/6 to light yellowish brown. El-Dammer occupies flat to nearly desert plains and has gravel surface. The soil is deep and has dark yellowish brown10YR4/4 to olive colour 2.5Y4/4, non calcareous to slight calcareous to moderately alkaline pH 8.2

3.2 Physical characteristics

Table 1. Shows soil physical properties of Abu Gidian, Wadi Sherife, Muckabrab and El-Dammer soils. All soils were characterized by high total sand content ranging from 49 to 57 percent, which reflected in the relatively low saturation which range from 34 to 44%. The sand content in the 0-30cm depth of soils was comparatively more than in the 30-60cm depth in all soils. Silt content in the all soil ranged from 21 to 34 per cent in 0-30cm and 30-60cm depth of soils. There was no distinct difference among the soils depths in relation to their location position. The distribution pattern in general was uniform in the depths with an increase in the lower horizons. Clay content ranged from 15 – 30% in all soils. 21-22% in Abu Gidain soils 16- 17% in Wadi Sherife soils 15 in Muckabrab, and 28-30% in El-Dammer soils, respectively. An increasing trend of clay from 0-30cm to 30-60cm horizons was evident in Wadi Sherife and El-Dammer while decreasing in Abu Gidain and Muckabrab soils. (Table 1.). The soil texture was sandy clay loam in the upper and the lowest depth, with an

overall average texture of sandy clay loam (55% sand, 23.5% silt, 21.1% clay) in Abu Gidain soils. The soil texture was sandy

Table 1. Physical properties of studied soils

Soil	Depth (cm)	Sand	Silt	Clay	Textural class	Bulk Density Mg/m3	Porosity %	Moisture retention	
			(%)					1/3bar mm	15bar mm
Abu Gidain	0-30	55	23	22	Sandy clay loam	1.4	47	19.5	10.3
	30-60	55	24	21	Sandy clay loam	1.4	47	22.6	12.3
Wadi Sherife	0-30	57	27	16	Sandy loam	1.4	43	15.7	8.3
	30-60	49	34	17	Medium loam	1.4	43	16.2	8.4
Muckabrab	0-30	61	24	15	Sandy clay loam	1.5	43	17.1	9.6
	30-60	56	29	15	Sandy loam	1.5	43	19.9	10.7
El-Dammer	0-30	51	21	28	Sandy clay loam	1.3	51	21.7	11.45
	30-60	48	22	30	Sandy clay loam	1.48	44	22.9	11.71

Loam in the upper depth, and medium loam in the lowest depth, with an overall average texture of sandy loam (53% sand, 30.5% silt, 16.5% clay) in Wadi Sherife soils. The soil texture was sandy clay loam in the upper depth, and sandy loam in the lowest depth, with an overall average texture of sandy loam (58.5% sand, 26.5% silt, 15% clay) in Muckabrab. The soil texture was sandy clay loam in both depth, upper and lowest depth, with an overall average texture of sandy clay loam (49.5% sand, 21.5% silt, 29% clay) in El-Dammer soils. These coarse textures control the variability of nutrient storage capacity, limit the water holding capacity and roots may grow under sub-optimal soil water due to water deficits Gachene, (2003). Soil texture is the most stable physical characteristic of the soils which has influence on a number of other soil properties including structure, soil moisture availability, erodability, root penetration and soil fertility (Msanya, *et., al*. 2003; Landon, 1991). This is because texture is a composite of the coarse fraction (sand) and the finer fractions (silt and clay) and an increase or decrease in one component imparts the opposite effect on the other and hence affects physico-chemical properties of the soils. Results on bulk density and total porosity are presented in Table 1. Whereby, the mean bulk density ranged from 1.4 to 1.5 Mg/m3 in Abu Gidian, Wadi Sherife, El-Dammer soil and Muckabrab soil with an overall average of 1.42Mg/m3.

