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An International Journal on Research and Development in Soil Tillage and Field Traffic, and their Relationships with Soil Environment, Land Use and Crop Production

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Compaction and Shading Effects on Surface Cracking in a Vertisol*

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ABSTRACT

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The effects of soil compaction and shading on surface cracking were studied in miniplots on a Vertisol at ICRISAT Center. Two distinctly different types of cracking were observed: (1) Type 1, wide and deep cracks, associated with bigger intercrack structural units (ISUs); (2) Type 2, narrow and shallow cracks, associated with smaller ISUs. Although differences in the areal shrinkage on the soil surface were rather small across the treatments, compaction and shading resulted in Type-1 cracking, and uncompacted and unshaded treatments produced Type-2 cracking. The equivalent diameter of ISUs was increased approximately twice by shading and three times by compaction. These differences may be attributed to: (1) structural changes during compaction; (2) structural adjustments during drying. A qualitative model of crack initiation, which explains the observed effects, has been proposed.

These results have important applications in soil management. Type-1 cracking may improve infiltration and internal drainage and effective storage of water in subsurface layers. But for efficient seedling establishment, Type-2 cracking is preferred. Field experiments to test these concepts are warranted.

INTRODUCTION

The development of cracks owing to shrinkage is a major structural feature of many soils. Gross cracks, extending deep into the profile, define major structural units and play an important role in several processes. They can, for example, improve infiltration and deep soil water recharge (Stirk, 1954; Swartz, 1966; Shaw and Yule, 1978; Gardner and Coughlan, 1982; Bouma, 1984), and increase evaporation (Adams and Hanks, 1964; Ritchie and Adams, 1974). Between the gross cracks, surface cracks define intercrack structural units (ISUs). The frequency, size and rate of development of surface cracks, influences soil water, aeration and plant growth processes. The size and strength of

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ISUs influence the ease and effectiveness of tillage and are often a constraint that has to be managed in farming operations (Coughlan et al., 1989).

The shrink–swell process has been extensively studied (e.g. Haines, 1923; Stirk, 1954; Holmes, 1955; Fox, 1964; Berndt and Coughlan, 1977; Yule and Ritchie, 1980a, b). Differences in structure between cracking soils have also been studied and have been attributed to soil constituents (Smith, 1984), crop species and spatial arrangements (Johnson, 1962), rate and degree of drying (Coughlan, 1984) and to management practices such as tillage and stubble retention (Loch and Coughlan, 1984). In general, the effect of management factors on the definition of surface structural units by cracks is not well understood. Also, there has been little progress in the development of field techniques to manage the cracking process. Coughlan et al. (1989) list it as a priority area for research. In designing tillage systems, compaction and drying rate are two factors that can be varied. For example, compaction can be varied by management of wheel or foot traffic, and drying rate by shading. The present paper reports a study on the effects of differential soil compaction and shading on surface cracking in a Vertisol and discusses implications of surface cracking differences for moisture conservation, drainage and seedling emergence.

MATERIALS AND METHODS

Description of soil

The two experiments described in this paper were conducted on a Typic Pellustert (Kasireddipalli series) at ICRISAT Center near Hyderabad, India. The physical and chemical properties of this soil are presented in Table 1.

Soil preparation

The experiments were conducted in summer in an uncropped field. Steel frames 150-cm square and 30-cm high were installed in the soil to a depth of 15 cm. The enclosed areas are henceforth referred to as miniplots. The dry (18% w/w water) soil in each miniplot was thoroughly tilled by hand hoe to 20-cm depth to erase past soil-management effects and to create a uniform soil structure. The soil surface was levelled by hand rake to minimize micro-relief differences.

