MORPHOLOGICAL, PHYSICAL AND CHEMICAL CHARACTERIZATION OF SOILS REPRESENTING THE CLAY PLAINS OF THE SUDAN

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ABSTRACT

The morphological features and physico-chemical properties of seven pedons representing the major soil types in the clay plains of Sudan were studied. Soil profiles were dug in the clay plains of Sudan and seven profiles were selected in a transect from East of Rahad River, across Gezira, and west of the White Nile. The objectives were to investigate morphological features and physico-chemical characteristics of these soils, forms and soil samples according to genetic horizons. Twenty-eight soil samples and four genetic horizons were selected from the seven soil profiles; and were selected for morphological physical and chemical characteristics. The results showed that, these soils are deep with more than 150 cm depth, cracking surface, very dark grey 10YR3/1 to dark brown and well drained. Soil texture was clay with variation in relation to physiography (40-70), soil consistency was firm to very friable, and pH was alkaline 7.2 to 8.9 with low to high organic carbon of 0.03 to 1.3% and high CEC (53-89) c mol (p+) kg-1). The organic carbon content and CEC were higher in Rahad and Gezira soils which might be due to the clay translocation and organic carbon content accumulation. These soils had high cation exchange capacities due to the high clay content. Also, most were alkaline, non – saline with ECe (0.2-2.1dS m^{-1}) and non -sodic. The major pedogenic processes are illuviation/ colluviation.

Similarity the colour and texture of most of the soils indicated the dominant influence of parent material. Most of the studied sites were classified as Chromic Haplotorrerts and Typic Haplotorrerts and soils in the area belong to the order Vertisols

Keywords: Morphological, Physical, Chemical, properties, Vertisols, Clay plains, Sudan

1. INTRODUCTION

It is generally accepted that earth materials (fine earth) < 2mm effective diameter are known as soils. The sand fraction (2 to 0.02mm) is usually composed of primary minerals; the silt fraction (0.02 to 0.002 mm) are also mostly primary minerals whereas the clay fraction (<0.002 mm) are secondary minerals except for rare cases of weakly weathered soils (Bohn *et al.*, 1979). The central clay plains is located at (Latitudes 10° and 16° N and longitudes 32° and 37° E), in Republic of the Sudan. It is covers the areas between the White Nile and Blue Nile. The parent materials of the clay soils which cover almost this entire area belong to two broad groups: alluvial, deltaic and paludal sediments from rivers belonging to the Nile system (aggradational clay plains), and colluvial-alluvial deposits derived from local rock weathering, pediplanation and short-distance transport (degradational clay plains), (Worral, 1956). Man is dependent on soil because he obtains all the basic necessities of life like food, fiber, shelter from it, but good soils are also dependent on human civilization. Due to the intimate relationship of man's prosperity with soil, it is very essential that unwise exploitation and misuse of soils be avoided. The knowledge of the soils in respect of its origin and formation, nature and properties and distribution becomes imperative in this connection. Such information's are not only useful in agriculture but are equally important for foresters, geologists and engineers for land use planning and soil management etc. Knowledge of the kinds and properties of soils is critical for decision making with respect to crop production and other land use types. It is through precise measurement and full understanding of the nature and properties of soils as well as proper management of the nutrient and moisture requirements that one can maximize crop production to the allowable potential limits (Esayas *et al.*, 2006). In order to evaluate the quality of our natural resources and their potential to produce food, fodder, fiber, and fuel for the present and future generations, detailed information on soil properties is required. Assessment of soil for land use planning is increasingly important due to increasing competition for land among many land uses and the transition from subsistence to market based farming in many countries (Blum *et al.*, 2003). Soil characterization is required to classify soil and determine chemical and physical properties not visible in field examination (Buol et *al.*, 2003). The study areas are from the most important agricultural regions in Sudan. Thus, the study objectives are to study their morphological, physical and chemical properties of soils representing the clay plains of the Sudan, according to their genetic horizons.

2. MATERIALS AND METHODS

2.1 Location

The study area was located in the clay plains of Sudan and in a selected transect East of Rahad River, across Gezira, West of the White Nile and further South in Malakal. The studied profiles were selected to represent the Rahad (profiles R-1 and R-2), Gezira (profiles G-1 and G-2), and White Nile (profiles W-1and W-2) and Malakal (profiles M-1). Geographical Positioning System (GPS) readings were taken for reference purposes. Table 1 describes some pertinent site features of the studied area.

