vity will have to be balanced against the cost of finding alternative feed for livestock prevented from grazing the fields.

Earlier maturing cultivars offer an opportunity to manipulate competition gaps. In practice, however, the number of options is fairly limited. New cultivars will need to be screened to determine their consistency of performance in the existing cropping systems.

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EFFECT OF SOIL CRUSTING ON SEEDLING GROWTH IN CONTRASTING SORGHUM LINES†

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SUMMARY

Seedling growth from sowing to emergence of two crust tolerant and two susceptible sorghum genotypes is described. Tolerant genotypes had longer mesocotyls with faster growth rates than the susceptible genotypes. The mechanism involved in crust tolerance appears to be that of avoidance by fast growth.

Desarrollo de plantas jovenes en suelos con capa exterior endurecida

RESUMEN

Se describe el desarrollo de las plantas jóvenes, desde la siembra hasta la emergencia, de dos genotipos de sorgo tolerantes a capas duras y dos tipos susceptibles a las mismas. Los genotipos tolerantes presentaron mesocotilos de mayor longitud y una mayor intensidad de crecimiento que los genotipos susceptibles. El mecanismo para lograr la tolerancia a las capas duras parece ser el evitarlas a través del rápido crecimiento.

INTRODUCTION

the semi-arid tropics, sorghum (*Sorghum bicolor* (L.) Moench) is frequently ɔwn in soils with a poor physical structure, which are prone to crusting or pping (Hoogmoed, 1983) with the result that poor seedling establishment is a ajor problem (Peacock, 1979). Soil crusting results from compaction due to rain ops and the subsequent drying of the compacted surface (Cary and Evans, 74). Considerable genetic variation exists in sorghum in its ability to emerge rough the soil crust (Soman *et al.*, 1984; Maiti *et al.*, 1986). The purpose of this ıdy was to compare the growth and morphology of crust tolerant and sensitive notypes of sorghum between sowing and emergence and to understand the echanism involved in differential emergence.

MATERIALS AND METHODS

ıe growth of crust tolerant and susceptible sorghum genotypes was compared, ing a field technique described in Soman *et al.* (1984), in the 1987 and 1988 dry

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seasons (Experiments 1 and 2). Four genotypes were used, two of which a tolerant, IS 17605 and IS 12743, and two susceptible, IS 22237 and IS 2331 (Table 1). Three experiments conducted in 1985, 1986 and 1987 with differen seed lots showed that these genotypes were consistent in their response to crustec soil.

The experiments were conducted at the ICRISAT research centre in an Alfiso field (Udic Rhodustalf, Patancheru series with 77% sand and 8% clay). The fielc was irrigated to allow the weed seeds to germinate, and rotavated and discec repeatedly to get a dry and fine seedbed. Ten broad beds, each 1.2 m wide, wer prepared and smoothed with a bed shaper. Each experiment consisted of paired 2 m long rows sown at 0.30 m spacing along the length of the broad beds (fou rows to a bed). Paths of 0.5 m were left between each set of four rows. On genotype was sown at 80 seeds per row to each pair of rows. One row of each pai formed the crusted plot and the second the control (crust broken) plot. Pairec plots were laid out in a randomized block design with four replications. Ther were six plots per entry per replicate to allow for daily sampling from one to si days after sowing (DAS).

Seeds were sown at a depth of 50 mm with a John Deere 7100 planter on 2 March 1987 and 16 February 1988. After sowing, the surface of the beds wa smoothed with a bed shaper. Water was applied evenly, at a rate of 14 mm pe hour for two and a half hours, using two parallel lines of sprinklers, 12 m apart After irrigation, the plots were left to dry. The surface crust on the control row was broken mechanically, with a roller type crust breaker (Awadhwal anc Thierstein, 1983), at three DAS when the surface was dry enough for thi operation.

To measure growth, seedlings were carefully dug up, first by removing soil above the seed zone and locating the seedling and then by excavating soil until the tip of the radicle was located. Seedlings were removed every morning until 6 DAS in Experiment 1 and 4 DAS in Experiment 2. At each sampling, 25 seedlings were dug out in each treatment. The seedlings were divided into root (radicle), shoot

Table 1. *Percentage of seedlings emerged in crusted and control treatments four days after sowing (standard errors in parentheses)*

Genotype	Mean seedling emergence	
	Crust	Control
Tolerant		
IS 17605	40.8 (2.2)	55.0 (3.5)
IS 12743	44.7 (4.0)	47.8 (3.6)
Susceptible		
IS 22237	8.0 (2.1)	67.0 (2.5)
IS 22317	14.1 (7.2)	35.7 (3.8)

(plumule), leaves (after emergence) and seed. From four DAS onwards, many seedlings of the tolerant genotypes emerged, while those of the susceptible genotypes frequently remained below ground so that all their seedling parts (shoot and radicle) were subterranean until the end of the experiment. Although the growth of seedlings was monitored from one to six DAS, the effect of crust and control treatments was analysed only up to four DAS, the day after the crust was broken to create the control.

