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Cracking patterns in the Vertisols of the Sudan Gezira at the end of dry season

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A b s t r a c t. Cracking patterns have been investigated in field conditions at three different sites in the Vertisols of the Sudan Gezira. The selected sites differed in particle size distribution with the clay content increasing from the north to south of the region. The natural soil moisture regime was also differentiated with the rainfall rate increasing from the north to the south. However, the three sites have been under irrigation for over 70 years. In this study, the intensity of cracking was expressed as crack depth, width and length as well as distances between cracks at the end of dry season. Approximated calculations of the cracks' volume based on field measurements were made. The intensity of cracking was increasing from the north to the south which indicates that cracks' intensity in the Gezira Vertisols is associated with the soil clay content and water regime.

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

INTRODUCTION

Vertisols cover an area of 257 Mha world-wide [2], mainly in Africa and India. Vertisols expand and contract with changes in moisture content and develop vertical cracks when drying out. They are composed of 2:1 clay minerals that expand when water is absorbed. When their moisture content decreases, the soil matrix starts to shrink. When the force holding soil aggregates and particles together is less than the tensile stress, cracks are formed. These cracks play an important role in the development of Vertisols. Hence, they are considered an important feature in the soil classification. Soil cracks allow for an enhanced water entry into the Vertisols. An initial penetration is rapid, but may only continue for a short time as some of the Vertisols cracks can close quite rapidly. This is especially true for the Gezira Vertisol [1,6]. Soil cracking is a source of important hydraulic conductivity. Hydraulic conductivity of these soils was greatly underrated when considered as related to the fraction of small pores only [8]. Vertisols expansion and contraction is an important characteristics to be considered when soil water relations are determined or expressed. Failure to take shrinkage into consideration resulted in an underestimation of up to 25% of the available water capacity of the Vertisols when determined in the laboratory conditions [3].

Cracks cause an increased loss of soil moisture with depth, through evaporation from the crack surface, even though this loss may be significantly reduced under fully established crops. Cracks are also the reason for a considerable increase in the irrigation water requirement at the time of the first irrigation after dry season [6,9]. Cracks may also be the source of tunnel erosion in the semi-arid regions, especially with events of heavy irrigation or high rainfalls. Soil cracks may cause physical damage to crop roots.

This study aimed at a better understanding of the cracking phenomena in the Gezira Vertisols; and an insight into the factors controlling soil cracking in order to be able to obtain a simple field technique that may reduce water losses through evaporation from cracks, yet retaining beneficial effects of cracks on water infiltration into the soil profile. Results reported in this work include basic analytical data, and field measurements of cracks' dimensions at the selected sites in the Sudan Gezira.

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MATERIALS AND METHODS

Three locations in the Sudan Gezira were chosen for this study. The selected sites represent the South, North and Central Gezira. The Central Gezira was represented by a profile from the farm of the Gezira Research Station at Wad medani. Examination of the sites was carried out at the end of dry season. Figure 1 shows location of the selected sites. Table 1 gives a summary of the characteristics of sites studied.

Soil profiles were dug at the three sites. Morphological description of profiles was done with particular emphasis on cracks' depth and width. Cracks' dimensions were carefully measured in the sample area of 4 m^2 duplicated at each site. Cracks' length and width was directly measured with a meter tape and their depth was measured using a flexible probe as described by Zein Al Abedine and Robinson [9]. Soil samples were taken for laboratory analysis. Cracks' volume was calculated from the dimensions measured within the sampled area using cracks' width as the base for the bilateral forming the shape of the crack cross-section. Cracks' depth was divided into 10 cm intervals and it was assumed that the width of these intervals decreases linearly with depth.

Particle size distribution was determined following the standard pipette method. Electrical conductivity (EC) and soil pH were measured in a 1:5 (soil : water) soil suspension. Exchangeable cations were extracted in a 1M ammonium acetate solution at pH 7 and determined by an Atomic Absorption Spectrometry. Extraction of ammonium as a measure of cation exchange capacity (CEC) was done by IM NaCl after washing excess ammonium with 95% ethanol. Total carbon and nitrogen were determined by a CNS analyser.

