Journal of Agriculture and Rural Development in the Tropics and Subtropics
Volume 108, No. 2, 2007, pages 113–121

Properties of New Reclaimed Soils in the Merowi Irrigation Project of North Sudan

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Abstract

This study is a correlation analysis between main productivity limiting soil parameters of desert soils of North Sudan. The indications are based on data of 52 soil profiles representing the desert plain as the main land form of the region. The results show a high significant correlation of cation exchange capacity with both clay and silt in two soil depths. This positive correlation is a new guide for better understanding of the colloidal behaviour of desert soils. The salinity and sodicity interactions of the studied soils were tested via correlation analyses of EC_e, ESP and SAR for salinity and sodicity, respectively. The high positive correlation between EC_e and ESP indicates a strong association of saline and sodic soils in the desert plain of Northern Sudan. The high positive correlation of ESP and SAR enables a formula to estimate ESP by using the SAR data.

Keywords: Colloidal activity, desert soils, salinity, sodicity, Sudanese soils

1 Introduction

In recent soil survey studies that cover about 390,857 ha in North Sudan, located between longitudes 30° 20' and 31° 50' and latitudes 17° 45' and 19° 45', about 30% of the total area were identified as Desert Plain Soils (Lahmeyer International, 2005). The same soil survey findings revealed high soil variability within the plain, mainly in $CaCO_3$ content, soil depth, dominant textural class and salt accumulation. The high variability of soils of the desert plain in North Sudan is a consequence of variability in intensity and prevalence of effects of different soil factors on soil processes and formations.

The soils that were selected for this study originate from alluvial and colluvial deposits of undifferentiated fine to coarse textured superficial deposits (Lahmeyer International, 2004). This may contribute to another source of high variability within these

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soils. The hyper aridity of the plain associated with the presence of geomorphologic inclusions is resulting in localized salty depressions (Bonifica-Geoexperts, 1986).

The variation in soil textural classes, ranging from gravelly to clay loam, formed on lithic contact of Nubian Sandstone Formation, may explain why these soils are mostly of shallow depths. Likewise, the soils of the desert plain are affected with adjacent sand plains that appear in many places as infillings of old wadies interrupted in the area.

With consideration of the above mentioned variability of soils of the plain and revised sources of variability, this study is objected towards deeper understanding of main properties of the plain soils through studying the multiple and pairwise correlations between different properties of the desert soils and how their characteristics are related to each other.

2 Materials and Methods

The soil data that have been analysed in this study were collected from recent soil survey documents of the Merowi Irrigation Project, which is a newly proposed scheme irrigated by the river Nile in the study area of North Sudan. Fifty two soil profiles, morphologically described and analysed for physical and chemical characteristics, were selected for the statistical analyses of this study.

The studied soil characteristics were:

- Soil salinity (EC_e) expressed in dS m^{-1} of the extract of the saturated soil paste.
- Soil sodicity expressed in ESP and SAR.
  ESP = Exchangeable Sodium Percentage = percentage of sodium of all exchangeable cations.
  SAR = Sodium Adsorption Ratio = $[\mathrm{Na}]/[\mathrm{Ca}+\mathrm{Mg}]/2)^{0.5}$.
- Textural classes expressed in sand, silt and clay (percent by weight).
- Cation exchange capacity (CEC) expressed in cmol (+) kg^{-1}.
- Soil reaction expressed in pH (pH of paste extract, same extract as used for soil salinity determination).
- Available phosphorus (P Olsen) expressed in mg kg^{-1}.
- Soil bulk density (BD) expressed in g cm^{-3}.
- Available water capacity (AWC) expressed in cm in top one meter.

Each soil characteristic was determined for the 52 soil profiles for 0-30 and 30-90 cm soil depths, denoted by D1 and D2, respectively. The methods used for chemical and physical analyses are those proposed by the Land and Water Research Centre of Sudan which were adapted from Ryan *et al.* (1996).

