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Selected morphological characteristics of soils from Gezira Vertisols, with particular reference to cracking

E.A. Elias[1], F.M. Salih[2], A.A. Salih[2], and F.Alaily[3]*

[1]Water Management and Irrigation Institute, University of Gezira, P.O. Box 20, Wad Medani, Sudan
[2]Land and Water Research Center, Agricultural Research Corporation, Wad Medani, Sudan
[3]Institut für Ökologie und Biologie, TechnischeUniversität - Berlin, Salzufer 11-12, 10587 Berlin, Germany

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A b s t r a c t. Three sites from the Vertisols of the central clay plains of Sudan representing northern, central and southern Gezira were examined in the field for different morphological characteristics at the end of the dry season. Trends of gradual changes in the soil morphological properties were observed as one moved from the North to the South in the region. Intensity of cracking increased, content of $CaCO_3$ and gypsum decreased and the size of prisms that form the prismatic structure increased from the North to the South. Similar trends were observed for soil colour, root distribution, contents of mineral fragments and soil acidity. It is suggested that these differences are related to the soil clay content and moisture regime. Approximated calculations of the volume of cracks based on the field measurements of these dimensions were made. It was also possible to study soil cracking behaviour between two irrigation treatments in the central Gezira. A non-crop condition was used in this study, as the pattern of cracking was followed only between two watering events on the bare soil.

K e y w o r d s: soil, Vertisols, cracks, Gezira, Sudan

INTRODUCTION

The Vertisols in Sudan comprise of, mainly, the central clay plain in addition to the southern clay plain and the Nuba Mountain clays. The central clay plains of Sudan is of special importance to the economy of the country as it hosts most of the important agricultural schemes. The part of the central clay plains that falls between the Blue and White Niles and is bordered to South by the railway line extending between Sennar and Kosti is called Gezira. The cropped area in Gezira constitutes no less than half of the total irrigated area of 1.8 Mha (Soil Survey Administration, 1983) in Sudan and produces cotton, the main cash crop in the country, and a considerable share of wheat and other crops. Gezira clay plain falls between the latitudes of 13°30´ and 15°30´ North and the longitudes of 32°30´ and 33°30´ East. The soils are predominantly typical Vertisols that expand and contract markedly with changes in moisture content and develop deep vertical drying cracks. These soils are developed from deposits carried by the Blue Nile from the Ethiopian Highlands. The Gezira clay plains show a gentle slope of 0.02% from the South to the North. The altitude changes from 410 m a.s.l. in the South to 200 m in the North. Temperature varies from 20 to 37°C. The rainy season extends from July to October with an annual rainfall of 450 mm in the South and 200 mm in the North. The rainfall at Wad Medani is 400 mm per annum. Clay content may reach 60% or more throughout the soil profile. The dominant clay minerals are smectites (Adam *et al*., 1983; Blokhuis, 1993; Blokhuis *et al*., 1964; Fadl, 1971). Soil pH is between 8 to 9.5 with little change below the soil surface (Robinson *et al*., 1969). The soil content of organic carbon and nitrogen is very low. The remaining natural vegetation cover is a scatter of *Acacia spp* with grasses and annual herbs. The Gezira is mainly used for agriculture which has started in the region in the year 1911 with a pilot farm at Taibah using water pumped out of the Blue Nile. Irrigation in Gezira, now, is through gravitational flooding by water from the Blue Nile. A major canal carries water from Sennar dam to the north to irrigate the whole of the scheme.

The mineral composition of these soils leads to the swelling of clays when water is absorbed by 2:1 clay minerals. When the moisture content decreases, the soil matrix starts to shrink. At the point when the force holding soil aggregates and particles together is less than the tensile

*Corresponding author e-mail: eltijanielias@yahoo.com

stress, cracks are formed. The cracks of dry soil are an important property of Vertisols development and, therefore, they are considered as important in the classification of these soils. Soil cracks allow for deep water penetration in Vertisols. This penetration is rapid and only exists for a short time as cracks do close quite fast specially in the case of the Gezira Vertisol (Blokhuis, 1985; Farbrother, 1996). Soil cracking is thus a source of an important hydraulic conductivity. Ritchie *et al*. (1972) highlighted the fact that hydraulic conductivity of these soils could be greatly underrated when taken as that fraction due to small pores alone.

