

Studying the Characteristics of Vertisols to Set Up Field Management Practices at Dinder Area (Sennar State - Sudan)

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ABSTRACT

The development of irrigated agriculture in Dinder area was part of the program to heighten the Rosaries Dam built on the Blue Nile and irrigate more lands on both banks of the river. The Dinder Area on the right bank of the river encompasses two parts, Dinder North (DN) and Dinder South (DS). The Dinder North area is situated between Dinder River in the west and Khor Al Atshan in the north east. The Dinder south area lies between Dinder River to the north east and Khor Al Aqalayin in the west. The area of Dinder is nearly flat to very slightly undulating with predominantly cracking clay soils (Vertisols). The soil study area is in semi-arid zone and experiences rainfall in the order of 500 mm in its northern edge, increasing to some 800mm at its southern boundary near Dinder National Reserve Park. This soil study has been based on semi-detailed soil survey data [13] with the key specifications are a field density of 1 observation each 150 ha and map scales of 1:50,000 and 1:100,000. Previously published soil study information was reviewed and incorporated in the findings and the database of this study. The Vertisols have high potential for crop production, but some constraints emerge affecting crop performance and decreasing yields. Those limitations are aspects of land degradation, manifested in, 1) water erosion and; 2) deterioration of physical and chemical properties. Continuous cropping of Vertisols, through time, can lead to compaction and in some cases development of a hardpan in the subsurface, reducing porosity, intensity of cracking and obliterating water movement. Such adverse effects are indicators of degraded soil physical properties. The aim of this study is to show the pedological characteristics of the Vertisols of Dinder area and as well to recommend on their use and management in order to minimize the concurrence management hazards. Field management procedures should adhere to the recommended land and crop management systems. Parallel to this approach, the fertility status is likely to decline due to intensive farming of some nutrient-depleting crops, but this nutrient deficiency is correctable through implementing a fertilizer program. Those technical inputs if properly used and practiced they are expected to sustain crop production.

Key words: Dinder area; Vertisols; Morphological, Physical and Chemical Properties

1 Introduction

This study describes the soils morphological, physical and chemical properties of area of 235,923 ha, out of which 168,910 ha in Dinder North and 67,013 ha in Dinder South. The Dinder North area is situated between Dinder River in the west and Khor Al Atshan in the north east. The Dinder South area lies between Dinder River to the north east and Khor El Aqalayin in the west. The two areas are

connected by dry-weather road starting from Dinder town through the villages of Abu Hashiem, Al Azaza Damous, Um Baggara and terminating at the Dinder National Park. This road is suitable for accessing Dinder North area, but a crossing of the Dinder River at Al Azaza Damus was used to reach the northern parts of Dinder South area; the southern parts of Dinder South could easily be accessed from Umm Bagara [13].



Source : Development Plan [25].

Figure 1: Climatic Zones 1 and 2 at Dinder North and South Areas

Table 1: Dinder Area Monthly Rainfall and Evapotranspiration in Zone 1 and 2

Zone	(mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Zone 1 Southern Parts of Dinder (M1.1)	ETo (mm/day)	5.9	6.5	7.3	7.7	7.3	6.2	4.7	4.3	4.6	5.2	5.7	5.5	2,152
	Mean Monthly Rainfall	0.1	0.0	1.4	5.1	34.7	105.1	168.4	168.7	108.9	32.1	1.6	0.0	626
	1 in 5 year Low Monthly Rainfall	0.0	0.0	0.0	0.0	15.1	72.1	112.3	118.6	68.7	13.6	0.0	0.0	401
Zone 2 Northern Parts of Dinder (S1.1)	ETo (mm/day)	5.8	6.5	7.4	8.1	7.7	6.5	5.3	4.8	5.1	5.6	5.8	5.4	2,248
	Mean Monthly Rainfall	0.1	0.0	0.8	2.3	25.5	86.8	149.1	172.2	84.8	23.5	1.0	0.0	546
	1 in 5 year Low Monthly Rainfall	0.0	0.0	0.0	0.0	8.0	51.6	92.7	120.2	41.0	6.0	0.0	0.0	319

(Source: Rosaries-Dinder-Rahad Development Plan [25])

Recent climatic maps showing the different climatic regimens in Sudan were produced based on Papadakis climatic classification [38]. The climatic zones are based primarily on the water balance, using monthly rainfall and potential evapotranspiration data (Penman formula). The differentiating criteria are significant for agriculture, whilst the zones also correspond with natural vegetation zones. In this context two main climatic zones are defined, in which the climate of the northern parts of the study areas lie in the semi-arid zone whereas the southern parts lie in the monsoon zone (Figure 1). Brief descriptive account of the main climatic parameters is given in Table 1.

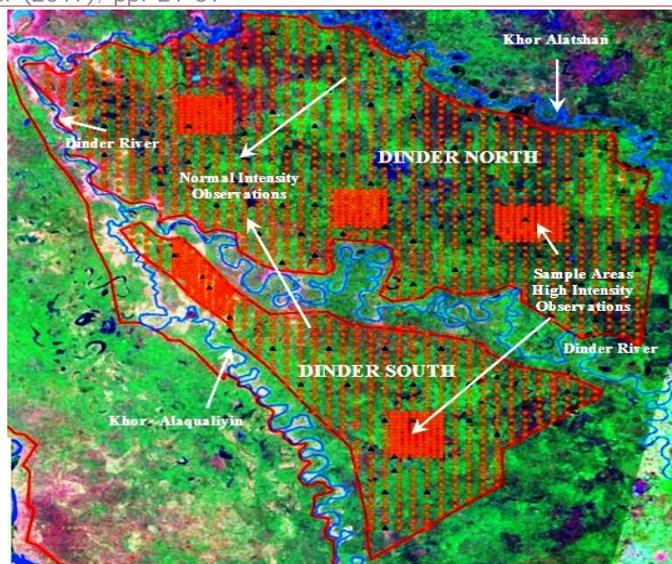
No bedrock exposures are seen in the study area of Dinder North and South, but data from the Geological Research Authority of Sudan (GRAS) maps and published works [36], [20] and [30] has shown that the underlying geological formations include Basement Complex metamorphosed schist, gneisses, and igneous rocks, overlain by Nubian Formation sandstones, in turn covered by a thick fill of alluvial sediments of the late Cenozoic El Atshan Formation. The area lies in the south eastern part of the Blue Nile basin, a tectonic trough with over one thousand meters of sediments in parts, and subject to continued petroleum exploration. The origin of superficial alluvial deposits of the study area was briefly discussed by [39] in relation to the old course of Rahad and Dinder rivers, and by [35] who indicated that the alluvium in this area consist of plains which are mantled by dark, alkaline, cracking Vertisol clays.