Table 1. General description of the research area.

Location	Pedons	Coordinates (GPS)	Slope	Surface Cracks	Drainage Classes	Land use	Landform
Rahad	R- 1	1580487 N 0598235 E	0-1%	75 mm	Moderate-well drained	S&F	Plain
Rahad	R-2	1590775 N 0643104 E	0-1%	77 mm	Moderate-well drained	S&F	Plain
Gezira	G-1	1575275 N 0531909 E	0-1%	80 mm	Moderate-well drained	S,C,G&Gr	Plain
Gezira	G-2	1581936 N 0556520 E	0-1%	80 mm	Moderate-well drained	S,C,W,&F	Plain
White Nile	W-1	1545061 N 0418121 E	0-1%	70 mm	Moderate-well drained	S,W&F	Plain
White Nile	W-2	1547331 N 0435851 E	0-1%	-	Moderate-well drained	S&F	Plain
Malakal	M	1065365 N 0359225 E	0-1%	70 mm	Moderate-well drained	None	Plain

* S= Sorghum, C=Cotton, W=Wheat, G=Groundnut, F=Fallow and Gr= Grazing

2.2 Climate

According to Wad Medani Meteorological Station and van der Kevie (1976). The study area lies in the arid zone. Table 2 shows the essential climatic features of the study area. The data show that the average annual rainfall is variable. Generally, across the transect from White Nile to Rahad the rainy season extends from mid July to October and reaches its peak in August (Table 2.). The average total annual rainfall in the area is about 281 mm. The annual potential evapotranspiration is very high and is about 241 mm. The mean relative humidity is generally low of a value 41% and reaches a peak during the rainy season of 68%, but is only about 21% throughout the rest of the year. There is relatively great direct control of air and soil temperature by solar radiation. Average solar radiation is about 77 % and reaches up to 88% during December and January. Meanwhile, average annual temperature is about 28.7^0 C this reaches its an average maximum in May of about 41.5^0 C and lowest values in January of about 14.1^0 C During most of the year the prevailing wind blows from the northern direction except in the rainy season where the south-western wind prevails with a mean speed of about 2.2 m/s. Malakal receives an average of 783mm of rainfall per year (or 65mm per month, on average there are 79 days per year with more than 0.1mm of rains (precipitation) or 7 days with a quantity of rain per month). The driest weather is in January and February when an average of zero rainfall (precipitation) occurs. The wettest weather is in August when an average of 167mm of rainfall occur across 17 days. The average temperature in Malakal is 28^0 C, the highest monthly average temperature is 39^0 C in March: the lowest monthly average temperature 18^0 C in December. The average annual relative humidity is 38.9% and the average monthly relative humidity ranges from 16% in February to 65% in August. Average sunlight hours in Malakal range between 5.0 hours per day in July and 9.9 hour per day in January: there are averages of 2798 hours of sunlight per year with an average of 7.7 hours of sunlight per day. (Sudan Meteorological Service, 1971-2000).

Table 2. Wad Medani Climatologically Normals for the Years, 1971 – 2000.

Month	1	2	3	4	5	6	7	8	9	10	11	12	Year
MMax T (ºC).	32.9	37.1	33.7	36.7	36.3	36.2	35.1	36.6	40.3	41.5	41.2	38.1	34.7
MMin T (ºC)	14,1	20.4	15.4	18.4	22,0	22.3	22.6	23.4	25.1	24.6	21.8	18.9	15.9
MAT (ºC)	23.5	28.7	24.5	27.5	30.1	29.2	28.8	30.0	32.7	33.1	33.5	28.5	25.3
AR (mm)	-	280.7	-	1.3	11.1	48.6	102.1	77.6	22.6	16	1	-	-
SH (%)	88	77	88	88	79	71	61	55	70	74	83	84	83
MWS (m/s)	2.19	2.2	2.19	2.19	1.4	2.19	2.2	3.1	3.1	2.2	2.19	2.19	2.2
MRH (%)	34	41	37	36	50	65	68	59	42	32	21	22	27
PE (mm)	161	2304	158	171	167	171	164	192	234	241	231	217	176

Source: Sudan Meteorological (1971-2000); MRH = Mean Relative humidity (%); PE = Potential evapotranspiration; MWS = Mean wind speed (m/s); AR = Annual rainfall (mm); MAT = Mean Annual Temp (^{0}C); MMin T = Mean minimum temp.(^{0}C); MMaxT = Mean maximum temp (^{0}C); SH = sunshine hours (%).