Cracks in these soils cause huge losses of irrigation- or rain-water through evaporation from the cracks surface, a process of high relevance to irrigation schedules. Cracks are also a reason for a considerable increase in the irrigation water requirements of crops in the first irrigation (Farbrother, 1996; Zein El Abedine *et al*., 1971). However, quantitative analysis of clay minerals may be useful in predicting cracking intensity in the swelling shrinking soils.

This study aimed at reflecting an image of the soil morphology and a better understanding of cracking phenomena. Results reported in this work include basic morphological observation reported as in the field at the time of sampling selected plots of Vertisols in the Sudan Gezira. The study also gives a report on the cracking intensity between two irrigation treatments. Basic analytical data and a detailed study of dry season cracks have already been published (Elias *et al*., 2001).

MATERIALS AND METHODS

Soil profiles from the Gezira clay plains were examined in the field. The studied profiles were selected to represent the northern Gezira (Wad Shair) profile NG, the central Gezira (Wad Medani) profile GRS and the southern Gezira (Gondal) profile SG. Location of sites in the Gezira region is shown in Fig. 1. Table 1 summarises information on the sampled sites, mainly with regard to their history of land use.

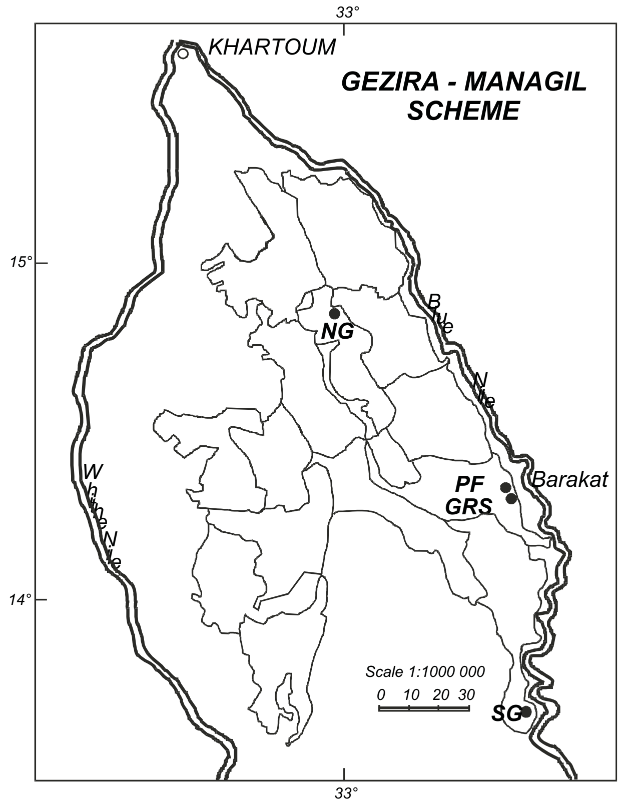

Fig. 1. Location of study sites in the Gezira part of the central clay plains of Sudan.

T a b l e 1. Last irrigation date, crop of last season and length of dry period before sampling in the three study sites

Location	North	Central	South
Symbol	NG	GRS	SG
Date soil pit dug	21/4/99	19/4/99	20/4/99
Date examined	21/4/99	19/4/99	20/4/99
Approx. No. of irrig. seasons	73	73	73
Parent material	Blue Nile alluvial	Blue Nile alluvial	Blue Nile alluvial
Rainfall (mm)	292	354	430
Temperature (°C) (mean annual)	36.2	36.7	36.7
Physiography	Plain	Plain	Plain
Slope	15 cm/1000 m	15 cm/1000 m	15 cm/1000 m
Crop Rotation*		Cotton; Groundnuts; Wheat; Dura; Fallow	
Last crop	Dura	Wheat	Dura
Last irrigated	Oct. 1998	Feb. 1999	Oct. 1998

* Crop rotation applies to all sites.