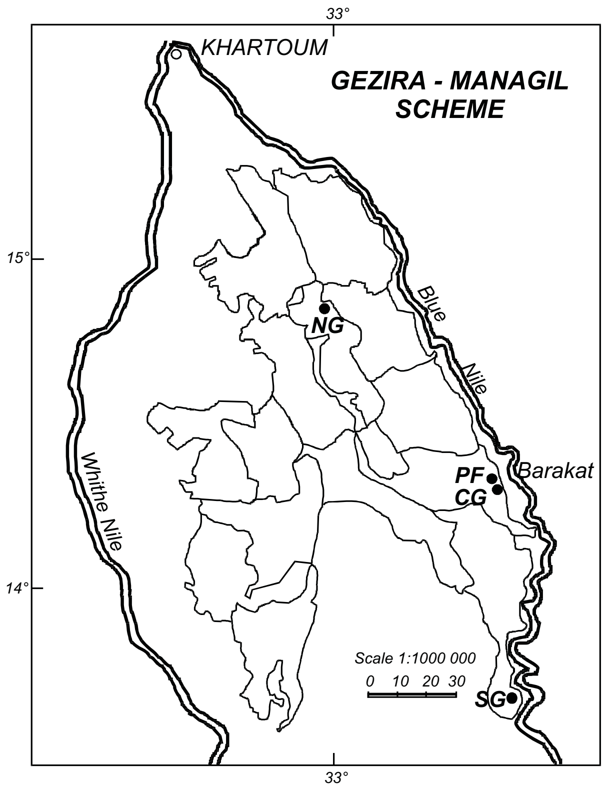

Fig. 1. Location of the study sites in the Gezira part of the central clay plains of the Sudan.

RESULTS AND DISCUSSION

General

The soils at the three sites had chemical and physical properties reflecting a gradient from the south to the north in respect to most of the features determined, see Table 2. Clay content ranged from 40 to 45% in the North Gezira (NG), 52 to 59% in the Central (CG) and 57 to 65% in the South Gezira (SG). Cation exchange capacity followed the same pattern as the clay content. All soils had pH values in the alkaline range. Soil EC was increasing with the increasing depth with the highest value found in the lowest horizon of the CG profile. The ECs of the surface soil always increased during the period with no-rain or irrigation due to evaporation at the surface and the upward movement of soil moisture and salts. The closer to the surface, the higher salt concentration. Thus, the top horizons in the profiles NG, CG

T a b l e 1. Basic information on the studied sites

Location	North	Central	South
Symbol	NG	CG	SG
Parent material	Blue Nile alluvial	Blue Nile alluvial	Blue Nile alluvial
Annual rainfall rate (mm)	292	354	430
Temperature °C (mean annual)	36.2	36.7	36.7
Physiography	Plain	Plain	Plain
Slope	< 1%	< 1%	1%
Crop rotation	Cotton; Groundnuts; Wheat; Dura; Fallow		
Last crop	Fallow	Wheat	Fallow
Last irrigated	Oct. 1998	Feb. 1999	Oct. 1998

T a b l e 2. Basic properties of the soils under investigation

Depth (cm)	EC ($\mu S\ cm^{-1}$)	pH	CEC ($mM_c\ kg^{-1}$)	Organic-C ($g\ kg^{-1}$)	Total N ($g\ kg^{-1}$)	Clay (%)
			Profile NG			
0-25	243	8.4	434	4.79	0.30	40
25-45	407	8.9	463	4.01	0.20	42
45-70	700	9.0	429	2.46	0.19	43
70-90	943	8.7	518	5.31	0.18	47
90-110	924	8.6	525	5.54	0.18	49
110-150	914	8.8	504	3.99	0.14	45
			Profile CG			
0-10	325	7.4	594	6.35	0.34	52
10-35	275	8.4	626	5.44	0.23	55
35-65	490	8.9	618	4.79	0.19	56
65-85	731	8.7	621	5.96	0.18	55
85-115	1371	8.3	682	6.30	0.22	58
115-150	3605	7.6	679	6.43	0.22	58
			Profile SG			
0-3	651	7.4	691	7.50	0.43	57
3-35	406	8.5	631	4.99	0.26	58
35-88	597	8.6	720	6.00	0.24	59
88-110	1893	7.9	804	8.81	0.22	63
110-150	1895	7.7	784	8.38	0.24	65