Experiment 1

This experiment was conducted in two miniplots (replicates). Soil within the miniplots was wetted uniformly by quickly flooding the surface with 50 mm of water. On the following day, each miniplot was divided into three 50-cm wide strips. The wet soil in the middle strip (Zone A in Fig. 1) was loosened

TABLE 1

Major characteristics of the Kasireddipalli soil series, a Typic Pellustert, at ICRISAT Center, Hyderabad, A.P., India (Source = El-Swaify et al., 1985)

Horizon	Depth (cm)	Distribution (%) of <2 mm particles[1]				Coarse fragments >2 mm (% of whole soil)	Organic carbon (%)	Carbonate as $CaCO_3$ (%)	pH (1:2.5) H_2O suspension	EC (1:2.5) H_2O suspension (ds m^{-1})	Water retention (gravimetric %)	
		Coarse sand (2.0-0.2)	Fine sand (0.2-0.02)	Silt (0.02-0.002)	Clay (<0.002)						1/3-bar	15-bar
AP	0-16	18.3	25.3	16.3	40.1	10	0.27	1.1	8.1	0.10	32.5	18.7
B 12	16-57	17.6	15.6	17.3	49.5	18	0.12	1.1	8.5	0.20	34.9	20.5
B 13	57-118	8.9	10.0	20.4	60.7	3	0.18	1.4	8.5	0.25	33.4	20.5
B 14	118-115	9.9	10.4	19.4	60.3	20	0.12	2.2	8.2	0.30	35.8	21.3

Depth (cm)	Exchangeable cations (meq 100g)					CEC NH_4OA_c (meq 100g)	Exchangeable sodium (%)	Base saturation (%)	CEC/clay ratio	Clay fraction mineralogy[2]				Sand fraction mineralogy[2]				
	Ca	Mg	Na	K	Sum					Am	KK	MI	SM	QZ	FDM	FDP	FM	FE
0-16	24.5	3.4	4.0	0.7	32.6	34.9	11	93	0.87	4	14	7	64	5	10	55	10	20
16-57	23.9	3.2	5.4	0.6	33.1	35.2	15	94	0.71	6	13	7	65	5	25	50	5	15
57-118	22.7	14.5	6.3	0.8	44.3	48.3	13	92	0.80	5	13	7	68	5	10	55	5	20
118-155	22.2	14.5	7.6	0.8	44.9	43.6	17	100+	0.72	5	13	7	63	5	15	55	5	15

[1]Values in parentheses are particle diameters (mm). [2]Am = amphibole; KK = kaolinite; MI = mica; SM = smectite; QZ = quartz; FDM = feldspar-microcline; FDP = feldspar-plagioclase; FM = ferromanganesium minerals; FE = magnetite.

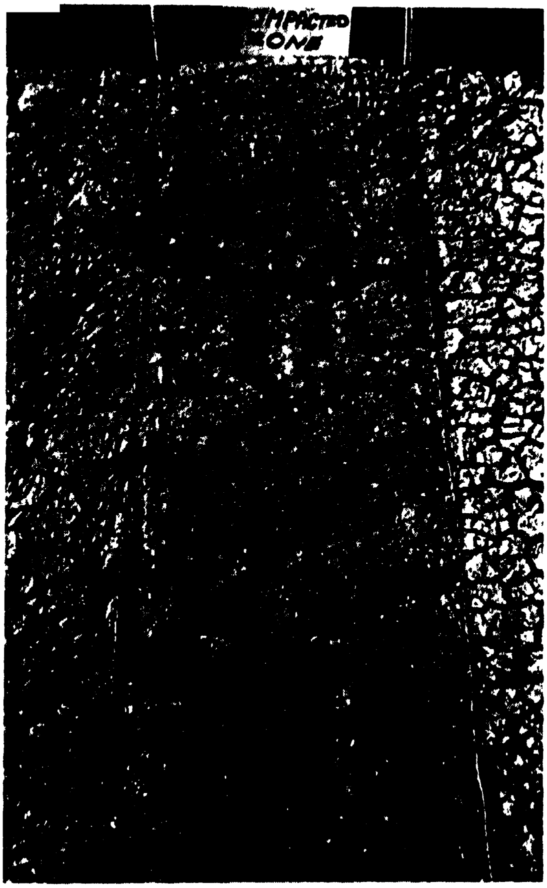

Fig. 1. Effect of differential soil manipulation on surface cracking in a Vertisol. The surface soil in Zone A (middle) was compacted whereas in Zone B (left and right), it was not disturbed. Note the longitudinal orientation of a crack in the middle of Zone A.