The plant community in study area consists of a mix of *Acacia mellifera*, *Bosciasenegalensis*, and *Cadadarotundifolia*, with scattered *Acacia senegal*, *Acacia seyal* and *Balanitesaegyptiaca*, and open areas of grasses and herbs (Figure 3). *Acacia mellifera* is continuously being exploited to provide a new land for cultivation. Because of its gum Arabic production *Acacia senegal* is not destroyed. In contrast to *Acacia senegal*, *Acacia seyal* is regularly cut for charcoal making. *Acacia seyal* was noted to be regenerating well in the area. *Balanitesaegyptiaca* is widespread in the area forming parkland. It is fire-resistant, hard to cut, does not produce a good quality charcoal, is good for shade, and has edible fruits which are collected and sold. The most abundant grasses include *Cymbopogon nervatus*, *Sorghum purpureo-sericum*, *Hyparrheniarufa* and *Cenchrusciliaris*. Most of the study area has extensive rainfed farming, mostly sorghum. Much of this is undertaken by large semi-mechanised enterprises either on their own account or by contractors working for village communities. A considerable number of grazing animals and nomadic tribes were noticed all over the area and most probably they come at the end of the rainy seasons to look for water which remains in the depressions and khors for quite some time. Sorghum is by far the most widespread crop. Over the whole area it consistently occupies just fewer than 70% of the farmed area (excluding the non-agricultural land). The percentage of sesame grown – about 6% – is constant throughout the area. Outside of the sorghum and sesame cropped lands, other crops combined to occupy only about 3% of the cropped area [13].

2 Materials and Methods

A total of 4091 augers and 86 profile pits were made (DIU, 2009). The locations of all pit and auger sites are demarcated on Landsat images 2006. These locations are based on GPS co-ordinates and shown on figure 1. Field recording of soil auger sites and soil profiles was on standardized proformas and soils were described following the [17] “Guidelines for Soil Description”.

The observations included: Auger number; Surveyor; Date; GPS co-ordinates; Landform; Topography; Slope; Site; Surface Features; Termitaria; Trees; Shrubs; Land Use; Water-table; Soil drainage class; Samples; Soil type; Depth of cracking; Soil code; Soil horizons (for each: boundary, color, color code, mottles, texture class, cracks, clay skins, slickensides, coarse fragments, reaction to dilute hydrochloric acid, calcium carbonates, iron-manganese, gypsum, and other recorded features). At all auger sites soil samples were collected from the 0.0-0.3, 0.3-0.6 and 0.6-1.0 m depths, for pH, salinity (EC) and sodicity (SAR) screening.



(Source: DIU, 2009)

Figure 4: Sites of Soil Augers and Profile Pit Observations (red dots) in Dinder Area that are Demarcated on Landsat (October 2007).

3 Results and Discussions

3.1 Surface Features and Morphological Properties

The unique character of Vertisols is derived from the interaction and development of morphological features manifested both in the surface and in the soil profile. They have specific properties related to smectitic mineralogy [8] causing high coefficient of expansion and contraction leading to cracking and mulching. This sets up a steady churning process in the pedon, resulting in a process of vertical mixing and developing specific features uncommon to other soils. These features include:

3.2 Surface mulch

The surface mulch comprises fine and medium sized granules (5-15 mm) occasionally obscuring surface cracks in depressions. It is the first surface feature to be identified on the soils of the study area, and varies in thickness between 10-30 mm, but is thicker on the shedding sites particularly on the usually higher yielding lands associated with *nal* grass (*Cymbopogon nervatus*) when under fallow. The mulch is a water-conserving feature reflecting beneficial agronomic practices, such as harvesting of groundnuts, tubers and shallow-rooted vegetable and growing of food grain (sorghum and sesame). Such cropped areas are relatively more in Dinder North than Dinder South. It is reported that soils having thick surface mulch requires less energy to till. In irrigated farming, sprinkler irrigation may be more satisfactory because it would make gradual wetting possible and offering the possibility of structural improvement [21]. However, some of the clays do not form mulch on drying but produce "crusty surface". These crusty surface soils are commonly found in depressions.

3.3 Cracks and Slickenside

Cracks are soil surface and subsurface manifestations. In the study area they vary in width between 1.0 and 5.0cm and extend to a depth of 60-80 cm, and occasionally deeper to 1.5 m. Water deficiency and tillage are the most important plant growth factors for the management of Vertisols. Lack of water is a problem, at times, in all Vertisols because taxonomic criteria dictate that they must have desiccation cracks at 50 cm depth and 1.0 cm width in most years [33]. [21] Have indicated that

presence of cracks implies that there are at least seasonal periods of high water suction and water deficiency. They further have viewed the cracks into three groups: The first group includes vertically oriented cracks that outline prisms that are relatively wide, usually exceeding 5mm width at the surface when the soils becomes dry, and develop progressively deeper as further drying occurs. The second group represents randomly oriented narrow cracks, 1.0 mm or less in width and tend to be closer together and do not develop until water contents are around 15 bar retention. These outline the angular blocks and have less importance as regard to root ramification, because soil fabric has reached strength where root entry is limited. The third group of cracks occurring at about half meter depth, are formed by soil movement, and made up of intersecting slickensides. The low angles at which these intersect give this zone a platy appearance. In the study area, the cracking intensity in terms of width and depth is much more than postulated by [21].