The bulk density was attributed to lower organic matter, compaction and less aggregation in soils of Entisols and Inceptisols whereas in these soils bulk density values could be due to their coarse texture and low organic matter content. According to Landon and Booker (1991) soil bulk density has a ultimately affects crop major impact on the dynamics of water and air in the soil and crop root development which growth and yield. Therefore, deep sub-soiling is required to improve the bulk density and thus soil water uptake (Landon and Booker, 1991;

Pikul *et al.*, 2003). The porosity was 47% in Abu Gigian, 43% in Wadi Sherife, and Muckabra soil in two depths while was 51% in upper depth and 44% lowest depth in El-Dammer soils, with an overall average of 45%, thus not liable to restrict crop growth. Since porosity is calculated from the relation between bulk density and particle density of soil, it is very much influenced by the soil bulk density as the particle density is not greatly altered by agricultural manipulations (Lai et al. 2004).

The data on moisture retention illustrated that the moisture retention at 1/3 and 15 bar consistently decreased in all the soils (Table 1). The moisture retention ranged from 15.7 to 22.9 and 8.3 to 12.3 per cent at 1/3 and 15 bar respectively in the soils. The difference in the moisture retention might be due to variation in clay and organic carbon content and heterogeneity of parent material

3.3 Physico-chemical and chemical characteristics

Soil pH is the most important chemical characteristic of the soil solution. The very strongly alkaline reaction values suggest possible low availability of both the macro and micro plant nutrients for uptake by crops. The overall pH values of the studied soils ranged from 7.7 to 8.8, indicating slightly alkaline to alkaline in reaction (Table 2). There is no specific trend in pH values of different soils where pH values were found to decrease with depth. The pH of of Abu Gidain, ranged from 7.9 to 8.0, Wadi Sherife, 8.5 in the two depths, Muckabrab 7.7 to 8.8 and El-Dammer soils ranged from8.1 to 8.2. This might be due to decrease in bases with depth. Electrical conductivity (EC) values of the all soils varied from 1.3 to 22.8 dSm−2. Electrical conductivity (Table. 2), values of the of Abu Gidain, ranged from 2.04 to 4.20 dSm−2, Wadi Sherife, 14.70 to 22.8 dSm−2, Muckabrab 4.00 to 18.7 dSm−2 and El-Dammer soils ranged from 1.30 to 7.00 dSm−2 and in accordance with the EC rating, the soils of Abu Gidain, Wadi Sherife, Muckabrab and El-Dammer soils were saline (ESP<15, SAR< 13); surface soil is saline

Table 2. Physico-chemical and chemical of studied soils

Soil	Depth (cm)	pH	EC dSm^{-1}	N	Base saturation %	O.C	CaCO	Exchangeable cations (cmol (+) kg^{-1})				CEC Cmol kg^{-1}	P mg kg^{-1} soil	SAR	ESP %
								Ca^{+2}	Mg^{+2}	K^{+}	Na^{+}				
A G	0-30	8.0	2.04	0.03	40	0.08	2.4	8.8	2.26	0.7	9.6	27	2.3	4	5
	30-60	7.9	4.20	0.02	44	0.12	3.2	5.4	2.3	0.8	20.3	22	3.0	6	8
W S	0-30	8.5	14.7	0.02	40	0.25	2.2	7.6	1.5	0.5	7.1	18	3.5	9	12
	30-60	8.5	22.8	0.07	43	0.20	2.5	28.1	6.3	0.6	36.5	20	2.8	22	25
Mu	0-30	8.8	4.00	0.03	39	0.09	3.0	10.4	2.6	0.4	21.4	15	2.6	10	14
	30-60	7.7	18.7	0.03	38	0.09	4.1	26.8	6.9	0.5	15.0	20	2.9	34	32
El-D	0-30	8.2	1.30	0.03	36	0.20	1.4	5.5	1.5	0.8	7.07	26	2.8	4	5
	30-60	8.1	7.00	0.02	49	0.20	1.3	26	6.3	0.6	36	31	2.6	10	11

* AG= Abu Gidain, WS=Wadi Sherife, Mu=Muckabra, El-D= El- Dammaer

While subsurface is sodic soil (ESP>15, SAR>13); sodic soil and saline soil (ESP >15, SAR>13) respectively. Similarly the calcium carbonate (CaCO3) content within the all soils varied from 1.3 to 4.1%. The increase of CaCO3 in the lower depth might be due to calcification and inheritance from parent material (Singh et al., 2007).