with a hand tool to a depth of 15 cm and the loose soil was taken out. This soil was filled back in its original place and compacted in layers of 5 cm depth by a pneumatic wheel, weighing 25 kg and having a surface contact width of 12 cm. The soil in the remaining 2 strips (Zone B in Fig. 1) was left undisturbed. Subsequently, 50-mm water was applied uniformly to both the miniplots and the soil was allowed to dry. The surface soil had a mean bulk density (0–6 cm core samples) of 1.45 ± 0.01 g cm^{-3} ($30.1 \pm 0.4\%$ w/w water) in Zone A, and 1.33 ± 0.01 g cm^{-3} ($30.4 \pm 0.5\%$ w/w water) in Zone B. Eight days after the second wetting, the cracking patterns were photographed, and the depth of major cracks ($>$ 5-mm width) was measured by probing with a 2-mm diameter wire. A minimum crack width of 5 mm was chosen arbitrarily, although Northcote (1971) uses cracks of a similar width in the surface as a diagnostic feature for cracking clay soils. During the drying period, United States Weather Bureau (USWB) open-pan evaporation was 10–12 mm day^{-1}.

Photographs of the cracking patterns were analyzed by an Area Meter (Delta-T Devices Ltd., Cambridge, U.K.)* to determine the mean area of ISUs and the area of cracks at the soil surface (as a percentage of the total surface). The mean equivalent diameter of the ISUs was computed.

Experiment 2

The experiment had two treatments (each replicated twice): (1) control (similar to the uncompacted soil in Experiment 1); (2) shading with a polythene film.

The miniplots were wetted uniformly by applying 60-mm water. In the shading treatment, a white polythene sheet (milky white, 1000 gauge) was fixed about 15 cm above the soil surface over the whole plot (supported by steel frames). The surface soil had a bulk density of 1.30 ± 0.2 g cm^{-3} (30.2 ± 0.5% w/w water). After 8 days of drying, the cracking pattern was photographed and the depth of major cracks measured by a 2-mm diameter wire. During the drying period USWB open-pan evaporation was 10–13 mm day^{-1}. The photographs were analysed and computations made as in Experiment 1.

RESULTS

Effects of soil compaction

Figure 1 and Table 2 show that soil compaction leads to the formation of deeper and wider cracks and bigger ISUs. Although the area of cracks on the soil surface in the compacted and uncompacted zones was only slightly different, the size of ISUs and depth of cracks were markedly different.

TABLE 2

Effect of compaction on size of cracks and intercrack structural units (ISUs)

Treatment	Crack depth (cm)	Surface crack area (% of the total)	ISUs	
			Mean area (cm^2)	Equiv. diam. (cm)
Control	2.0	18.3	23.3	5.4
	(±0.10)[1]	(±1.5)	(±1.5)	
Compacted	5.1	16.1	199.4	15.4
	(±0.27)	(±1.3)	(±25.0)	

[1]Figures in parentheses are standard errors.

*Mention of commercial products or companies does not imply endorsement or recommendation by ICRISAT, nor prejudice against any other manufacturer.

In the compacted soil (Zone A in Fig. 1) a major crack was oriented logitudinally along the direction of movement of the compacting wheel. This crack was intersected at variable intervals by transverse cracks.

Effect of shading

Data presented in Table 3, and Figs. 2 and 3 clearly demonstrate that shading resulted in formation of deeper and wider cracks and bigger ISUs.

TABLE 3

Effect of shading on size of cracks and intercrack structural units (ISUs)

Treatment	Crack depth (cm)	Surface crack area (% of the total)	ISUs	
			Mean area (cm^2)	Equi' diam (cm)
Control	1.8 (±0.1)[1]	15.1 (±1.2)	37.0 (±2.9)	6.8
Shaded	3.1 (±0.1)	13.0 (±1.7)	140.1 (±9.6)	13.4

[1]Figures in parentheses are standard errors.

Fig. 2. Surface cracking in a shaded miniplot.