2.3 Soil sampling

Soil samples were collected from seven soil sites representing the clay plain. The soil profiles were studied in the field and described following the format Guideline of Soil Profile Description FAO (1975). The soil samples were collected according to genetic horizons and classified following the USDA Soil Survey Staff (1999). The soil samples collected were air dried and crushed using a wooden mortar and pestle and sieved to pass a 2 mm sieve. These samples were used for chemical and physical analyses

2.4 Chemical and physical analyses

The soil samples were saved at room temperature and analysed according to the methods used in the laboratory of Land and Water Research Centre, (LWRC) Agricultural Research Corporation (ARC) Wad Medani, Sudan. Particle size distribution was determined following the pipette method (Jackson, 1958). Electrical conductivity was determined (SCS, 1972). Calcium carbonate equivalent values were obtained using the acid neutralization method (Richards, 1954). Soil pH was measured according to the methods of McLean (1982). Organic matter, was determined by Walkley –Black procedure (Jackson, 1958). Total nitrogen was determined by the micro-Kjeldahl procedure as outlined by (Jackson 1958). Available phosphorus was extracted (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 EDTA. Exchangeable Sodium Percentage (ESP) was calculated using the following equation :

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

Sodium Adsorption Ratio (SAR) was calculated from the soluble cations by the following equation:

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

3. RESULTS AND DISCUSSION

3.1 Morphological characteristics

The landscapes of the studied soils are colluvium/alluvium depositions situated on the flat plain, (slope ≤ 1%). There is surface mulch of 2 to 3 cm thick for Rahad and Gezira soils only. Bundey and Westin (1965) showed that colour gradation is a good criterion for interpreting drainage conditions among soils. All the soils are considered to be moderately well drained. The dominant colour is very dark greyish brown to dark brown ranging in Rahad, dark brown in Gezira and dark grey in both White Nile soils. The major morphological properties are present in table 3. The studied soils occur in arid zone. Cracks developed to a depth more than 1 meter (125cm) in most the studied sites. Their width at the surface range from 3cm to 8cm. Slickensides were observed in the studied soils. The paralleled structure was attributed to the soil texture, swelling and shrinkage in these soils. The mulching effect can hide the surface cracks.

Table 3. Morphological Characterization of Soils

Site (Pedons)	Depth (cm)	Mussel colour (Moist)	Texture	Structure	Consistence (Moist)	Roots	Boundary
R-1	0-40	10YR3/2	C	mo m sbk	firm	c f	c s
	40-80	10YR3/2	C	mo m sbk	firm	c f	c w
	80-125	10YR3/2	C	f m sbk	firm	-	c s
	125-175	10YR3/2	C	ma	firm	-	c s
R-2	0-35	10YR4/3	C	mo m p sbk	firm	fe f	c w
	35-60	10YR4/2	C	mo m p sbk	firm	fe f	c w
	60-100	10YR4/3 &10YR3/2 (50%)	C	moa sbk	firm	Fe f	c w
	100-130	10YR3/2	C	ma	firm	fe f	g w
G-1	0-50	10YR3/2	C	mo m sbk	friable	v fe f	c s
	50-90	10YR3/2	C	mo m sbk	firm	fe f & m	c w
	90-120	10YR3/1	C	mo m a	firm	fe f& m	c s
	120-150	10YR3/1	C	ma	firm	v fe f	c s
G-2	0-25	10YR4/3	C	mo m sbk	firm	c f & m	c w
	25-55	10YR4/3	C	mo m sbk	firm	fe f &	c w