Lengths of radicle, plumule, coleoptile and mesocotyl, and dry weights of root, shoot and seed were recorded. All materials were dried at 90°C and cooled before weighing. The crust strength, moisture content and temperature of the soil were measured using the technique described in Soman *et al.*, 1984. The loss of seed dry weight and the conversion efficiency (CE)—the dry matter of the seedling as a fraction of the dry matter lost by the seed—were calculated and compared for the genotypes.

RESULTS

The environmental factors measured in the two experiments were similar, except for soil temperature where the variation was largely due to the difference in the times of planting and the prevailing air temperature (Table 2). Crust strength, the variable of most relevance in this study, was 1.6 kg cm^{-2} in Experiment 1 and 1.5 kg cm^{-2} in Experiment 2 four DAS.

Seedling dry weight

The dry weight per seedling four and five DAS was affected by the presence or absence of a surface crust (Table 3), the results indicating that growth was inhibited by the physical condition of the soil where the crust had not been disturbed. Seedling weight of crust tolerant genotypes was generally greater than that of susceptible genotypes from one DAS in both crusted and control treatments.

Table 2. *Mean crust strength (kg cm^{-2}), soil moisture (%) and soil temperature (°C) at 20 mm depth (measured at 1400 h) for the two experiments (standard errors in parentheses)*

Days after sowing	Crust strength	Soil moisture		Soil temperature
		Surface (0–25 mm)	Seed zone (26–50 mm)	
		Experiment 1		
	0.31 (0.10)	8.1 (0.7)	8.6 (0.5)	42.0 (0.1)
	1.60 (0.20)	2.0 (0.6)	4.4 (0.6)	47.0 (0.7)
		Experiment 2		
	0.46 (0.03)	7.6 (0.3)	8.7 (0.3)	38.5 (0.5)
	1.50 (0.70)	2.5 (0.2)	6.7 (0.3)	41.1 (0.4)

Table 3. *Mean seedling weights (mg) of crust tolerant and crust susceptible genotypes in Experiment 1*

Days after sowing	Tolerant		Susceptible		
	IS 17605	IS 12743	IS 22237	IS 23317	SE
		Crusted treatment			
1	1.1	1.3	0.9	0.6	0.09
2	5.0	4.6	4.5	3.4	0.18
3	9.0	7.8	7.9	6.5	0.27
4	11.7	10.2	9.0	8.5	0.36
5	14.2	10.7	11.1	10.5	0.51
6	13.0	10.3	9.1	8.8	0.46
		Control treatment			
1	1.3	1.4	0.9	0.9	0.10
2	4.8	4.7	4.6	3.4	0.16
3	9.0	7.9	7.6	6.3	0.27
4	12.4	10.3	8.5	8.6	0.47
5	15.9	13.8	11.2	11.3	0.59
6	16.6	14.0	9.7	11.3	0.77

Seed dry weight and conversion efficiency

Seed dry weight of the four genotypes and the rate of loss of seed dry matter to produce new growth differed among the genotypes (Fig. 1). The rates showed no clear differences between crust tolerant and susceptible genotypes, but there were significant correlations between seed weight and the rate of loss of seed weight from both the tolerant and susceptible genotypes. The susceptible genotypes utilized about 60% of their seed dry matter for forming seedling tissue and the tolerant genotypes only about 40% (Table 4). Although there were significant differences between crusted and control treatments, the higher conversion efficiencies of the crust susceptible genotypes suggest that they used less dry matter for respiration.

Plumule extension

The plumule comprises the coleoptile and the mesocotyl, the internode between the seed and the coleoptile node. Both coleoptile and mesocotyl length differed significantly among the genotypes. Generally, the crust tolerant genotypes had slightly longer coleoptiles than the susceptible genotypes and this difference was more pronounced one DAS (Fig. 2, a and b). Crusted and control treatments did not have any effect on the length of coleoptile. The growth rates of the coleoptile were only marginally different between the tolerant and susceptible groups of genotypes.