The first and second groups of cracks are dominantly manifested in the soil profiles developed on flat shedding sites where water movement via the cracks is rather well distributed favoring increased cracking intensity in terms of width and depth. On the other hand, the third category of cracking pattern is described in soils developed on the receiving sites and depressions; the intensity of which is partially obliterated by increased water content at shallow to medium depths of the profile where vertisolic characteristics of slickensides and pressure faces are common and pronounced. Generally the types of cracks, as elaborated above, furnish a plausible explanation as to their functions in accelerating water movement that determine the depth and frequency of irrigation water required and hence improving water management in the soils of the study area. However, [9] reported that most of the normal irrigation application 10 cm of water can be accommodated in the cracks. They added that the cyclic depth of water penetration appears to be limited to about 60cm.

3.4 Gilgai and Depressions

“Gilgai” however denotes micro-relief at a larger scale, superimposed on this unevenness [16]. In Dinder area Gilgai consists of small mounds in a continuous pattern of small depressions, or depressions surrounded by a continuous network of narrow ridges. Several hypotheses have been put forward to explain the Gilgai micro-relief. These have in common that they relate Gilgai to mass movement in swell/shrink soils. For Gilgai to form the soil must have sufficient cohesion to transfer pressures all the way to the soil surface and this occurs during the process of swelling and shrinking. Apart from the dissected complex riverain lands along Dinder River, Khor Al Atshan and Al Aqalayin, the study area comprises a vast, flat to very slightly undulating, clay plain. Within the plain gently undulating and undulating land is usually associated with shallow depressions and khors (Figure 2 and Figure 3; [13]. Landsat 2006 interpretations and ground checking have confirmed their presence. The shallow depressions receive run-off and can remain wet for 2 to 3 months after the rains. Some of these receiving sites are old back swamps that have been cut off from the rivers and, whilst often apparent from imagery, are almost imperceptible during field study. Soils of the depressions are Vertisols similar to the surrounding plain and often the only indications of shallow depressions in the dry season are by flood marks on trees, uncultivated soil, or a cover of low weeds.



Figure 2: Local Depressions in Old Back swamps (maya) created by River Meanders.



Figure 3: Heglig Tree (*Balanitesaegyptiaca*) in a Depression. Dinder North (The water mark at its stem indicates the level of water during rainy season).

3.5 Calcium Carbonate Concretions and Aggregates

Glaebular and other forms of pedogenic carbonate have been described from profiles in the clay plains of Central Sudan [3]. The carbonate concentrations have differentiated into types based on their appearance in thin sections. Carbonate has also been described from stereomicroscopic observation of undisturbed soil fragments and wet-sieved fractions over 0.5 mm and in soil profile walls. X-ray diffraction shows that in all samples the carbonate mineral is calcite [3], [4]. Soft, powdery types of carbonate are diffused nodules or channel neo-calcitants; hard, discrete types are generally nodules, sometimes concretions, septaria and pedodes (Figure 5). The hard types have been differentiated on the presence and form of “impregnations” by iron and manganese (dendrites of manganese, neo- or quasiferans) and of cutans (generally manganese).

Often there is a relation between types of pedogenic carbonate present and other profile characteristics. soft, powdery types appear to have formed in situ. Hard, discrete types in Vertisols are inherited by transport within the profile, due to churning. The accretion of the carbonate and formation of “impregnations” and cutans are due to processes which are – or have been- active in the lower part of the profile, below the present churning zone [3]. In Dinder area prominent, hard, whitish CaCO_3 nodule of small and medium sizes (5 -25 mm) are commonly found at the surface of the relatively depressional areas. At substratum depth dominant soft and hard calcium carbonate concretions and nodules are usually found where these depth are often moist and high concentration are associated with the dark brown old alluvium calcareous layers (Figure 5). It seems that the fluctuating relatively high moisture content at lower depths coupled with churning processes in

Vertisols largely determined the amount and translocations and eventually distribution of calcium carbonate nodules and concretions.

3.6 Physical properties

All soils are > 2.0m deep. The Vertisols clay varies in depth from 1.5 to \geq 4.0m. The strata beneath the clay are heterogeneous brown, dark brown or dark yellowish brown silty clay, clay loams or sandy clay loams. With the exception of infiltration test, no tests were carried out for bulk density (BD), infiltration, permeability or AWC on the Vertisols of the study area because conventional methods don't apply to shrink-swell montmorillonitic clays. The values for such untested parameters were extracted from [26]. The infiltration tests were conducted in the study area using double ring infiltrometers. The values represent the basic infiltration rates which show almost consistent trends of 1.4 cm/h due to the behavior of the homogenous soils of the study area. The optimum basic infiltration rates for surface irrigation are considered to be in the range of 0.7 to 3.5 cm/h, although acceptable normal values range from about 0.3 to 6.5 cm/h. However, it is reported that the methods of infiltration measurement can suffer from a number of errors including, lack of adequate pre-wetting of dry expanding clays that need weeks of pre-wetting before major shrinkage cracks are closed; and soil disturbance effects during project development which may alter the soil - water intake characteristics [26].