The multiple and pairwise correlations for different soil properties were obtained by using JMP 5.1 software (SAS Institute, 2000).

3 Results and discussion

In Table 1, physical and chemical characteristics of the soils from the 52 profiles are shown. Table 2 shows the correlations between different properties of the studied soils.

Table 1: Physico-chemical characteristics of the 52 studied soil profiles.

	0-30 cm soil depth (DI)		*30-90 cm soil depth (D2)*	
	Range	*Mean*	*Range*	*Mean*
$CaCO_3$ (%)	0-13.4	2.53	0-14	2.83
Sand (%)	31-96	65.39	30-90	52.69
Silt (%)	3.0-40	18.95	0-45	22.88
Clay (%)	1.00-39	15.18	5.0-34	20.48
CEC (cmol (+) kg^{-1})	5.0-32	14.38	7.0-38	19
pH (paste)	7.2-8.3	7.87	6.5-8.4	7.61
Avail. P (Olsen) (mg kg^{-1})	0.3-3.6	1.65	0.2-3	1.41
SAR	1.00-33	4.95	1.00-83	9.49
ESP	1.00-40	7.21	1.00-89	11.57
EC_e (dSm^{-1} at 25 °C)	0-27	2.84	0-33	5.03
Bulk density (gcm^{-3})	1.7-2.04	1.88	1.69-2.02	1.86

3.1 Texture and Cation Exchange Capacity

Looking at Table 2 together with Fig. 1a & b and 2a & b, it is obvious that the CEC is highly correlated not only to clay but also to silt at 0-30 and 30-90 cm soil depth, indicating a considerable contribution of the silt fraction to the colloidal activity.

Since a colloid is defined as having a spherical radius smaller than 1μm (van Olven, 1977), the explanation of the source of negative charge (colloidal activity) of silt may be related to the aggregation of fine clay particles known as pseudo-silt. This is in line with Vitroino and Tadaeu Ferria (2003) who found an increase in colloidal negative charge of silt-size aggregates of tropical soils from Brazil.

In a recent study Pio (2006) found a significant correlation of CEC with silt and clay for soil series of Northern Sudan. Moreover, mineralogical studies revealed smectitic constituents of the silt fraction of soils under comparable conditions (Ahmed, 2002). These three layer clay minerals contribute to the negative charge in silt-like particles. These findings are important to be considered when the colloidal behavior of tropical soils is under question (see also Elgabaly and Khadr (1962); Morras (1995).

The correlations presented in Table 2 show a high significant negative correlation between sand and CEC in contrast to silt and clay. Because of their absence of negative charges, sand particles do not contribute to the colloidal complex. For this reason, if we deal with cultivation of sand and loamy sand soils, application of organic manure is essential to improve CEC and soil moisture conditions (Asadu *et al.*, 1997; Peinemann *et al.*, 2000). The content of organic matter of the soils in North Sudan is very low (<1%). In the past, soils of this region were evaluated as low fertility soils because of their low clay content and low colloidal activity. However, the contribution of the silt size particles to the colloidal complex as in the present study may add to improve the interpretation of the soil fertility status of such soils. This silt fraction is not only advantageous to soil fertility, but it is also imparted as improving the water holding capacity and therefore the available water capacity (AWC, Table 2).

Table 2: Correlations between different properties of the studied soils (calcium carbonate, sand, silt, clay, cation exchange capacity, pH of paste extract, phosphorus (Olsen), sodium adsorption ratio, exchangeable sodium percentage, electric conductivity of the extract, bulk density and available water capacity)