Variation in the length of the mesocotyl between the tolerant and susceptible genotypes was more pronounced than that of the coleoptile (Fig. 2, c and d). This difference was significant from day one until the seedlings emerged in the tolerant genotypes (four DAS). The growth rates of the mesocotyls were higher for the tolerant genotypes than for the susceptible genotypes that did not emerge above

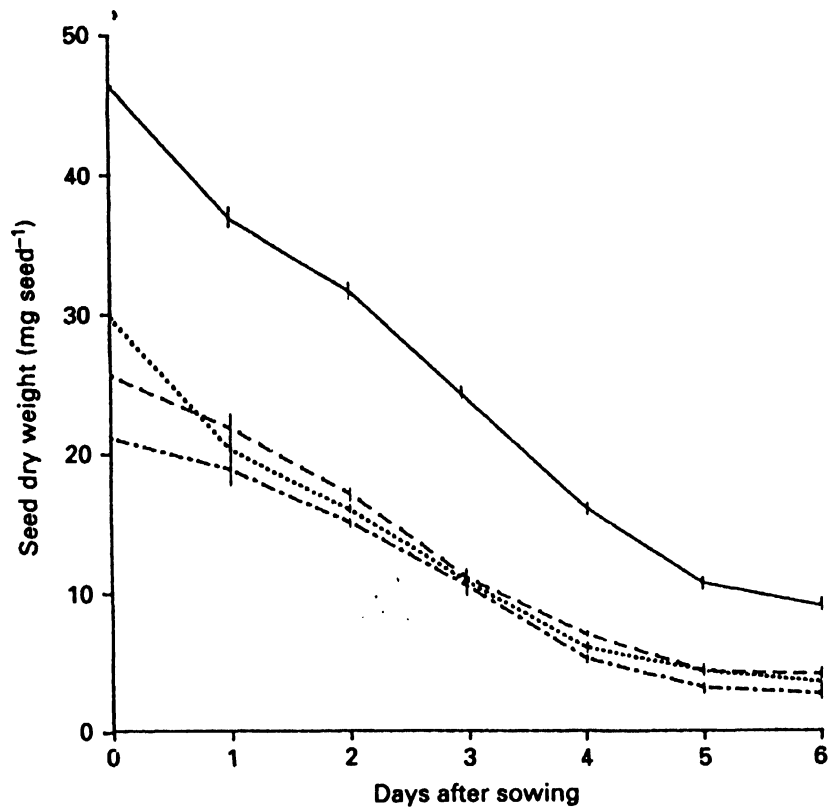

Fig. 1. Seed dry weight of the two crust tolerant (IS 17605 ——, IS 12743 – – –) and the two crust susceptible (IS 22237 · · · ·, IS 23317 – · – · –) genotypes in the control treatment for Experiment 1. Vertical bars denote SE.

ground. The difference was greatest for the first two days' growth. There was little difference between tolerant and susceptible genotypes in the length of radicles and no effect of crust treatment on radicle length in either experiment. The method of crust simulation used (Soman *et al.*, 1984) did not cause the soil below the surface crust of 2-3 mm to harden and the radicles were, in general, not mechanically stressed. At emergence (four DAS) susceptible genotypes had larger root/shoot ratios than tolerant genotypes although both parts remained below ground. This was a direct result of the greater plumule weight in tolerant genotypes.

Table 4. *Initial seed dry weight (mg), seedling dry weight (mg) and seed dry matter conversion efficiency (%) of the seedlings after four days growth (the values are means of the two experiments, with standard errors in parentheses)*

	Initial seed dry weight	Seedling dry weight		Conversion efficiency	
		Crusted	Control	Crusted	Control
Tolerant					
IS 17605	46.2	14.2 (0.45)	15.1 (0.47)	39.2	53.3
IS 12743	25.5	7.9 (0.59)	8.9 (0.66)	28.0	27.0
Susceptible					
IS 22237	29.6	11.2 (0.71)	11.5 (0.81)	64.0	53.5
IS 23317	21.0	8.9 (0.98)	9.9 (1.24)	60.1	66.4