3.7 Chemical and mineralogical properties

The soil particle size analysis recorded clay content in the range of 55-75% that belongs to the clayey class in the FAO textural triangle and to the likely smectitic mineralogy. The CEC values are fairly consistent with this range of clay content [8], [4] also provides important data on clay mineralogy of the central Sudan soils. The total nitrogen and organic carbon contents are very low ranging from 0.02 – 0.04 % to 0.6 – 0.8 % respectively indicating very low organic matter content that coincides with the amounts usually present in an arid climate. The total phosphorus, extracted with sodium carbonate buffered at pH 8.5, dominantly varies between 1 and 5 ppm but exceptional few high figures range between 12-34 ppm. Dominant amounts are deficient for most crops and questionable for cereals and grasses. The availability of phosphorus is critical to plant uptake because soil alkalinity (pH 8.5 – 9.0) causes fixation and/or formation of insoluble compounds. However, crops vary in response and therefore the requirement for fertilizers application need to be assessed after determining soil reactions.

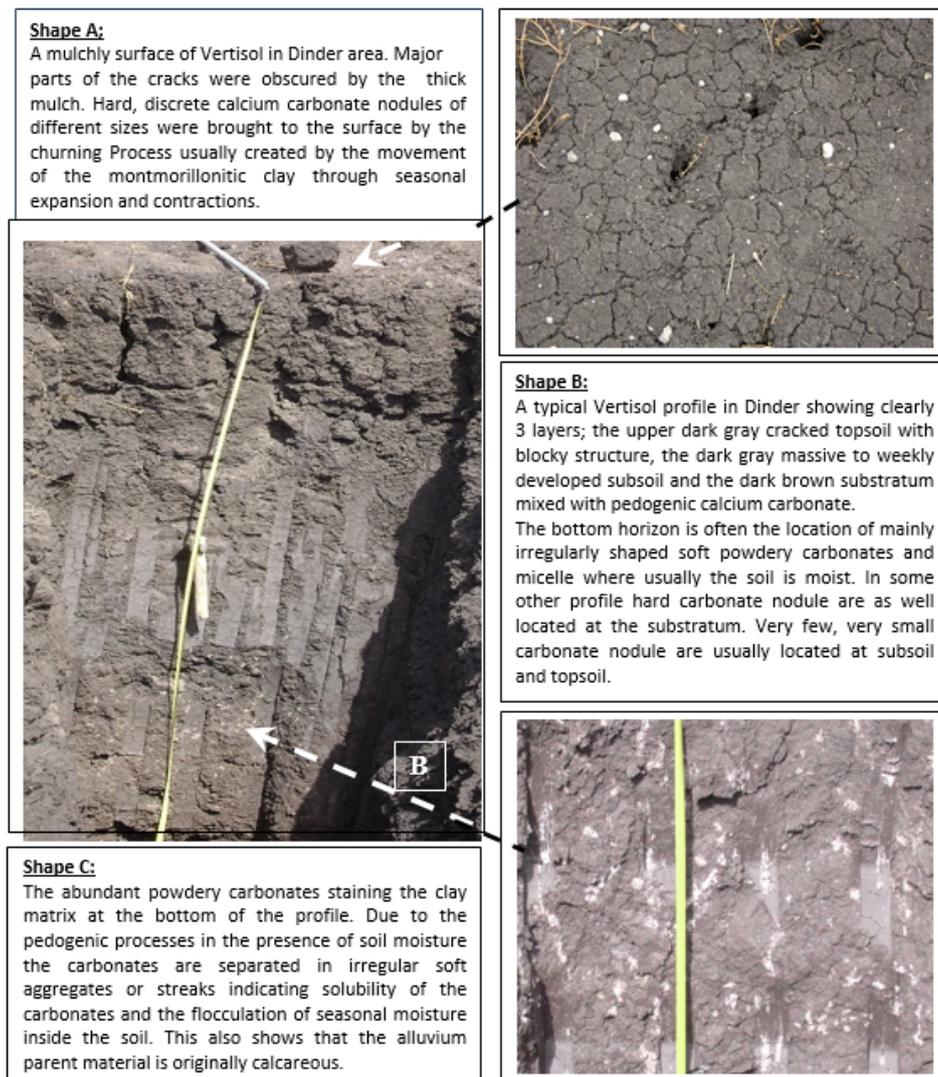


Figure 5: Calcium Carbonate nodules, concretions and aggregates in Vertisols of Dinder

The soil reaction is alkaline varying between mildly to strongly alkaline in almost all of the soils of the area. The pH values of the saturation extract range from 7.4 – 8.9 but these rates tend to be higher with the increase of the soil-water ratio (dilution effect). In this respect, pH values exceeding 9.1 are occasionally found in the suspension 1:5 soil-water ratio. Although the reaction of the soil matrix is slightly to moderately calcareous, the CaCO_3 content ranges from 3.7%. Higher contents are infrequent and occur in the substratum in some profiles. However, these soils may contain CaCO_3 more than that recorded in the analytical results: this is because the analyses were carried out in the "fine earth" (< 2 mm dry soil sieved without any gravel) of the samples that passed the 2 mm sieve. In this regard, it is observed that CaCO_3 concretions larger than 2mm have been retained in the sieve as part of the gravel fraction of the sample which is not considered for the analysis. Smaller sized fragments of concretions will pass through the sieve and be included in the testing. The field method of applying HCL acid on the soil matrix to check the presence of CaCO_3 proved to be a reliable indicator of soil calcareousness.