Selected sites differ in particle size distribution with clay content increasing from the north to the south (Table 2). The natural regime of soil water is also different as rainfall increases from the north to the south. The studied sites are on flat areas, with a slope of 1% or less. Land use in profiles NG and SG is according to the Gezira Scheme rotation while profile GRS was in a plot of the Gezira Research Station farm. Each profile was divided into horizons according to the dry soil structure or according to other visible features. When a layer was moist, the soil consistency was used to differentiate between horizons. The profiles were described according to FAO (Food and Agriculture Organization of the United Nations, 1977). The reported observations included soil colour (using Munsell's colour chart), texture, structure, consistency, soil pores, mineral fragments, content of roots, boundaries between horizons, soil pH and intensity of cracking. The soils were tested for the possible presence of $CaCO_3$ using HCl.

T a b l e 2. Electrical conductivity (EC), pH, organic carbon and clay content of the studied soils

Depth (cm)	EC (μS cm^{-1})	pH	Organic C (g kg^{-1})	Clay (%)
		North Gezira		
0-25	243	8.4	4.79	40
25-45	407	8.9	4.01	42
45-70	700	9.0	2.46	43
70-90	943	8.7	5.31	47
90-110	924	8.6	5.54	49
110-150	914	8.8	3.99	45
		Central Gezira		
0-10	325	7.4	6.35	52
10-35	275	8.4	5.44	55
35-65	490	8.9	4.79	56
65-85	731	8.7	5.96	55
85-115	1371	8.3	6.30	58
115-150	3605	7.6	6.43	58
		South Gezira		
0-3	651	7.4	7.50	57
3-35	406	8.5	4.99	58
35-88	597	8.6	6,00	59
88-110	1893	7.9	8.81	63
110-150	1895	7.7	8.38	65

Intensity of cracking at the end of the dry season was assessed on the basis of direct measurements of cracking dimensions in a sample area of 4 m^2 duplicated in each site. Cracking patterns between two irrigation treatments were also studied. A plot in the Gezira Research Station was ploughed and leveled and divided into 14 sub-plots. These sub-plots were irrigated once a day. On the 14th day, the volume of cracks developed between the first and second irrigation was measured in all 14 sub-plots. The volume measured was that equivalent to the volume of very fine sand required to fill the cracks formed in the area selected.

RESULTS AND DISCUSSION

Morphological characteristics

All sites were examined at the end of April. It idea was to examine the study sites at end of dry season to assess cracking intensity. Information on the sites and description of profiles are given in this text.

The adopted soil classification in Gezira is the US taxonomy (Soil Survey Staff, 1975) which classifies profile GRS as fine, montmorillonitic, isohyperthermic, a typical Chromusterts, profile SG as a very fine profile of the same class and profile NG as fine, montmorillonitic, isohyperthermic, a typical Torrerts. According to the FAO (FAO-ISRIC ISSS, 1998), all three profiles are Calcic Vertisol while FAO (Food and Agriculture Organization of the United Nations, 1974) classifies these soils as chromic Vertisols.

Change in the pH level of 0.5 unit or more was noted in the profile NG in the North of Gezira when moving from the surface at 25 cm (pH 7.7) to deeper layers where pH reached 8.4 in the layer at 45-70 cm of the profile. This same finding applies to the profile SG in the South of Gezira where pH was changing between 7.7 and 8.4. Change in pH down the profile in GRS was by 0.5 unit of pH or less. This little change in the soil pH, around pH 7.5 or more, confirms the results by Blokhuis *et al*. (1964).