						m	
	55-80	10YR4/3	C	mo m a b	firm	-	c s
	80-120	10YR3/2	C	ma	firm	-	c w
W-1	0-35	10YR4/1	C	mo v c p/c m sbk	very friable	c f & m	c w
	35-55	10YR4/1	C	mo m c sbk	very friable	fe f	c w
	55-90	10YR4/1(70%)& 10YR3/1(30%)	C	w f m sbk	friable	-	g s
	90-115	10YR4/1	C	w m sbk	friable	-	g s
W-2	0-20	10YR5/2	C	mo c sbk	firm	fe f	c w
	20-35	10YR4/2	C	w f m sbk	firm	fe f	c w
	35-55	10YR3/2	C	w f m sbk	firm	-	c w
	55-80	10YR3/2	C	ma	firm	-	c w
	80-100	10YR4/3	SC/SL	ma	firm	-	c s
M-1	0-28	10YR3/2	C	mo m sbk	firm	c f	c w
	28-65	10YR3/2	C	mo m sbk	firm	fe f	g s
	65-103	10YR3/2	C	m f sbk	firm	v fe f	c w
	103-140	10YR3/1	C	ma	firm	-	c g w

Mussel colour (Moist): Very dark greyish brown = (10YR3/2); Dark greyish brown= (10YR4/2); Dark brown= (10YR4/3); Very dark grey= (10YR3/1); Dark gray= (10YR4/1); Greyish brown (10YR5/2. Texture: c=clay. Structure: mo=moderate; m=medium; sbk=subangular blocky; f=fine; ma=massive; p=prismatic; c=coarse; w=weak; a= angular; b=blocky. Roots: c= common; f=fine; v=very fe= few m=medium. Boundary: C=Clear; W=wavy; S=Smooth; G=gradual.

3.2 Physical characteristics

The physical properties of the seven soils profiles are shown in Tables 4. The higher clay content (>46%) was associated with greater water holding capacity, swelling and shrinking when wet and dry. Results of mechanical analysis of the Gezira soil profiles indicate that the total clay content increases slightly with depth as found by Said (1975) and Fadl (1971). The increase of clay with depth is probably due to in-situ clay synthesis (weathering). The White Nile soils are also clay soils except the lower horizons which have the highest percentage of sand (67%) giving a sandy clay loam texture. This may indicate a difference in the source of the parent material from the Gezira soils. In the profile W-1 the clay content increases with depth till the 155 cm depth, while silt decreases with depth. Grain size (particle size in soil) distribution is one of the most important characteristics of sediment. This is true because grain size is a powerful tool for describing a site's geomorphic setting, interpreting the geomorphic significance of fluid dynamics in the natural environment, and distinguishing local versus regional sediment transport mechanisms as well because grain size is a dominant controlling factor in sediment geochemistry. Large particles are usually heavier than small ones, and take more energy to move around.

A very strong wind is needed to move sand-sized grains while a trickle of water moves them easily. Since it takes more energy to move water than air, the moving water already contained more energy than the wind. Water energy is supplied by gravity, as the water flows from high elevations to lower elevations. This may indicate that the sources of the parent materials of these soils are Ethiopian highlands.

ISSN: 2455-7668

Table 4. The physical and chemical properties of studied sites.