The EC of the saturation extract rarely exceeded 4 dS/m at 25 °C. which indicates a very low hazard of salinity in these soils? The types of salts, as given from analysis of the exchangeable and soluble cations and anions, are dominantly sulphates followed by chlorides. Bicarbonate is present in little amounts while carbonates are either as a trace or not detected. The exchange complex in soils of this area is fully saturated with basic cations of Ca⁺⁺, Mg⁺⁺, Na⁺, and K⁺. Exchangeable H⁺ and Al⁺⁺⁺ (exchange acidity) is therefore, non-existing. The Cation Exchange Capacity CEC ranges from 55 – 75 meq/100gr soil. Potassium and sodium are determined separately and results indicated that potassium is very low compared to sodium. The Ca⁺⁺ + Mg⁺⁺ are calculated by difference between the CEC and exchangeable Na⁺ + K⁺, and therefore are not reported separately. This approach is adopted because of the occurrence of calcium sulphates in water adding more Ca⁺⁺ and Mg⁺⁺ to the soil solution which likely giving rise to erroneous estimates. The practical experience indicates that the SAR values, obtained by applying 1:5 soil-water rates methods are low and under estimated and this could be attributed to the following:

- 1- Solubility of Ca⁺⁺ and Mg⁺⁺ increases in higher soil-water ratios than Na⁺ ;
- 2- The soil matrix is calcareous, containing CaCO₃ in very fine particles that release Ca⁺⁺ into the solution, giving rise to increased Ca⁺⁺, and eventually Ca⁺⁺ + Mg⁺⁺.

3.8 Micronutrients

The soil micronutrients that have been analyzed on this survey (Fe, Mn, Zn, and Cu) have provided data that indicates that the soils of study area are deficient in some of the available forms. In the case of Fe, and Zn, they are present in contents well below the crop requirements. Levels for Mn and Cu (subsoil only) are adequate, and this difference appears to confirm the recycling of nutrients down cracks to the deep subsoil where they are largely unavailable to field crops. The high soil pH and calcareous reaction of soil matrix apparently, are the main constraints to the availability of all determined micronutrients (DTPA test), which are evaluated in Table 2, following [31]. The figures between brackets like (1.16) indicate averages in the soils of Dinder study area while other indicates the ratings [31]. Table 2 shows that Fe and Zn are low while Cu and Mn are adequate. Accordingly Zinc and Iron deficiency is highly probable.

Table 2: Evaluation of Soil Micronutrients (ppm) in the Soils of the Dinder Area

Grade	Fe	Mn	Zn	Cu
Low	< 2.0 (1.16)	< 1.8	< 1.0 (0.16)	< 0.5
Moderate	2.0-4.0	-	1.0-1.5	-
Adequate	> 4.0	> 1.8 (4.0)	> 1.5	> 0.5 (0.85)

3.9 Salinity and Sodicity in Dinder Areas

The laboratory results show that the Dinder North and South areas in general may be classified as non-saline (Table 3 and 4). The content of soluble salts is very low, such that it is considered the growth of even sensitive crops would not be affected. The EC of the saturation extracts for all samples very rarely exceeds 4 dS/m at 25 °C. The types of soluble salts were determined for all samples collected. Soluble sulphates are the most dominant followed by chlorides. Bicarbonates are present in small amounts; carbonate is the least found, and is completely lacking in many profiles. The low salinity would appear to reflect the increased rainfall in the Dinder area and its effect on leaching of soluble salts.

Table 3: Ranges of pH, EC and SAR Values in Dinder North

Soil horizon	Auger Data									Profiles Data		
	pH			EC			SAR			ESP		
	Range	No of samples with pH values > 8.5	%	Range	No of samples With EC values ≥ 2.5	%	Range	No of samples With SAR values ≥ 12	%	Range	No of samples With ESP values ≥ 25	%
Surface	6.6–9.3	41	3.1	0.1–1.0	0	0.0	1.0-9.0	0	0.0	1–25	2	3.3
Subsoil	6.1–9.7	83	6.2	0.1–0.6	0	0.0	1.0-9.0	0	0.0	1–32	2	3.3

Total soil observations in Dinder North = 1390 (1330 augers+ 60 profiles)

Table 4: Ranges of pH, EC, SAR and ESP Values in Dinder South

Soil horizon	Auger Data									Profile Data		
	pH			EC			SAR			ESP		
	Range	No of samples with pH values > 8.5	%	Range	No of samples With EC values ≥ 2.5	%	Range	No of samples With values ≥ 12	%	Range	No of samples With ESP values ≥ 25	%
Surface	5.5–9.1	11	1.8	0.04-8.3	1	0.2	0.1-12.0	1	0.2	1–33	8	30.8
Subsoil	6.1–9.0	33	5.2	0.01-1.0	0	0.0	0.8-12.0	2	0.3	2–31	10	38.5

Total soil observations in Dinder South = 642 (616 augers+ 26 profiles)

Calcium and magnesium are the dominant exchangeable cations in the soils. With increasing depth their relative percentage decreases, whereas sodium increases in these lower horizons. Some horizons below the surface, and at variable depths, have ESP values more than 15 which was the original limit set up by the USDA's Salinity Laboratory at Riverside, California. For long this was widely accepted as a boundary defining sodic soils. Local experience, with Sudanese Vertisols had indicated that some relaxation was needed, and this limit may be increased to a value within the range of (25-35) before the adverse effect of exchangeable sodium is clearly shown in locally adapted field crops grown in this area [37]. The performance of crops had not shown a decline in yield that could be attributed to an ESP of 15. It was considered that the combination of high clay content and high CEC might have imparted a buffering effect to the harmful level of exchangeable sodium [14].

Based on a worldwide review of soils [26] stated that in general terms, high ESP values have a greater deleterious effect upon soils with 2:1 lattice clays than on those with 1:1 clays. Moderate soil alkalinity occurs in higher values (pH > 8.5) in limited sites within Dinder North area (Table 3) particularly within the soil substratum, compared to the values of very limited sites recorded in Dinder South (Table 4). This situation could possibly be created as a result of the effect of apparent relatively more moist

climatic conditions prevailing in Dinder South area (Figure 1 and Table 1) with possible movement of salts into the substratum (subsoil) due to availability of moisture. Similarly, this holds applicable for both the salinity (EC) and sodicity (SAR). The three tested parameters are commonly mild or nearly optimum in most parts of Dinder Areas. Therefore, the adverse effect on the availability of nutrient elements would not be to the limit that renders low fertility statuses.