Information on the sampled sites

Profile: NG
Location: Plot 4, Canal No. 2, Toris Block, Wadi Shair Group
Classification:
SSS (Soil Survey Staff, 1975): Fine, montmorillonitic, Isohyperthermic, Typical Torrerts
FAO (Food and Agriculture Organization of the United Nations, 1974): Chromic Vertisol
FAO (FAO-ISRIC ISSS, 1998): Calcic Vertisol
Parent material: the Blue Nile alluvials
Physiography: Plain
Slope: 1%
Drainage: Moderately well drained
Presence of surface stones: None
Evidence of erosion: None
Land use: Cultivated & Grazing
Last irrigated: October 1998
Date of examination: 21.04.1999

0-25 cm Brown (10YR5/3) dry, brown to dark brown (10YR4/3) moist; clay; moderately coarse and medium sub-angular blocky; hard dry, firm moist, sticky and plastic wet; few fine tubular pores; common fine and medium roots; common to few $CaCO_3$ gray nodules; few $CaCO_3$ white concretions; few weatherable mica; calcareous matrix; few cracks 0.5-2 cm wide; clear wavy boundary; pH-7.7.

25-45 cm Dark brown (10YR3/3) dry and moist; clay; weak coarse prismatic broken to medium and fine sub-angular blocky; hard dry, firm moist, sticky and plastic wet; few tubular pores; common fine roots; few $CaCO_3$ gray nodules; few crystals of gypsum; few very fine $CaCO_3$ concretions; calcareous matrix; few cracks 1-3 cm wide, pH-8.3.

45-70 cm Dark brown (10YR3/3) dry and moist; clay; weak medium and fine sub-angular blocky; very hard dry, very firm moist, sticky and plastic wet; common $CaCO_3$ white concretions; few gypsum crystals; common tubular pores, few fine roots, few pressure faces; calcareous matrix; few cracks 0.5-2 cm wide; gradually smooth boundary; pH-8.4.

70-90 cm Very dark grayish brown (10YR3/2) 60% and 40% brown to dark brown (10YR4/3) moist horizon; clay; weak fine and medium sub-angular blocky; slightly firm moist, sticky and plastic wet; common fine tubular pores, common $CaCO_3$ white concretions; few sandy grains; few to common gypsum crystals; few decayed roots; few very fine roots; calcareous matrix; gradually smooth boundary; pH-8.3.

90-110 cm Very dark grayish brown(10YR3/2) 80% and brown to dark brown (10YR4/3) 20%; moist horizon; clay; massive; friable moist , sticky and plastic wet; few large $CaCO_3$ spots; common fine and medium concretions of $CaCO_3$; common gypsum crystals; few fine tubular pores; calcareous matrix; clear smooth boundary; pH-8.2.

110-150 cm Heterogeneous colour (10YR3/2) 50%, (10YR3/4) 30% and (10YR4/4) 20%; clay; massive; firm moist, sticky and plastic wet; few fine tubular pores, no roots; many white patches of $CaCO_3$; many white concretions of $CaCO_3$; common gypsum crystals; calcareous matrix; pH-8.2.

Profile: GRS
Location: Agricultural Research Farm, Wad medani, Barakat Block, Central Group
Classification:
SSS (Soil Survey Staff, 1975): Fine, montmorillonitic, Isohyperthermic, Typical Chromusterts
FAO (Food and Agriculture Organization of the United Nations, 1974):Chromic Vertisol
FAO (FAO-ISRIC ISSS, 1998): Calcic Vertisol
Parent material: Blue Nile alluvials
Physiography: Plain
Slope: < 1%
Drainage: Moderately well drained
Presence of surface stones: None
Evidence of erosion: None
Land use: Research farm
Last irrigated: February 1999
Date of examination: 19.04.1999

0-10 cm Brown to dark brown (10YR4/3) dry and moist; clay; strong medium and fine sub-angular blocky; slightly hard dry, firm moist, sticky and plastic wet; common fine tubular pores; common $CaCO_3$ nodules; few shale fragments; Calcareous matrix; many fine and medium roots; clear wavy boundary; partially closed cracks (by mulch); pH-7.8.