⟶ **Depth 30-90cm**

	$CaCO_3$	*Sand%*	*Silt%*	*Clay%*	*CEC*	pH_e	P_{Olsen}	*SAR*	*ESP*	EC_e	*BD*
$CaCO_3$		0.0274	- 0.0189	0.0468	0.0228	-0.1735*	0.0439	-0.0144	-0.0230	0.1767	0.1525
Sand%	-0.0956		-0.7723***	-0.7399***	-0.7398***	-0.0975	-0.1555	-0.1049	-0.0884	-0.1708	-0.2561
Silt%	0.0869	-0.8823***		0.2821	0.4105**	0.1764	0.1995	0.0881	0.0781	0.0567	0.0058
Clay%	0.1036	-0.8395***	0.5479***		0.7804***	0.0269	0.0530	0.1224	0.1165	0.2364*	0.3875*
CEC	0.1101	-0.7266***	0.5257***	0.7987***		0.0764	-0.0091	0.1305	0.1024	0.1977	0.1663
pH_e	-0.1300	0.0142	-0.0153	-0.0407	0.0591		-0.1725	0.1655	0.1353	-0.0898	-0.0049
P_{Olsen}	0.3501**	-0.2579	0.2977*	0.1519	0.1708	-0.0002		0.1849	0.2086	0.2501	-0.0493
SAR	0.2574	-0.3264*	0.2538	0.3470*	0.2785	-0.0126	0.2827		0.9851***	0.6990***	0.0491
ESP	0.2511	-0.3311*	0.2377	0.3698**	0.2364	0.0032	0.2537	0.9486***		0.6802***	0.0680
EC_e	0.2147	-0.1399	0.0737	0.1947	0.1265	-0.2343	0.1147	0.7940***	0.7135***		0.1864
BD	0.1989	-0.1641	0.1933	0.0931	0.1165	-0.0569	0.0776	0.3199	0.2789	0.2963	
AWC	-0.2437	-0.3640	0.3641*	0.2905*	0.1514	-0.0517	0.2350	0.0769	0.0842	-0.0558	0.1862

Depth 30-90cm ⟵

Note: *, **, *** stand for significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$ level, respectively

Figure 1: Pairwise correlations between different soil characteristics (depth 0-30 cm)