and SG had a depth of 25, 10 and 3 cm, respectively. The EC values for these three horizons were 243, 325 and 651 $\mu S\ cm^{-1}$, respectively. The highest values of EC are found in the thinnest horizons. Thus, if all the surface horizons were 0-3 cm deep, they could all have the EC values of around 600 $\mu S\ cm^{-1}$. Unfortunately, the present sampling procedure does not allow to verify the above statement. In the north of Gezira, at the Soba project, water is in a such short supply that visible salt accumulations are frequently seen on the soil surface soil during dry spells which results in extremely high EC values.

Description of cracks at the end of dry season

Fewer cracks per unit of surface area (4 m^2) were found in the north of Gezira, where the crack depth was 50 cm or less when measured by a flexible probe, and the width was no more than 3 cm. Table 3 shows the mean values of the cracks' dimensions. However, in the Central Gezira cracking depths of 70 cm were reached with widths of up to 5 cm. The southern Gezira site had cracks of up to 80 cm deep and 8 cm wide. A common shape of the soil blocks surrounded by the cracks, is a square and not a polygon. Thus, it was possible to describe the distance between cracks with two dimensions. This is especially true in the case of the South Gezira.

The volume of cracks found in this study amounted, on average, to 650 $m^3\ ha^{-1}$ in the SG representing an equivalent of 65 mm of water. In the Central Gezira, it was 230 $m^3\ ha^{-1}$. The cracking volume in the north of Gezira was as low as 70 m^3ha^{-1}as the above area has the least cracks especially after fallow season. The results have also shown that the intensity of soi1 cracking (volume of cracks) at the end of dry season increased from the north to the south of Gezira. The intensity of cracks seems to be linked to the soil clay content which

T a b l e 3. Mean depths and widths of cracks at the soil surface, and distances between cracks as observed in the 4 m^2 sampled area at each site. Approximations of the total crack volume per ha are included

Profile	Depth (cm)	Width (cm)	Volume of cracks (m^3ha^{-1})	Range of distances between cracks (cm)
NG	23	2.1	70	90-105
CG	44	3.5	230	58-102
SG	48	4.9	650	40-50

increased in the same direction as the cracks. Figure 2, which is a plot of the total cracks' volume of the three sites studied against the clay content at each site. Climatic data show clear trends of increasing aridity from the so uth to the north in the studied region. Relationship between the cracking intensity at the end of dry season and soil water regime is further reflected in the plot showing the cracking volume against the ratio of annual precipitation to potential evapotranspiration presented in Fig. 3. The north of Gezira has the lowest ratio of rainfall to the potential evapotranspiration. Hence, it is the driest site. Despite this, the north of Gezira has the lowest cracks' volume. This indicates the importance of the total water amount available in the site during the rainy season. Lower amount of water available in the north may be associated with an insufficient soil wetting. The maximum soil shrinking capacity is not attained upon drying as the soil matrix is not thoroughly wetted. However, this relationship needs to be confirmed. It is clear that the cracks' intensity in the Gezira Vertisols is mainly associated with the soil clay content and water regime.

Visual examination of cracks in the soil profiles showed cracks one meter deep or more in the Central and South Gezira. The cracks' width measured in the studied profiles ranged from 0.5 to 5 cm in the SG, 0.5 to 3 cm in CG and 0.5 to 2 cm in the profile NG (Table 4). In the previous study [9], the volume of cracks at the end of dry season in the Gezira Vertisols reached up to 867 m^3 ha^{-1}, an equivalent of 86.7 mm of water. In the irrigated plots, the volume of cracks was between 222 and 313 $m^3 ha^{-1}$. Elshal [4] quoted a figure of 75 mm of the equivalent water, which was more than the amount needed to increase soil moisture to the field capacity, required to fill up soil cracks at the first irrigation in the cracking soils in Egypt.