10-35 cm Brown to dark brown (10YR4/3) dry and moist; clay; moderately very coarse prismatic structure broken to coarse and medium sub-angular blocky; hard dry, firm wet, sticky and plastic wet; common fine tubular pores; common $CaCO_3$ gray nodules; few sand grains; few shale fragments; few white soft $CaCO_3$; calcareous matrix; common fine roots and few medium roots; 2-3 cm wide cracks; clear wavy boundary; pH-7.9.

35-65 Dark brown (10YR3/3) moist (presence of residual moisture); clay; weak medium and fine sub-angular blocky; firm moist, sticky and plastic wet; few fissures; common fine tubular pores; few fine and medium roots; common $CaCO_3$ gray nodules; few shale fragments; few gypsum crystals; few white soft patches of $CaCO_3$; weak slickensides; calcareous matrix; gradually smooth boundary; pH-8.2.

65-85 cm Dark yellowish brown (10YR3/4) 60% and very dark grayish brown (10YR4/2) 40%; clay; weak medium sub-angular blocky; very firm moist, sticky and plastic wet; common fine tubular pores; few fine and medium roots; few $CaCO_3$ gray nodules; common white soft patches of $CaCO_3$; few crystals of gypsum; few pressure faces; few fissures (no cracks); calcareous matrix; gradually smooth boundary; pH-8.3.

85-115 cm Very dark grayish brown (10YR3/2) 80% and dark yellowish brown (10YR4/3) 20%; clay; massive structure; very firm moist, sticky and plastic wet; some fissures (no cracks); few $CaCO_3$ gray nodules; few gypsum crystals; common sot patches of $CaCO_3$; calcareous matrix; few medium roots; few shell fragments; gradually smooth boundary; pH-8.3

115-150 cm Very dark grayish brown to very dark gray (10YR3/1.5); clay; massive structure; firm moist, sticky and plastic wet; common fine tubular pores; no roots; common white patches of $CaCO_3$; common gypsum crystals; few $CaCO_3$ concretions; strongly calcareous matrix; pH-8.3.

Profile: SG
Location: Plot 3, Gondal canal, Gondal Block, Southern Group
Classification :
SSS (Soil Survey Staff, 1975): Very fine, montmorillonitic, Isohyperthermic, Typical chromusterts
FAO (Food and Agriculture Organization of the United Nations, 1974): Chromic Vertisol
FAO (FAO-ISRIC ISSS, 1998): Calcic Vertisol
Parent material: Blue Nile alluvial
Physiography : Plain
Slope: 1%
Drainage: Moderately well drained
Presence of surface stones: None
Evidence of erosion: None
Land use: Cultivated
Last irrigated: October 1998
Date of examination: 20.04.1999

0-3 cm Brown to dark brown (10YR3/3) dry and moist; clay; strong, medium and fine sub-angular blocky structure; slightly hard dry, firm moist, sticky and plastic wet; common fine and medium tubular pores; common $CaCO_3$ gray nodules; common fine and medium roots; calcareous; few sandy grains; few biological activity; common cracks 1-5 cm wide; wavy boundary; pH-7.7.

3-55 cm Dark brown (10YR3/3) dry and moist; clay; weak to moderately very coarse prismatic structure broken to a very coarse sub-angular blocky; very hard dry, very firm moist, sticky and plastic wet; common fine tubular pores; common very fine roots and few medium; common $CaCO_3$ gray nodules; very fine $CaCO_3$ white spots and concretions; few shell fragments; few biological activity; clear wavy boundary; common cracks 2-5 cm wide; pH-8.4.

55-88 cm Dark yellowish brown (10YR3/4) moist 60% and very dark grayish brown (10YR3/2) moist 40%; moist horizon; clay; weak medium and fine sub-angular blocky; firm most, sticky and plastic wet; few to common fine tubular pores, few $CaCO_3$ gray nodules; few shell fragments; common white soft patches of $CaCO_3$, common pressure faces; weak slickensides; calcareous matrix; few cracks 0.5-2 cm wide; gradually smooth boundary; pH-8.3.