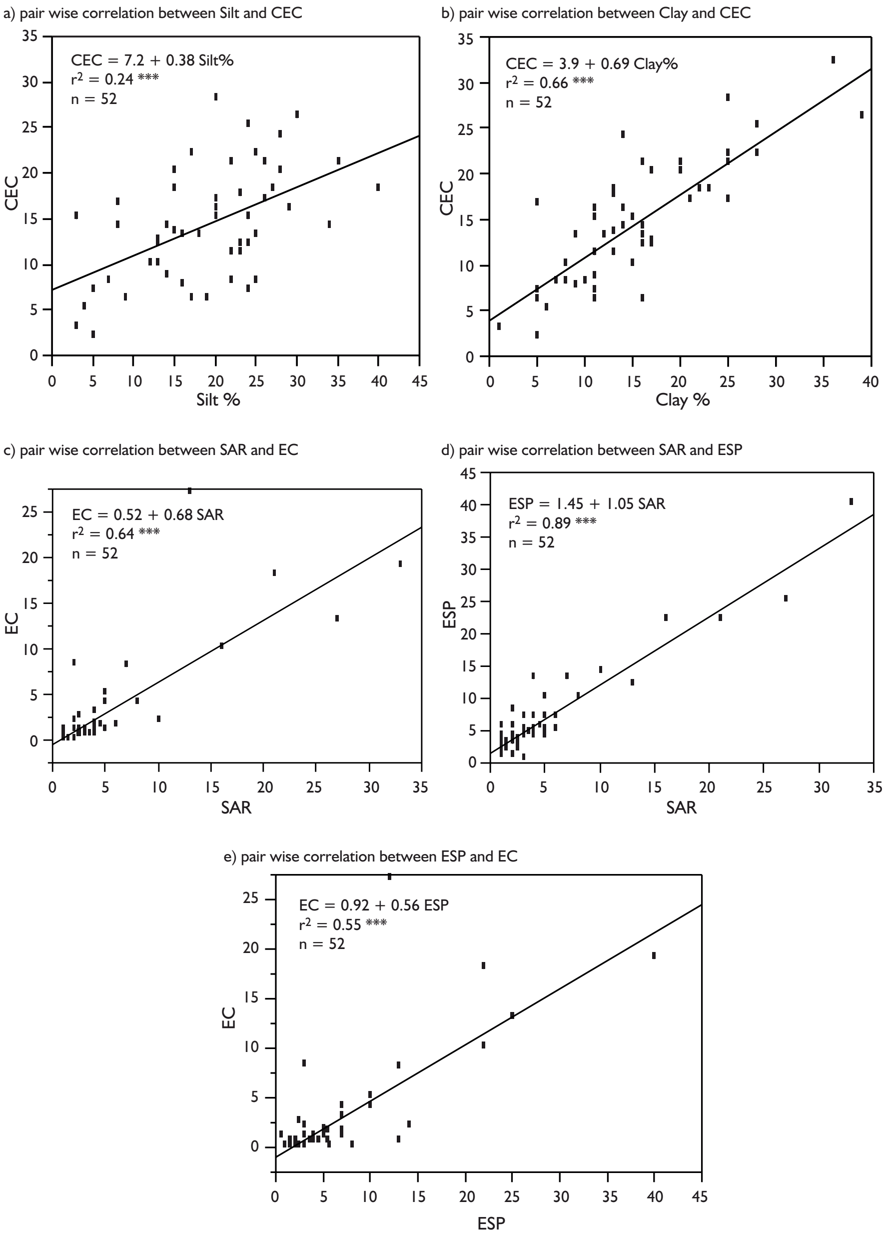
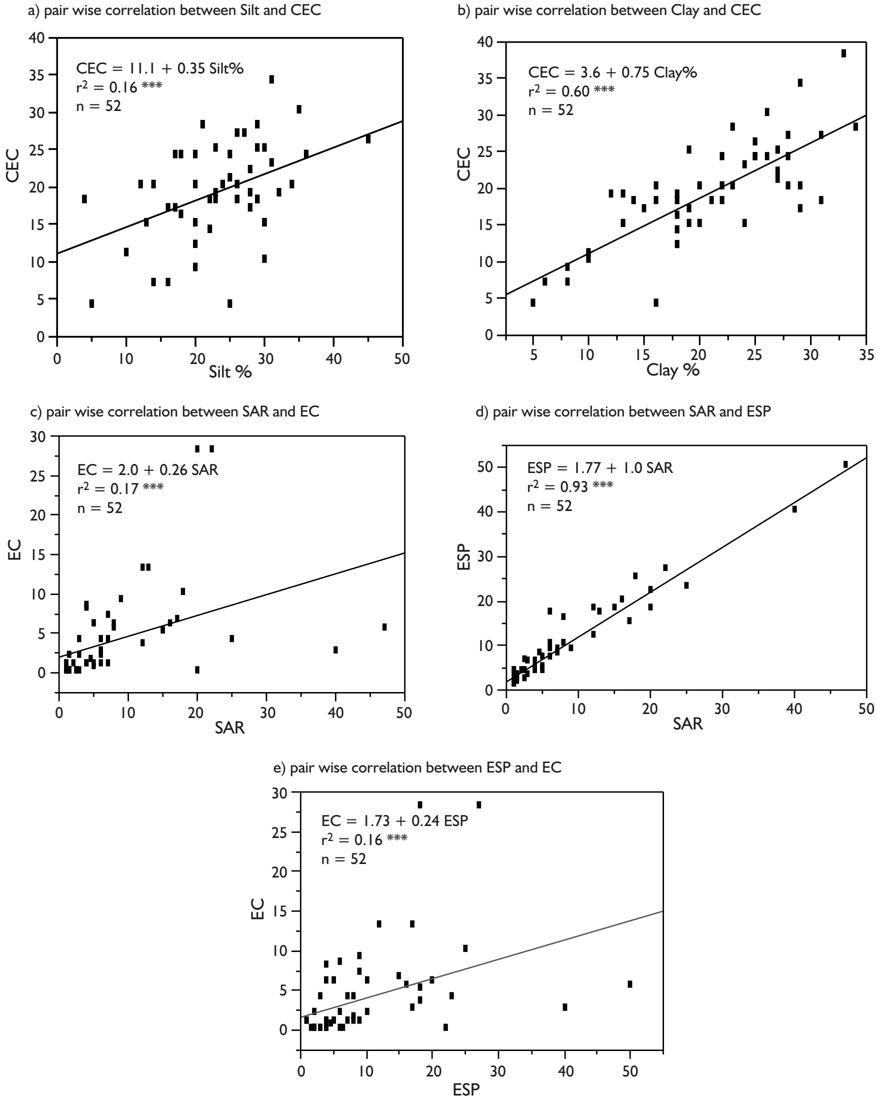