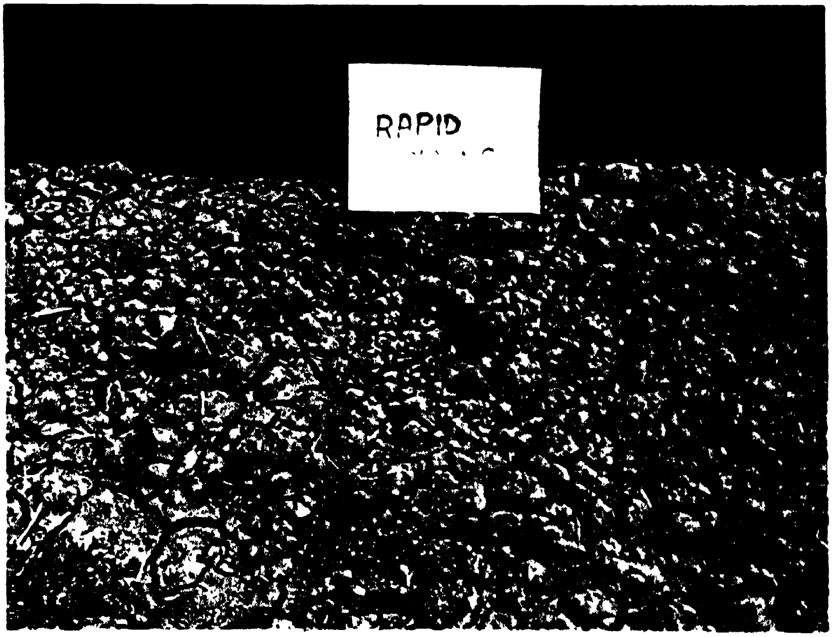

Fig. 3. Surface cracking in an unshaded miniplot.

DISCUSSION

The miniplots used in this study were too small for a representative sampling of gross cracks which are generally observed in the field at an interval of about 1 m or more. This paper uses the term ISU rather than 'intercrack unit' because the latter term generally refers to relatively bigger units, defined by the gross cracks. In the hierarchy of structural units, the ISU lies between the intercrack units and the subunits defined by hairline cracks.

A qualitative model of crack initiation

The difference in cracking observed in this study can be explained in terms of a qualitative model of adjustments to stress as the soil dries.

In the early stages of drying, water drains from relatively large pores during the structural shrinkage phase in relatively wet soil (Yule and Ritchie, 1980a, b). With further drying, tension in the soil water film rearranges and reorients the internal structural units of microaggregates and agglomerates in the soil matrix. When internal friction, owing to bonding mechanisms, is such that stresses cannot be relieved in this way, the water film fails and 3-dimensional shrinkage begins (Fox, 1964). This failure occurs where tensile strength is weakest. This would be where the soil is wettest or where the homogeneity of the cohesive forces is perturbed, e.g. by relict structural arrangements resulting from tillage and wetting. In relatively more homogeneous soils failures will be less frequent and will propagate further. In these soils, cracks will be wider and longer.

The effect of compaction

The compacted soil in experiment 1 had fewer but larger cracks than the uncompacted soil, i.e. failures leading to crack definition were less frequent. The fact that the proportion of the surface occupied by cracks was nearly similar in both the treatments indicates that, overall, the degree of shrinkage in the immediate surface was also similar. This suggests that the explanation for the difference lies in the way tension is relieved in each soil rather than to any change in the extent of shrinkage.

The uncompacted soil, after slaking in the initial wetting process, would have consisted of structural units each with subunits in random array. The air-filled porosity after wetting was 0.10 $cm^3\ cm^{-3}$ which would represent structural pores. The uncompacted soil therefore had relict structural arrangements. In contrast there was no air in the compacted soil. Thus the compacted soil would have had a drastically altered structure. Structural bonds in the original soil would have been destroyed by the compaction treatment and units probably tended to be arranged in parallel orientation. Microstructural units would be free to move and reorient into an array with homogenous pore size distribution and within which new bonding arrangements would form. Cohesion would therefore be greater and failure planes less common. Water flux to the evaporating surface may have been more rapid in compacted soil (Brown, 1970) thus slowing the onset of tension and allowing more time for particle rearrangements. This would have led to the formation of larger ISUs. Thus we attribute the differences to increased cohesion brought about by more uniform void structure coupled with more rapid water flux.