88-110 cm Very dark grayish brown (10YR3/2) moist 70% and 30% dark yellowish brown (10YR3/4) moist; moist horizon; clay; massive to weak medium and fine sub-angular blocky; slightly firm moist; sticky and plastic wet; few white concretions and patches of $CaCO_3$; few fine tubular pores; few shell fragments; few biological activity (cortivina); calcareous matrix; few cracks 0.5-1 cm wide; gradually smooth boundary; pH-8.2.

110-160 cm Very dark grayish brown (10YR3/2) moist; clay; massive; friable moist, sticky and plastic wet; common fine tubular pores; few fine hair roots; common white patches and white concretions of $CaCO_3$; weak slickensides; no cracks; calcareous matrix; pH-8.2.

Soil structure was used as a base for differentiation between surface horizons in the profiles. The surface horizons of the profile GRS and that of the SG, were of medium and fine sub-angular blocky structure. In the profile NG, the sub-angular blocky structure was moderately coarse. Thickness of this horizon was 25, 10 and 3 cm in the three profiles from the North to the South. The subsurface horizon is harder than the surface. This could possibly be due to a plow layer at 3-55 cm and the 25 to 45 cm profiles SG and NG, respectively. Although the relatively harder horizon of 65-85 cm in the profile GRS is deeper than a plow layer but it coincides with the depth of the maximum possible penetration of cotton roots in these soils (Farbrother, 1996).

Concerning carbonate content of the three profiles under study, few to common gray nodules or soft patches of $CaCO_3$ were noted in the central and southern Gezira profiles. In the profile NG in the North of the region, $CaCO_3$ gray nodules were accompanied by white concretions and white soft patches of $CaCO_3$. The carbonate content of this soil was increasing deep down the profile. Few gypsum crystals were observed in the 35-115 cm horizon of the profile GRS and increased in intensity in the horizon of 115-150 cm. In the NG profile, the presence of gypsum crystals was common and increased down the profile. Gypsum crystals were not observed in the South of Gezira as this is an area of relatively higher precipitation. Hence leaching of gypsum out of the profile is possible. Carbonate distribution in the soil profile fits well with expectations for these semi-arid soils (Yaalon, 1982) as carbonates remain on or close to the surface with the carbonate front retreating deep down the profile with increase in rainfall.

Intensity of cracks in dry soils

Intensity of cracking at the end of the dry season was elaborated in the previous paper (Elias *et al*., 2001). The measured distance between cracks decreased from 105 cm in the NG to 85 cm in the GRS and to 50 cm in the SG. The maximum cracks depth in the three profiles was 38, 70 and 78 cm from the North to the South. The measured cracking width at the soil surface was 3, 5 and 8 cm in the three sites form the North to the South. It worth mentioning here that the cracks width and depth as measured in this study, seemed to be less than the actual dimensions. This is because some material from the soil surface were dropping into the bottom of the cracks decreasing the actual depth, and some of mulch and other materials at the soil surface decreased cracks width. The most frequently found dimensions for soil blocks contained within cracks was 100×105 cm in the profile NG, 58×85 cm in the GRS and 40×50 cm in the SG. The present study was undertaken at the end of the dry season when only major cracks were present and all small cracks of less than 0.5 cm width were closed. It is worth mentioning here that although the field study was undertaken at the end of the dry season, residual moisture from the last rain or irrigation resulted in an underestimate of the cracks dimensions even when dug out profiles were examined. It was also observed that the shape of soil blocks contained within the nets of cracks was not always polygonal. In some cases, these blocks had a square shape especially in the South of Gezira as demonstrated by the photograph (Fig. 2). Discussions on the cracks volume at end of the dry season and its implication on water movement were highlighted in other publications (Elias *et al*., 2001).

Fig. 2. Square-shaped soil blocks in the southern Gezira.