The data on organic carbon content (Table 2.) ranged from 0.14 to 0.96 %. All soils of the study area fall under low to medium content category of organic carbon except profiles of lowlands that fall under high content category. The OC content in all soils varied from 0.09 to 0.25 %. The highest OC content (0.0.25%) was observed in surface depth of Wadi Sherife soils and the lowest (0.08%) in surface depth of Abu Gidian soils. This shows that there is little or no translocation of organic carbon within the depths. The cation exchange capacity is a value given in soil analysis reports to indicate its capacity to hold cation nutrients. It is determined by amounts of clay and humus that are present in a soil. The overall cation exchange capacity (CEC) of the soils ranged between 15 and 30 cmol (+) /kg (Table 2), CEC content might be related to the soil texture, clay mineralogical composition, and accumulation of organic matter as indicated by Shoji et al. (1982) and degree of erosion. The CEC was low in the soils under study because the soils were sandy textured has little or no clay or humus content. It cannot hold much water or cation nutrients. The exchangeable calcium for the surface depths ranges from 5.5 to 10.4 cmol (+) /kg of soil, and from 5.4 to 28.1 cmol (+)/kg of soil in the subsurface depths in all soils. Magnesium contents vary from 1.5 to 2.6 cmol (+)/kg of soil for the surface depths and from 2.3 to 6.3 cmol (+)/kg of soil for the subsurface depths. The potassium values are higher in the subsurface depths than in the surface depths and are generally fairly adequate (0.6 to 0.8 cmol (+)/kg of soil) in the subsurface horizons except for El Dammaer soil where the surface soil depth in higher than subsurface depth (Table 2). Sodium values are high for these soils ranges from 7.07 to 36.5 cmol (+)/kg of soil, probably because the primary parent material that formed the deposited was initially high in sodium. The dominance of exchangeable bases on the exchange complex was in the order of $Na^+ > Ca^{2+} > Mg^{2+} > K^+$. In the exchangeable cations Ca, Mg and k increased with depth in all soil depths and K recorded a reverse trend in El Dammaer soils depths. Available phosphorus ranging from 2.3 to 3.5 mg P kg-1 soil in most of the soils depth horizons, Available phosphorus in Abu Gidain, and Muckabra increases in amount with depths while in Wadi Sherife, and El-Dammer soils decreases in amount with depth. Phosphorus (P) availability in the soil is one of the most limiting factors for plant growth and productivity in natural and agricultural ecosystems (Lynch and Deikman, 1998). Soil phosphorus is most available for plant use at pH values of 6 to 7. When pH is less than 6, plant available phosphorus becomes increasingly tied up in aluminium phosphates. As soils become more acidic (pH below 5), phosphorus is fixed in iron phosphates. When pH values exceed 7.3, phosphorus is increasingly made unavailable by fixation in calcium phosphates Phosphorus is an important plant nutrient necessary for root development, nodulation which is important for nitrogen fixation process, pod formation and filling in legumes. All the studied soils indicate that the available phosphorus is low ranged from 2.3 to 3.0 mg kg^{-1} soil. Low available phosphorus in the soils layers of the studies soils may also be attributed to high soil pH (>7.7) observed and could react with calcium (Ca) and magnesium (Mg) to produce phosphates that are not readily available for plant uptake (Table 2). All the studied soils are low in nitrogen content ranging from 0.02 to 0.07 %. This could be attributed to the prevailing dry condition where the biomass production is low and mineralization rate is high.

4. CONCLUSION

The present study showed that soils in the Northern states of Sudan are characterized by:-

- Low clay contents and very low organic carbon levels.
- Sand fraction has the highest and clay the lowest percentages in Abu Gidain, Wadi Sherife, and Muckabra,
- Clay has highest percentage in El- Dammar than silt.
- The overall pH values of the studied soils ranged from 7.7 to 8.8, indicating slightly alkaline to alkaline in reaction.
- In all the studied soils nitrogen content was low and ranged from 0.02 to 0.07 %. This could be attributed to the prevailing dry condition where the biomass production is low and mineralization rate is high.
- Low availability of phosphorus in these soil layers may also be attributed to high soil pH (>7.7) which could react with calcium (Ca) and magnesium (Mg) to produce phosphates that are not readily available for plant uptake.
- The overall cation exchange capacity (CEC) of the soils ranged between 15 and 30 cmol (+) /kg cation exchange capacity which might be related to the soil texture, with an overall average texture of sandy clay loam (55% sand, 23.5% silt, 21.1% clay).

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