Table 5: FAO (1970) Sodic Phase Units Compared to Present Survey Data

Soil Survey Study	Sodic Phase Units	Details	pH 1:5		ECe 1: 5		ESP	
			Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
FAO (1970)	Dinder sodic Phase 1970	Average	8.6	8.6	0.59	0.98	9.1	18.05
		Range	8.6	8.5 – 8.7	0.56 – 0.61	0.95 – 1.0	6.1 – 12	18 – 18.1
	Abel Sodic Phase 1970	Average	9.2	9.4	0.67	0.86	14	26
		Range	8.8 – 9.6	9.3 – 9.5	0.55 – 0.88	0.84 – 0.88	4 – 27	25 – 27
Dinder Area (Present Survey, 2008)	2008 Profiles within Dinder sodic Phase	Average	7.05	7.2	0.55	0.5	12	19
		Range	7.0 – 7.1	7.0 – 7.4	0.5 - 0.6	0.5	6 – 18	18 - 20
	2008 Profiles within Abel sodic Phase	Average	7.7	7.8	0.5	0.44	18.2	19.4
		Range	7.1 – 8.3	7.4 – 8.4	0.3 – 0.8	0.2 – 0.8	5 – 29	4 – 36

Useful to review the semi-detailed soil survey study carried out by [35] in Dinder area (including both Dinder North and South). On this early study soil samples were collected from profiles representing the different soil series and their sodic phases. These are the Dinder series (slightly sodic) and Abel series (sodic phase). The pH, salt percentage and sodium value were determined on these samples using soil water extract, and further converted into EC and ESP [35]. A comparative analysis is given in Table 5. This is based on placing soil sites within the sodic phase map units of the FAO study. Analyses from these areas have been related to profile data from the representative sites elsewhere in the Dinder N and S areas. The values in these categories coincide fairly well with the findings obtained from Dinder soil study areas which designate the study areas as non-saline and non-sodic with good nutrient status (Table 6).

Table 6: Levels of Selected Chemical Characteristics Used to Evaluate Relative Nutrient Status of the Dinder-Kenana soils

Relative nutrient status	pH Paste (1:5)	% Base Saturation	C/N Ratio	ESP	Water soluble Ca meq/L	ECe dS/cm
Good	6.6-8.4	>80	<11	<25	3.0	0-4
Fair	8.4-9.0	50-80	11-15	25-35	1.3	4-8
Poor	>9.0	>50	>15	>35	<1.0	>8

3.10 Prediction of ESP from SAR values as determined in 1:5 Soil-water suspension

The validity of the relationship between SAR and ESP is based on the equilibrium that may exist between soluble cations and exchangeable cations when the soil moisture content is within the field moisture range. Good correlations between the two parameters are more satisfactory when the soils under study are saline-sodic. When the water: soil ratio is increased from saturation to moisture content sufficient to dissolve gypsum and/or the fine particles of calcium carbonate, SAR values are underestimated. This is due to the fact that the content of soluble divalent cations (Ca^{++} and Mg^{++}) is increased in the extract at a ratio much higher than that of (Na^+), and this result in low SAR values.

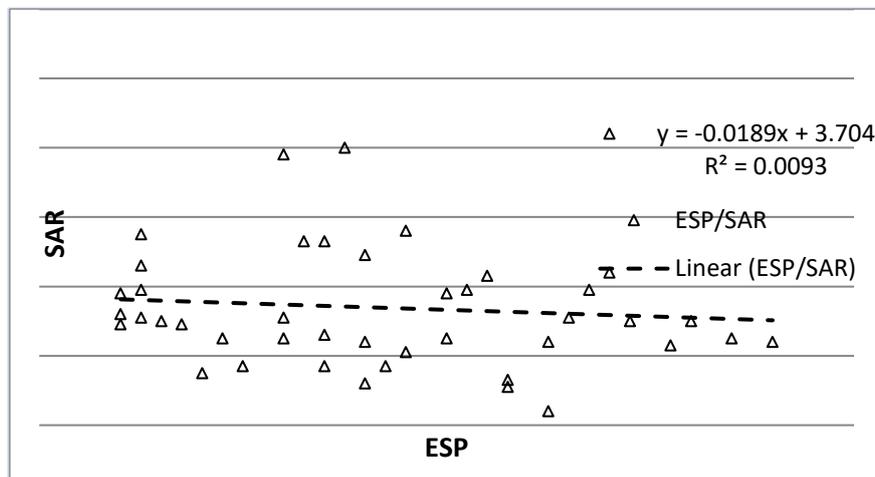


Figure 6: SAR (1:5 soil-water) Correlated with ESP Values in Dinder Area

Accordingly, the SAR values based on 1:5 soil-water suspensions do not correlate significantly with ESP values (Figure 6) so as to be taken to reflect accurately the amounts of sodium in the soil, and this could be attributed to a number of reasons [14]. Dinder soils are calcareous throughout the study area (DN and DS). The calcareous matrix of the soil contains very fine particles of CaCO_3 which may release some Ca^{++} in the analysis. Furthermore, gypsum crystals are commonly observed at the lower horizons of the soil profile. Therefore, it is likely that the low SAR values obtained for Dinder area are due to the increased solubility of the fine particles of calcium carbonate and gypsum crystals that are lowering sodium in the soil.

4 Conclusions

The problems involved with working the heavy clay Vertisols in the Central Clay plains of Sudan, whether for rainfed or irrigated cropping have received considerable attention over many decades [8]; [11]; [24]; [28]; [4]; [2]; [12]. The sustainable management of the cracking clays (Vertisols) identified and mapped in the study areas of Dinder North and Dinder South requires the application of appropriate and Sudan-proved techniques in land management and husbandry. Some techniques and components must be combined to perform the best management practices package. Therefore, this package includes six attributes, namely, 1) Farming and land management systems; 2) Fertility and fertilization 3) Crop management systems 4) Irrigation system; 5) Drainage; 6) Soil conservation.