Dynamics of cracking between two irrigation treatments

It was observed that the number of cracks increased in the first three days after irrigation with cracks having a width of <0.5 cm. After that, the number of cracks per unit area decreased and the cracks dimensions increased. It seemed in the Gezira conditions, when wider cracks were formed, smaller cracks were closed. This was shown in Table 3 and Fig. 3, where the number of cracks intersecting with a meter tape diagonally crossing the sampled area decreased with an increase in the number of days after irrigation. The above was accompanied with an increase in the cracks width. The volume of cracks between irrigation treatments was continuously increasing, and was 53, 59, 67, 130 and 148 m^3 ha^{-1} at day 3, day 5, day 7, day 13 and day 14 after irrigation, respectively. It was also observed that cracking in these soils started immediately after irrigation provide no standing water was left. With evaporation, the

T a b l e 3. Number and the maximum width of cracks intersecting with a meter tape diagonally crossing the sampled area and cracks volume (m^3 ha^{-1}) on different days after irrigation

Days after irrigation	No. of cracks	Width of cracks (cm)	Volume of cracks (m^3 ha^{-1})
1	0	0	0
3	19	>0.5	53
7	13	up to 1 cm	67
12	4	up to 1.5	130

soil continued to crack which led to a substantial increase in total surface exposed to evaporation and, hence, wider cracks. This is particularly so as the temperature of the soil surface in Gezira may reach up to 50°C and sun rays could reach down to the bottom of cracks leading to higher evaporation from the cracks' surfaces. Figure 4 shows changes in the cracks' volume resulting from moisture changes as a result of evaporation alone. The shape of the curve will not change if the soils under vegetative cover were considered and in this case additional water losses resulting from transpiration would yield higher cracks volume.

Patterns of cracking within an irrigation cycle may lead to the conclusion that the importance of large cracks at the end of the dry season was restricted to the first irrigation. An effect which is manifested mainly in the amounts of water required for this irrigation and conditions after the first irrigation remained within a normal cycle of cracks between irrigation treatments.

Cracks occurring between irrigation treatments were still the source of huge extra losses of water through evaporation from the cracks' surfaces. Cracks measured after watering a plot under no crop conditions represented a fraction of cracks generated by water losses through evaporation alone, when transpiration was not considered. Cracks under conditions of a very shallow rooting crop like wheat under the conditions of Gezira may be close to this type, especially when the crop was well established and acted as a cover reducing evaporation losses. However, Farbrother (1996) showed that the cracks that occur between irrigation treatments under a fully established cotton crop in the central Gezira, reached the depth of about 60 cm, the depth to which cotton roots may penetrate.

Fine cracks and fissures are found to be present at all the studied sites. The above findings were different from those reported by Grossman *et al.* (1985) which are known to develop only at the tension level higher than 1500 kPa. This study did not give much of weight to these small cracks and fissures as ultimately they do close when larger cracks are formed. It is also conceivable that the contribution of these 2-5 mm wide cracks to the total volume of cracks in the soil could be negligible when compared to the cracks of 100 cm deep 6-12 cm wide.