Figure 2: Pairwise correlations between different soil characteristics (depth 30-90 cm)



3.2 Salinity and Sodicity

Most of the soils in the investigation area were reported to be salt affected soils in many previous reconnaissance studies (HTS and MMP, 1965), but the chemical data that were used for these studies revealed that more than 90% of the tested samples had an EC_e(dS m^{-1}) and an ESP of less than 4 and 15, respectively.

Salinity and sodicity are separate and unique descriptions of the impact of soluble salts in soil and water. Sodicity represents the relative predominance of exchangeable sodium compared to other exchangeable cations, chiefly calcium, magnesium, potassium, hydrogen and aluminium and is expressed as ESP (exchangeable sodium percentage). The sodium adsorption ratio, SAR, is another expression of sodicity that refers to the ratio of adsorbed sodium and the sum of calcium and magnesium. Soil salinity is a characteristic of soils relating to their content of water-soluble salts and expressed mostly as EC_e (electrical conductivity of paste extract) and is measured as dS m^{-1} (Charman and Murphy, 2000). The inter-relation of all these soil parameters is important for the interpretation of their measures (van de Graaff and Patterson, 2001).

In the present study, multiple and pairwise correlations have been calculated between different soil parameters (Table 2) and between ESP, EC, and SAR (Fig.1c, 1d, 1e & 2c, 2d, 2e). There are high positive correlations between EC, ESP and SAR indicating a strong association of salinity with sodicity in the investigated soils. Association of salinity with sodicity in the study area was also observed in most of the soil surveys of the region which revealed many saline-sodic mapping units (Buramha, 1998).

Results in Fig. 1d and Fig. 2d confirm the highly significant correlation between SAR and ESP in both soil depths. Since both SAR and ESP are expressions of the level of sodicity, this finding may help to estimate ESP using SAR data. The estimation of ESP using SAR data is based on the fact that the exchangeable reactions take place between the soil solution and the exchange surface of the soil. Analytically, it is much easier to determine SAR instead of ESP. This topic was already discussed by several authors (USSL Staff, 1954; Rengasamy *et al.*, 1984; Elhagwa, 1989). Recent findings of correlation between SAR and ESP are described by Kopittke *et al.* (2006) and by Ganjegunte and Vance (2006). The results of our study revealed the following relations (Fig. 1d and 2d):

$$ESP = 1.45 + 1.05\,SAR \ \text{(for } 0-30\,\text{cm soil depth)} \quad (1)$$

$$ESP = 1.77 + 1.0\,SAR \ \text{(for } 30-90\,\text{cm soil depth)} \quad (2)$$

4 Conclusions

From our findings we conclude that:

(1) The silt fraction of the studied soils contributes to the negative charge of the exchange complex.

(2) There is a salinity-sodicity association in the studied desert soils.

(3) The proposed formula allow to calculate ESP using SAR data in the studied Sudanese soils.

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