4.1 Farming and land Management Systems

Vertisols are one of the most productive soils for irrigated agriculture. Their high water-holding capacity endows them with the ability to compensate better than most of the soils suffering from irrigation water deficit which is a major constraint for crop production and growth. Because of the widespread occurrence and high potential of Vertisols for increased productivity the Kenana Rahad II Irrigation Projects have been given a high priority for developing improved farming systems. The major kind of land use in the study area will be irrigated agriculture, under which the main farming system would be mechanized mixed cropping adopting diversified/intensified cropping and applying appropriate technology. Enhancing such an approach necessarily requires making use of land and crop management systems in which the agronomic practices likely to be employed in the study area will set up farming designs in terms of layout of basin, furrows or strips accommodating the proposed land utilization types. Tillage embraces all operations of seedbed preparation that optimize soil and environmental conditions for seed germination, seedling establishment and crop growth. It includes mechanical methods based on conventional techniques of ploughing and harrowing, weed control using herbicides, use of growth regulators, and fallowing with cover crop for direct seeding through residues mulch. The ploughing-till covers two operations, namely: Primary tillage: is the first and deepest tillage optimum, and forms the basis for the seedbed, and is based on ploughing or soil inversion; Secondary tillage: this operation is designed to refine the seedbed to conditions suitable for successful germination and unimpeded growth, using a disc.

Therefore, the soil moisture condition should be monitored for their optimum status before implementing tillage operations. This was recognized long ago at Tozi Research Farm on the Blue Nile left bank and discussed in the Rosaries, Dinder and Rahad Development Plan (Lahmeyer, 2008) and assessed earlier by others, for example [24] and [2]. The actual time for tillage is short due to the soils either being too dry and hard, or wet and plastic and impassable. On the rainfed schemes at Agadi, to the south of Damazin on the left bank of the Blue Nile, no-till cultivation involves heavy use of herbicides, and they estimated they only have about 17 planting days [25]. Intensive tillage operations with machines could have adverse effects on physical soil characteristics by compaction of the soil. Soil compaction is the reduction of soil volume due to external factors. Soil compaction is produced mainly by tillage machines and equipment. The risk of soil compaction is greater today than in the past due to an increase in the size of farm equipment. Soil compaction reduces soil productivity. Research in tilled soils in USA showed average first-year yield losses due to compaction of approximately 15%. Performing field operations on wet soils, using multiple field operations for crop production, eliminating perennial crops from crop rotations, and using heavy equipment contribute to more extensive and deeper compaction [40].

4.2 Fertility and fertilization

The chemical data obtained from the Dinder North and South surveys shows that the exchange complex are highly saturated (> 60%) with exchangeable cations. The nutrients in the exchange are indicating a high CEC (> 40 meq/100gm soil). Their availability to plant uptake is strictly governed by soil pH. Therefore, a fertility management programme requires assessment of the macro-micro nutrient storage in the soils of the study area in order to identify nutrient imbalances requiring application of desired kinds and doses of fertilizers and to predict deficiencies that might be brought about by growing nutrient depleting crops and to set up correction measures. For the very low nitrogen content found in these soils, many agronomists have conducted experiments in similar soils in the central clay plain of Sudan and showed the need for nitrogen fertilizers [5]. It is also found, that

for the efficient management of nitrogen and increased crop yields, nitrogen has to be applied with phosphorus fertilizers [6], [32], [27]; [23].

Phosphorus availability is probably the greatest constraint to agricultural production in Vertisols. This situation is linked up with pH dependant-available phosphorus and its response that shows a wide variation to reach maximum yields for different crops [32]; [41]. Another critical issue for phosphorus management in Vertisols is the source of phosphoric fertilizers being nitrophosphatic or mixture of ammonium sulphate and superphosphate, where the nitrophosphatic fertilizers gave better yields [27]. The third aspect in terms of phosphorous management is the use of organic waste and recycling of farm residues as a source of nutrients [1].. In this practice, decomposition of organic residues by microbial activity releases CO₂ that dissolves in water, forming organic and inorganic acids, lowering the soil pH rendering phosphorus soluble and hence making it available. Phosphorous fixation occurs in calcareous soils and is placed near the root zone (rhizosphere) since it is somewhat immobile. The potassium shows an unusual characteristic as the total content in the soils range from 1-3 meq/100g. Generally, within this range, response to potassium fertilizers is negative, because it is reported that response is likely when a soil has an exchangeable K value below 0.2 meq/100g of soil and unlikely when it is above 0.4 meq/100g [26]. Some research results attributed this mainly to potassium fixation by the dominantly 2:1 montmorillonitic clay [22]; [32]; [6]. Availability of trace elements to plants is influenced by many soil and environmental factors, which must be taken into consideration when interpreting soil test data The determination of the soil micronutrients (Fe, Mn, Zn and Cu) indicates that the soils of the study area and similar soils elsewhere (e.g. Gezira band Kenana) are invariably deficient in available forms [10]; [41]) and for some of them having trace element contents far below the levels required for plant uptake. The high soil pH is the main determining factor forming insoluble compounds.

- Zinc:The trace elements analyses have indicated low amounts of zinc in the soils of the Dinder area(0.16 ppm in topsoil only). Since the soils in Dinder Area are calcareous with relatively high pH and most of the proposed crops are sensitive to zinc deficiencies, the zinc content in the soil should be monitored and it would appear that adequate amounts of zinc should be added to the soils.
- Copper:The trace elements analyses have indicated adequate amounts of copper in the soils of Dinder Area with levels of 0.85 ppm in subsoil. Phosphate reduces the concentration of Cu in roots and leaves of plants, and heavy phosphate fertilization can induce Cu deficiency. Where application of phosphate fertilizers is practiced for soils low in Cu content, soils should be monitored to avoid depletion of this element.
- Iron:The trace elements analyses have indicated moderate amounts of iron in the soils of Dinder Area, with levels of 1.16 ppm in topsoil Since the soils in Dinder Area are calcareous with relatively high pH and most of the proposed horticultural crops are sensitive to iron deficiencies, the iron content in the soil should be monitored and additional amounts of iron may need to be added to the soils.
- Mn:A wide range of crops is sensitive to Mn deficiency, which is common in calcareous soils and soils of high pH similar to Dinder soils, although deficiencies are also frequently induced by liming and poor soil physical conditions, even in soil with pH >7.0 The of Mn is also highly dependent on the presence of other ions: Mn can induce Fe chlorosis, and there is some evidence which suggests that Fe and Zinc interfere with Mn uptake; Mn and P appear to be mutually antagonistic [26].