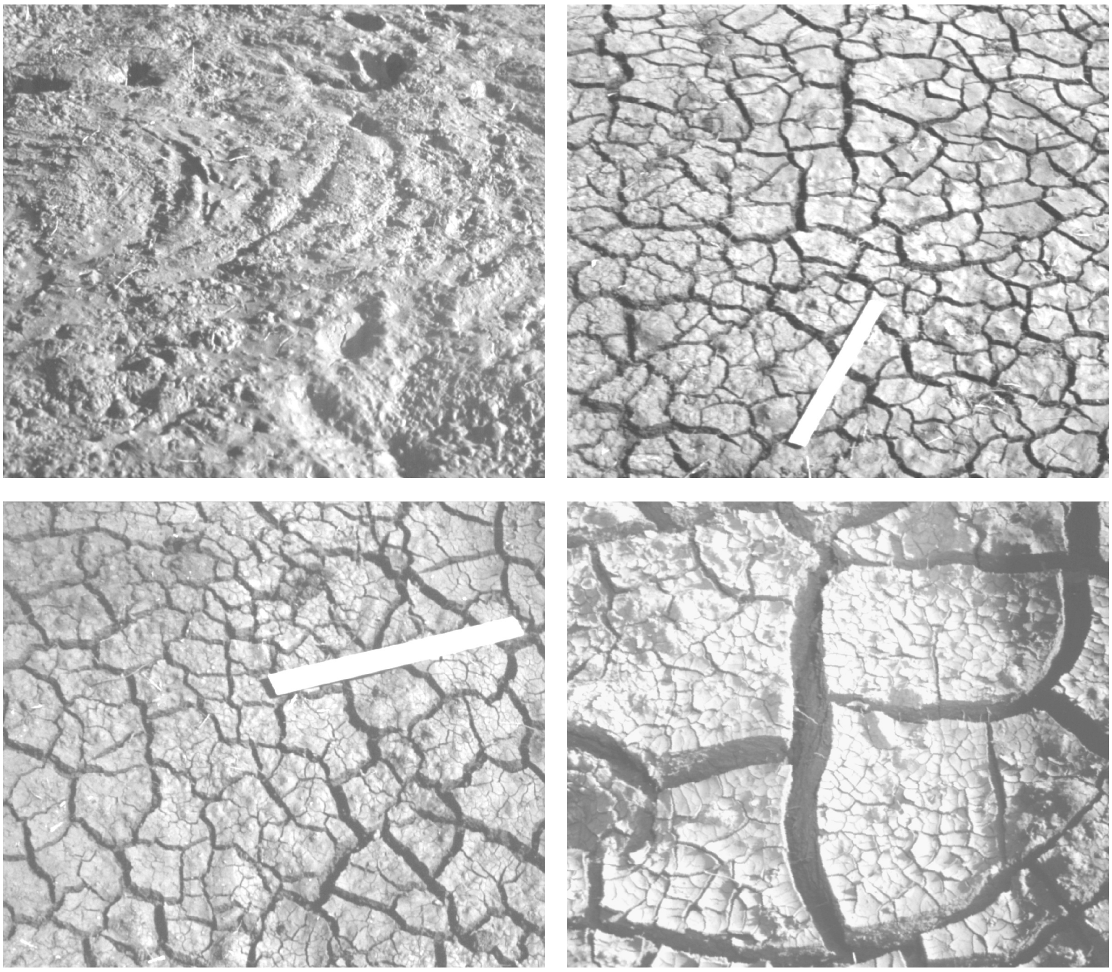

Fig. 3. Cracking patterns between the first and second irrigation treatments (no crop condition); day 1 (top left), day 3 (top right), day 7 (bottom left), day 12 (bottom right).

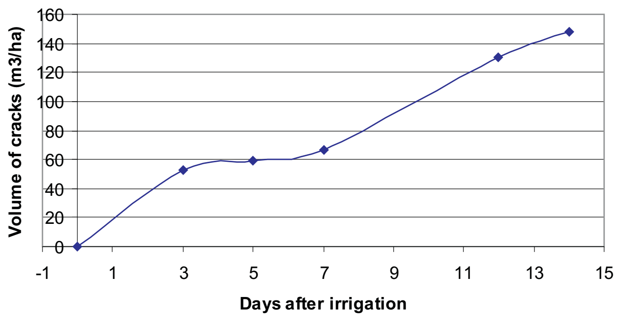

Fig. 4. Volume of cracks developed on the 3rd , 5th , 7th , 12th and 14th day after irrigation.

CONCLUSIONS

It was clearly observed that with decreasing aridity from the North to the South, the Gezira Vertisols increased intensity of cracking. The maximum cracks depth increased in the same direction. The cracks examined in the studied profiles were far deeper than those measured by the probe. It was also observed that carbonate and gypsum content decreased in the same direction. The above trends reflected the predominance of rainfall as an effective factor in the soil development. Cracks between irrigation treatments could be the source of huge extra losses of water through evaporation from the cracks' surfaces.

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