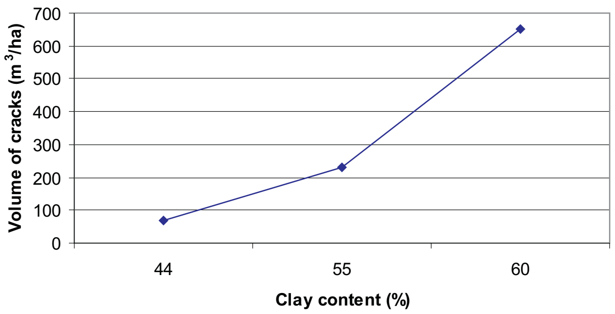

Fig. 2. Relationship between the soil clay content and cracks' volume at the end of dry season in the North, Central and South Gezira.

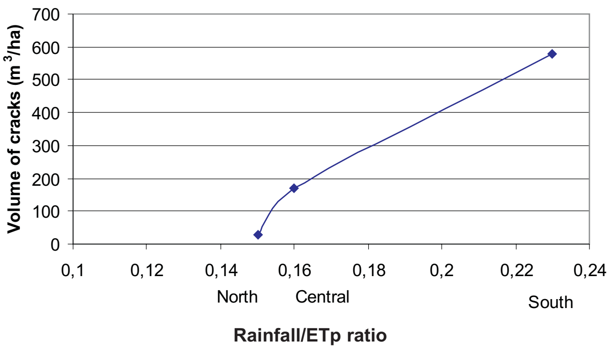

Fig. 3. Relationship between the annual rainfall ratio to the potential evapotranspiration and cracks' volume at the end of dry season in the North, Central and South Gezira.

T a b l e 4. Description of the cracking width measured in the studied soil profiles; an asterisk indicates a moist horizon; depths of the horizons as in Table 2.

Horiozon	Crack width (cm)		
	NG	CG	SG
1	0.5-2	mulched	1-5
2	1-3	2-3	2-5
3	0.5-2	*	0.5-2
4	*	*	0.5-1
5	*	*	non
6	*	*	-

Implications for water movement and distribution

Water entry after irrigation or rain and its re-distribution in the Gezira Vertisols is seriously affected by the extent of cracking. Water ability to penetrate from the soil surface to the depths greater than 50 cm is almost none. The only water route into deep soil layers is via cracks and then, lateral distribution of moisture takes place. It is, therefore, expected that after irrigation, higher moisture contents are found close to the cracks. While deep into the soil blocks or prisms surrounded by cracks, the soil has less moisture. Areas wetted by water movement through fissures are excluded. Not only are cracks important for the water movement in the conditions close to saturation, but they are also important at unsaturated flow conditions as they provide an easy and continuous route for the movement of water vapour. This is important, as it has been noted that the maximum presence of roots is normally observed closer to the cracks' surfaces. This may be due to the fact that the area around cracks is normally of the lowest bulk density (high moisture content) and hence, it is easier for roots penetration. On the other hand, the presence of more roots in the area leads to faster moisture depletion, and encourages more cracking. At higher tension levels, increasing water losses through evaporation and uptake by plants, result in the drier cracks' surface and increase soil strength around the cracks which can possibly lead to some restriction of further root movement.

CONCLUSIONS

The results obtained in the present study showed that cracks' number and size at the end of dry season increased from the north to the south in Gezira. Cracks observed in the studied soil profiles were far deeper than those measured by the probe. An increase in the cracking intensity from the north to the south seemed to be related to the soil clay content and water regime. The cracks at the end of dry season are of major importance in facilitating water movement down the soil profile and could be a source of huge extra water losses through evaporation from the cracks' surfaces.

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