Site	Depth (cm)	Particle-size distribution (%)				pH 1:5	ECe dS m^{-1}	Organic carbon	Total N	C:N	CaCO^{-3}	P mg kg^{-1} soil	Extrac Exchangeable Cation (cmol(+) kg^{-1})				CEC (cmol (+) kg^{-1})	ESP %	SAR
		Sand	Silt	Clay	Soil Texture			%					Ca	Mg	K	Na			
		%																	
R-1	0-40	7	21	72	C	8.1	0.2	1.33	0.055	24	6.0	7.0	1.0	0.5	0.73	3.73	87	4	1
	40-80	6	22	72	C	8.0	0.2	1.23	0.063	20	5.0	7.6	1.5	0.0	0.40	3.09	89	3	1
	80-125	7	23	70	C	8.0	0.3	1.19	0.044	27	7.0	8.4	1.5	0.0	0.36	3.23	88	4	2
	125-175	5	22	73	C	8.0	0.3	1.27	0.044	29	5.0	8.4	1.5	0.0	0.38	3.85	89	4	2
R-2	0-35	7	21	72	C	7.9	0.2	1.25	0.076	16	3.0	9.4	1.5	0.0	0.9	3.35	83	4	1
	35-60	6	22	72	C	8.1	0.2	0.89	0.057	16	4.0	9.6	1.0	0.5	0.76	2.62	89	3	1
	60-100	7	23	70	C	8.0	0.2	1.11	0.044	25	4.0	9.0	1.5	0.0	0.64	2.80	89	3	1
	100-130	5	22	73	C	7.6	1.9	1.33	0.041	32	3.6	9.0	6.0	2.0	0.61	7.05	82	9	6
G-1	0-50	27	22	51	C	7.9	0.5	1.16	0.036	29	3.0	7.40	2.5	0.0	0.55	3.06	64	5	3
	50-90	25	20	55	C	8.1	0.3	1.27	0.044	29	2.6	13.0	1.5	1.0	0.45	2.68	76	4	2
	90-120	16	26	58	C	8,1	0.6	1.19	0.050	24	2.8	10.4	2.0	0.5	0.43	4.74	81	6	4
	120-150	16	23	61	C	7.9	0.3	1.11	0.037	30	4.0	24.8	1.5	1.0	0.45	2.85	85	3	2

G-2	0-25	11	24	64	C	8.1	0.5	1.076	0.041	26	1.8	15.0	2.5	0.0	0.76	3.69	85	4	2
	25-55	9	28	63	C	8.1	0.2	1.023	0.044	23	1.2	7.4	1.5	0.0	0.66	2.63	84	3	1
	55-80	6	25	69	C	7.8	0.3	1.201	0.038	32	8.0	5.0	1.0	0.5	0.51	3.05	78	4	2
	80-120	4	26	70	C	8.1	1.4	1.060	0.053	20	7.0	7.0	5.5	1.5	0.51	6.77	81	8	8
W-1	0-35	8	29	63	C	8.9	0.3	0.060	0.038	28	4.0	8.4	1.5	0.5	2.88	1.25	87	3	2
	35-55	8	26	66	C	8.2	0.9	0.488	0.047	32	7.0	6.2	3.0	1.0	3.65	1.10	84	4	4
	55-90	6	23	71	C	7.8	1.5	0.03	0.034	30	7.0	5.4	4.0	2.0	5.89	1.01	89	7	5
	90-115	7	19	74	C	8.0	2.1	0.983	0.036	27	6.0	6.2	5.0	2.5	6.13	1.10	86	7	7
W-2	0-20	34	24	42	C	8.3	1.40	0.983	0.035	28	6.0	9.8	1.5	0.5	0.69	2.12	48	4	3
	20-35	30	25	45	C	8.4	1.32	0.030	0.045	23	5.0	8.0	3.0	1.5	0.46	7.18	53	14	12
	35-55	33	18	49	C	8.5	1.36	0.092	0.037	30	4.0	6.6	12.0	6.5	0.44	11.36	60	19	17
	55-80	28	17	55	C	8.6	1.33	0.967	0.043	22	5.0	6.2	13.0	5.0	0.36	16.14	71	23	21
	80-100	67	13	20	SCL	8.7	1.38	0.014	0.027	38	6.0	6.4	3.0	0.5	0.19	7.63	47	16	14
M-1	0-28	27	25	48	C	7.2	0.2	0.874	0.054	10	4.0	1.8	1.0	0.5	1.5	0.5	47	2	1
	28-65	31	24	45	C	7.8	0.3	0.0499	0.049	10	2.4	2.8	1.0	0.5	3.0	1.5	46	2	2
	65-103	27	25	48	C	8.5	0.2	0.468	0.036	13	1.6	2.6	1.5	0.0	12.0	6.5	48	1	1

103-140	24	26	50	C	8.3	0.2	0.452	0.035	13	1.2	2.4	1.5	0.0	13.0	5.0	53	2	1

3.3 Chemical characteristics

The chemical characteristics are presented in Tables 4. All the investigated soils have pH paste values ranging from 7.6 to 8.2, indicating that these soils are slightly to moderately alkaline with the exception of the neutral surface of Malakal soil (pH 7.2). The White Nile soils have moderately to strongly alkaline reaction (pH paste 8.3 to 8.9). The relatively higher alkalinity is probably related to high concentration of calcium carbonate ions, which ranges between 4-6% in the profile (W-2). The ECe of all soils under investigation classifies them as non-saline (<4 dS m^{-1}) with exception of the subsoil of W-2 (8.2 dS m^{-1}). Similarly, all the soils are non- sodic (ESP <15, SAR <13) except the soil from the White Nile (W-2) which registered the highest values (ESP 23, SAR 21).