The effect of shading

In the second experiment, shading would have reduced the amount of radiant energy reaching the soil surface. The evaporation rate would have been lower and the peak soil temperature would have been less (Anonymous, 1982). However, in this experiment, the initial soil structural arrangement was identical in each treatment. Again the approximate equivalence in final crack areas suggests the degree of overall shrinkage at the immediate surface was similar. In contrast to the first experiment the difference seems to represent the rate of drying (tension) as well as the soil's ability to adjust to applied stress. When tension is applied slowly the soil is apparently able to adjust internally to relieve tension before the cohesive strength is exceeded. This adjustment may be by rearrangement and reorientation of microstructural units. The movement of water into the evaporating surface may be able to keep pace with evaporation (i.e. the first stage of drying may extend for a longer time) so that stresses are applied uniformly throughout the soil matrix.

These results caused by shading are in agreement with those of Loch and Coughlan (1984) who suggested that retention of stubble as a mulch increased aggregate size. In our study, wider cracks were generally deeper cracks (Tables 2 and 3) indicating that the relationships observed on the surface extended into the vertical dimension as well. As cracks tend to be triangular in cross section, narrower cracks will generally be registered as shallow cracks, as the probe diameter (2 mm) was relatively large in relation to the width of minimum crack size recorded (5 mm).

Relevance to soil management

The cracking intensities observed in this study are of two different kinds: (1) Type-1 cracking, wide and deep cracks, associated with bigger ISUs; (2) Type-2 cracking, narrow and shallow cracks, associated with smaller ISUs. Both compaction and shading have caused Type-1 cracking but apparently by different mechanisms. In the compacted soil, structure modification before drying increased cohesion. In the shaded soil, internal structural adjustments during drying increased cohesion. The type of rearrangement is not known in either case but the much greater input of energy in compacted soil should give a more drastic effect. These internal structural adjustments could have implications for the subsequent wetting cycle. Rain exceeding the infiltration rate of the ISU will cause surface ponding and runoff into the cracks. When the water deficit is recharged and water is redistributed into the ISU the cracks will be closed. Cracks are important pathways and if they remain open for a longer time, they may conduct water into zones where it is more effectively stored than in the immediate surface (Loch and Coughlan, 1984). This would be desirable for self-mulching Vertisols in low and undependable rainfall regions where crops are grown only in the post-rainy season. Management practices to discourage self-mulching and create large ISUs could allow water to by-pass the surface layer, from which it is rapidly lost by evaporation. Both compaction and shading could be used to create water-shedding ISUs and relatively larger and deeper surface cracks in such regions.

In wetter regions, internal drainage is commonly a problem. Wider and deeper cracks created by deliberately compacting a zone (e.g. the furrow in ridge–furrow system) could prolong the useful life of cracks as large drainage voids for the soil in the neighbouring zone. This particular mechanism may also be responsible (at least partly) for the reduction of surface runoff in the broadbed-and-furrow system, in comparison with the traditional flat layout on Vertisols at ICRISAT Center in the early part of the rainy season (Miranda et al., 1983).

Many Vertisols are subject to serious compaction owing to field traffic in wet soil conditions. Wheel and foot traffic in the seeding zone should be avoided as it will encourage formation of coarse clods. If the ISUs of this study are taken to be representative of crust plates in a seedbed, it can be implied that an emerging seedling will have only one third the chance of being near a crack in compacted soil as compared with an uncompacted soil. Seedlings located near a crack are more likely to emerge than those away from it (Miller and Gifford, 1974). Thus, for efficient seedling establishment soil management should encourage Type-2 cracking. In such soils use of presswheels may prove harmful if they compact the soil sufficiently to influence ISU size.

CONCLUSIONS

This study shows that compaction and shading influence size of cracks and ISUs. Deeper and wider cracks, and bigger ISUs induced by compaction or shading may improve infiltration, internal drainage and effective moisture storage. But for efficient seedling establishment in the crust prone Vertisols, smaller ISUs should be preferred. Field experiments for testing these concepts are needed.

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