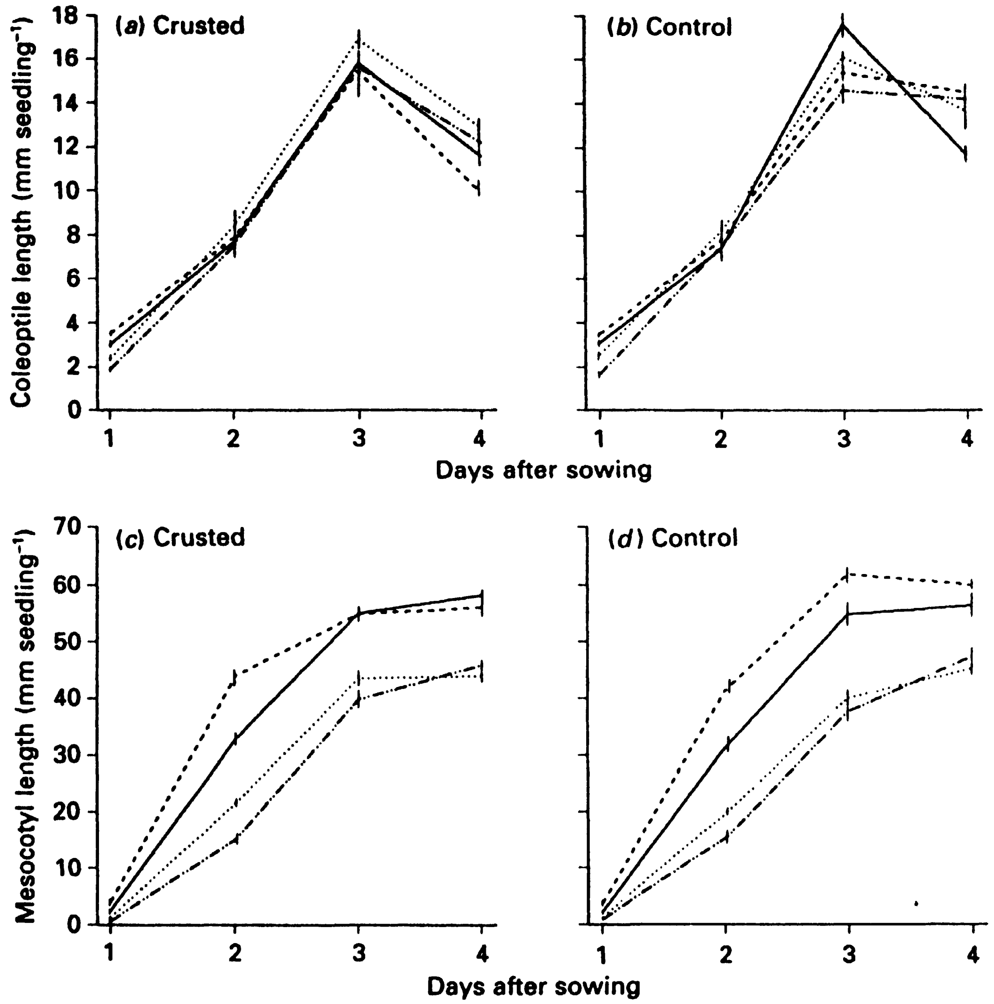

Fig. 2. Length of the coleoptile (a and b) and the mesocotyl (c and d) of the two crust tolerant (IS 1760! ——, IS 12743 – – –) and the two crust susceptible (IS 22237 · · · ·, IS 23317 – · – · –) genotypes in th crusted (a and c) and control (b and d) treatments in Experiment 2. Vertical bars denote SE.

DISCUSSION

Seedlings emerge through soil crusts in various ways. They may emerge individu ally, by exerting high pressure to break the soil crust, or in groups by exertin; cumulative force (Taylor, 1962). In these experiments the use of a precisior planter and control of weeds (Soman *et al.*, 1984) ensured that seedlings wer widely spaced in the seedbed, thus minimizing the possibility of emergence b cumulative force of several seedlings. The seedlings therefore emerged as a resul of the force they exerted individually on the surface crust.

Hadas and Stibbe (1977) reanalysed the data on coleoptile force in whea reported by Arndt (1965), and concluded that the rate of elongation of th coleoptile rather than its diameter was important in determining the amount o thrust exerted. In the case of sorghum we did not find any differences betwee genotypes or treatments in the plumule diameter, measured at three points alon; the length of the plumule (data not reported), suggesting that the difference i

thrust between crust tolerant and susceptible genotypes depended on differences in the elongation rate of the plumule. These differences were the key factor in differences observed in the vertical displacement of weighted discs, simulating a surface crust, by seedlings of sorghum during a five day period following germination (Schilling and Settimi, 1989). Because the strength of a crust increases over time (Soman *et al.*, 1984; Maiti *et al.*, 1986), faster plumule growth would ensure the emergence of tolerant genotypes before the crust became too hard to penetrate. This suggests that the mechanism involved in crust tolerant genotypes is crust avoidance resulting from faster growth of the plumule. The lack of any delay in emergence of the tolerant genotypes compared to that in the uncrusted controls tends to support this conclusion. Rapid plumule extension has also been found to contribute to faster emergence rates in wheat (Sunderman, 1964) and barley (Radford, 1987) under diverse seedbed conditions.

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