The cation exchange capacity (CEC) of the studied soils ranges from 82 to 89 cmol (+) kg^{-1}soil. Also, the cation exchange capacity value indicate the soils fertility potential. These high values CEC/clay are probably due to the high content of clay in these soils; mostly could be related to 2:1 expanding clays with dominant smectites clay minerals, except the subsoil of W-2 (47 to 50 cmol $^{(+)}$ kg^{-1}soil). In general, it is accepted that soils of the arid and semi –arid regions usually contain low content of both organic matter (organic carbon) and nitrogen, with organic carbon percentage of < 1. All the studied soils are low in nitrogen content ranging from 0.01 to 0.07 %. This could be attributed to the prevailing dry condition where the biomass production is low and mineralization rate is high.

Available phosphorus ranging from 5.0 to 9.8 mg P kg^{-1} soil in most of the soils horizons, except the lower depth of R-2 23.4 mg P kg^{-1} soil, G-1 which has the high value more than R-1 and R-2 except G-1 the top horizon has the lower 7.5 mg P kg^{-1} soil and G-2 which has high value in the top horizon 15 mg P kg^{-1} soil. Available phosphorus in R-1 increases in amount with depths, but the other soils it irregular when it is compared to R-1, this probably due to more prolonged weathering. The Malakal soil has the lowest amount of available phosphorus ranging between 0.6-2.8 mg P kg^{-1} soil. The values were low to support the growth of most plant. Hence, proper application of phosphorus fertilizer must be suggested in these studied soils. Calcium carbonate is uniformly distributed in all the soil profiles. This could be attributed to the low leaching processes because of the high clay content of these soils. It is apparent that the soil of White Nile has the highest percentage of $CaCO_3$ which ranges from 4-7, while in Gezira 1.2-8. The Rahad and Malakal soils have lesser amount $CaCO_3$ than Gezira and White Nile. Generally, Vertisols showed similar morphological, physical and chemical properties (Table 3.) in the studied soil due to similar parent material, topography and climate with exception of White Nile W-2. The soil taxonomy (Soil survey, 1999), of the studied site were classified as following Rahad R-1 was classified as Typic Haplotorrerts, Very fine, smectitic, isoheperthrmic; R-2 was classified as Haplotorrerts, Very fine, Smectitic, isoheperthrmic; Gezira G-1 was classified as Typic Haplotorrerts, Fine, smectitic, isoheperthrmic; G-2 was classified as Chromic Haplotorrerts, Very fine, smectitic, isoheperthrmic; White Nile W-1 Chromic Haplotorrerts, Very fine, smectitic, isoheperthrmic and W-2 was classified as Sodic Haplocambids, Fine clay, mixed, superactive

4. CONCLUSION

Thus, the present study clearly showed that soils are deep, having good drainage. The physical and chemical properties of studied soil are more or less similar; with the exception of Malakal site and part of the White Nile the remaining soils have been derived from the Ethiopian plateau which is dominated by basic and ultra basic rocks; these rocks give rise the dominance of smectites clays. Most of these soils are non-saline and alkaline with pH more than 7.6. The similar distribution pH value throughout the soil horizon in Rahad, Gezira and White Nile indicates the slow rate weathering and soil development in the studied area. The similar patterns of distribution for the electrical conductivity values indicate low leaching rate. These soils had high cation exchange capacity due to high clay content. Most of the studied site were classified as Chromic Haplotorrerts; Very fine, smectitic, isoheperthrmic; Typic Haplotorrerts; fine, smectitic, isoheperthrmic.

5. ACKNOWLEDGEMENTS

The Financial assistance from the Land and Water Research Centre of the Agricultural Research Corporation; the supervisory roles of Dr Fawzi Mohamed Salih and Dr. Elseir, Director, Land and Water Research Centre is greatly acknowledged.

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