In the study areas no artificial chemical fertilizers are being applied for crop production under both the traditional and mechanized rainfed farming although good field crop performance was noticed. Apparently, the fallow farming system is widely practiced to allow soils to rest and regain its natural fertility in order to withstand on-farm operations and any consequent land degradation which might appear due to continuous cropping. The application of chemical fertilizers under irrigated farming in the future project will draw on experience and technical knowledge gained from the neighbouring irrigated schemes e.g. Kenana Sugar Estate, the Gezira Scheme, and ARC research data. Since the Dinder soils are dominantly alkaline, the use of common fertilizer products that have acidic residual effect for lowering the high pH to levels favoring plant nutrient availability might be a useful intervention. Trials though, are needed though to assess this suggestion. In such a case the recommended compounds would be potassium nitrate, ammonium nitrate, ammonium sulphates, urea and superphosphate.

4.3 Irrigation system

The water from the Blue Nile will be utilized for crop production in the seven land utilization types proposed for the study area. The most recent and elaborate analysis was presented by [14]. Using the method, quoted by [14], suggested for the classification of irrigation water by [29] and therefore the Blue Nile water could be classified as C1-S1 i.e., low salinity and low sodium risk water. Therefore, this water quality can be used for irrigation with most crops on most soils with little likelihood that soil salinity or sodicity will develop. The classification is based only on the electrical conductivity and SAR. It does not consider other harmful effects from bicarbonate and boron. It was also indicates that, generally, the water of the Blue Nile can be used for the irrigation of all crops [14].

4.4 Crop Management Systems

The crop management sequence has an intact relation with the tillage system, in that, crop management systems embrace different aspects e.g. seedbed preparation, soil management, management of plant pests and plant production. The crop production within the seven land utilization types is believed can be achieved through adopting crop management systems including crop rotations, sequential cropping and a cropping calendar.

- Crop rotations

The crop rotation involves the growing of one or more crops alternately with fallow or with each other. It may be simple such as the wheat-fallow system in which one crop is produced in 2 years or complex where several crops are grown in a system requiring five or more years for completion [34].

- Sequential cropping

It is adapted to any type of cultivation system e.g. labour intensive, modern-high technology. It is merely an intensification of crop production in time dimension where water and other resources are available. It affords an opportunity to use land and water resource effectively throughout the period that is favourable to growing crops. By having a crop on the land for most or all of the year, the potential for erosion is also decreased.

- Cropping calendar

It is a system set up for keeping chronological timing records of all the farm management operations including crop cultivations, tillage, sowing and harvesting date, length of growing periods, fertilizer doses and yields [15]. Having had the agronomic advantages of rotational and sequential cropping been envisaged, it is for practical and yield benefits, recommending both crop management systems

as guided by the cropping calendar for crop production in all of the seven land utilization types proposed for the project area.

4.5 Irrigation system

The water from the Blue Nile will be utilized for crop production in the seven land utilization types proposed for the project area. The investigation of the composition of the water reported a calcium/sodium ratio of 4.2. The most recent and elaborate analysis is shown in Table 9.1 [14]. Using the method, quoted by Fadl (1969), suggested for the classification of irrigation water by [29], the Blue Nile water can be classified as C1-S1 i.e., low salinity and low sodium risk water. Therefore, this water quality can be used for irrigation with most crops on most soils with little likelihood that soil salinity or sodicity will develop. The classification is based only on the electrical conductivity and SAR. It does not consider other harmful effects from bicarbonate and boron. The water analysis of previous studies indicated that, generally, the water of the Blue Nile can be used for the irrigation of all crop components on proposed land utilization types. In this case, the possibility is remote for adding salts or building secondary salinization in the soils of the project area (Fadl 1969).

4.6 Drainage system

Excess surface water and internal soil water are potential limitations to crop production in cracking clays. Major irrigation systems often involve large areas, frequently covering either large farms or numerous small farms, and drainage of excess waters and leachates is essential. It is therefore; imperative that for nearly level fields with relatively flat slopes such as occur in the project area, a system of beds and furrows is most suitable. In the project area, the difficulty remains with the low-lying unconnected depressional areas (the receiving sites of seasonal flooding). Here drainage can be improved by connecting the enclosed depressions with a series of ditches which would permit discharge into natural drainage ways. If such soils are not drained, they will impose adverse drainage conditions that will severely limit crop growth [37]; such soils are given a wetness limitation (subclass symbol –w).

4.7 Soil conservation

The chemical analyses carried out for the soils of the project area indicated low contents of soluble salts and exchangeable sodium, that are generally well below the thresholds for development of salinity and/or sodicity, and hence the Dinder North and South soils are designated non-saline and non-sodic. The crop yields expected from cropping the proposed land utilization types are obtainable by applying the Nile water, which is classified as class C1-S1 irrigation water according to the USDA, Salinity Laboratory [29]. In this case, as long as the Blue Nile water does not deteriorate in quality, neither the irrigation water will add substantial amounts of salts to set up salinity, nor will a secondary salinization be developed in the soil. However, the possibility for the emergence of salinity and/or sodicity in the soils of the project area cannot be dismissed.

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