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Development of a technique to study seedling emergence in response to moisture deficit in the field – The seed bed environment*

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Summary

The ability of crops of sorghum (*Sorghum bicolor* (L.) Moench) to establish in farmers' fields depends largely on its capacity to germinate and emerge under limited soil moisture conditions. Studies on germination under moisture stress have been previously conducted using osmotic media which do not wholly reproduce the conditions of the seed bed in the field. Hence the need for a field screening technique. A line source irrigation system was used to provide five moisture regimes ranging from −0.08 MPa to −0.92 MPa. The drying rate of the soil and the soil temperature depended largely on incident radiation, and the relationship between the moisture content and daily soil temperature and daily radiation was consistant. Total porosity of the seed bed, derived from bulk density measurements and particle density ranged from 43.8% to 45.3%, which would allow sufficient aeration when as in the experiments conducted here, water content was low (< 0.14 g/g). Under these seed bed conditions the pattern of response of emergence to the moisture gradient was linear or curvilinear. Genotypic differences existed for emergence and its response to water level. The field method developed is useful for identifying genotypes able to germinate and emerge under conditions of low seed bed moisture.

Key words: Moisture deficit, sorghum, seedling emergence, seed bed, soil temperature, soil aeration, genetic improvement

Introduction

Low yields of sorghum and pearl millet in dry years are sometimes the result of poor stand establishment (Leonard & Martin, 1963). Poor establishment may be associated with inferior seed, inappropriate sowing methods, or an unfavourable seed bed environment (P. Soman, R. Jayachandran, F. R. Bidinger and J. M. Peacock, unpublished data; Anon., 1986).

Two years observations in farmers' fields in India, where the emergence of sorghum seedlings was less than 25% of seeds sown, showed that at sowing, soil moisture in the seed bed ranged from 3% to 20% (by weight), and the seed bed temperatures at 4 days after sowing (DAS) ranged from 32°C to 49°C at 50 mm depth and from 36°C to 50°C at 20 mm depth. Under these adverse conditions seedling emergence was poor even though the viability of the seed was high > 80% (P. Soman, R. Jayachandran, F. R.Bidinger and J. M. Peacock, unpublished data). Genetic improvement in seedling establishment might therefore be achieved through

*Submitted as Journal Article No. 794 by the International Crops Research Institute for the Semi-Arid Tropics selection of genotypes under seed-bed conditions of limited moisture and supra-optimal temperatures.

Laboratory studies have shown that, in sandy media, pearl millet and sorghum require a moisture content of between 25% and 50% of the field capacity for optimum germination (Fawusi & Agboola, 1980). Using polythylene glycol 4000, El-Sharkawi & Springuel (1977) found that sorghum seeds would not germinate at water potentials below − 1.0 MPa. Similarly, Stankov & Ladonina (1976) showed that osmotic potentials of sucrose solutions between 0 and (−)2.2 MPa progressively decreased the germination percentage of wheat, barley, oats and millet. Such studies on seed germination in controlled conditions using osmotic media do not necessarily represent the limiting conditions for moisture in the field. The physical properties of seed beds and the hydraulic conductivity of the soil also determine the moisture gradient that become established in the field and hence the supply of water to the seed. Germination also depends on the temperature and aeration of the soil.

A study of seed-bed characteristics was made on a single soil type to determine whether different levels of soil moisture that would affect seedling emergence could be created in the field and from this, to develop the methodology for the selection of genotypes better able to establish under limiting moisture conditions.

Materials and Methods

Field technique

The experiments were conducted in an Alfisol field (Udic Rhodustalf, Patancheru series) at ICRISAT Center located at 18°N, 78°E. This soil contained approximately 54% of coarse sand in the top 100 mm. The trials were done under the clear dry weather conditions of the summer season (March-May) under which there was rapid drying and heating of the seed bed.

The soil was disced and rotovated following primary tillage and then left to dry. Ten broad beds (1.2 m wide) were prepared five on one side of a line-source sprinkler system and five on the other. The five broad beds on one side of the line source representing one replicate and the five on the other side a second replicate of the genotype * irrigation treatments. Plots 2 m long, with a 0.5 m path between them, were laid out along each bed. Each plot was sown with four 30 cm rows of seed at a depth of 50 mm using a John Deere 7100 planter. Each row of each plot contained 50 seeds of a single genotype and there were between 80 and 200 genotypes in the different trials. Single row entries were randomised within the plots and beds of each replicate.

The central line-source sprinkler system (Hanks, Keller, Rasmussen & Wilson, 1976) provided a linear gradient of applied water ranging from 25 mm in the beds nearest to the sprinklers and to about 5 mm on the furthest beds. The delivery rate of the sprinklers was 14 mm h^{-1}. Plots were irrigated on the day of sowing and left to dry. The surface crust that formed on the soil was broken mechanically to facilitate seedling emergence (Soman, Peacock & Bidinger, 1984).

Seeds of sorghum cultivars were derived from plants grown in the same post-rain (September − January) season and kept in a cold store at 4°C. The tests were repeated in four years (1984, 1985, 1986 and 1987) with different sets of genotypes. Emerged seedlings were counted on the last day of emergence (7 DAS) when there was no further increase in emergence. Measurements are expressed as percentage emergence of the 50 seeds sown.

The environment

Cans were used to measure the quantity of water applied to each bed. The moisture content of the soil was estimated gravimetrically. A 10 cm core of soil was collected using a sampler fitted with four internal aluminium rings each 25 mm long, so that soil from each 25 mm zone within the upper 10 cm could be collected and analysed separately. Four samples from each bed on either side of the line source were taken daily starting the day after irrigation and continuing until all the seedlings emerged. Soil moisture potentials were estimated from pressure release curves plotted for the 0-100 mm soil zone.

The bulk density of the soil in the seed zone (25-50 mm) was determined in each bed to characterise the aeration porosity.

Soil temperature was measured at depths of 20 mm and 50 mm at 1400 h using thermocouple probes. Three measurements were made on each bed each day until the seedlings emerged.

Incident radiation, vapour pressure deficit, temperature and open pan evaporation were recorded during the experiment at a meteorological station located 400 m away from the experimental field.

Results and Discussion

The environment

The weather

Relevant weather data for two of the four experimental years are given in Table 1; the weather was generally very dry. The high saturation deficit (SD) prevailing during the first 4-5 days after sowing (3-5 kPa) and the high potential evaporation rates (8-12 mm per day) ensured rapid evaporation. These conditions rapidly depleted moisture in surface soil (0-100 mm) so that seeds were stressed as they germinated and emerged, 2 and 4 days after sowing, respectively.

Table 1. *Pan evaporation (PE), solar radiation (Rad), saturation deficit at 1400 h (SD), wind speed (WS) and maximum (T max) and minimum (T min) temperature for two of the trials at ICRISAT Center*

	Days after sowing	PE mm	Rad. $MJ\,m^{-1}\,d^{-1}$	SD kPa	WS $km\,h^{-1}$	T max °C	T min °C
1984 March (7 – 10)	1	4.6	16.0	2.8	7.5	30.2	21.7
	2	8.4	18.0	4.0	8.0	33.5	18.0
	3	7.5	16.1	4.2	6.4	34.0	20.6
	4	8.8	15.1	4.6	8.2	35.1	22.0
1987 March (25 – 29)	1	10.9	23.9	5.2	6.8	36.2	19.0
	2	11.5	23.1	4.9	10.6	36.0	18.5
	3	12.0	23.2	5.1	12.0	36.0	20.5
	4	8.4	17.7	4.6	7.8	34.6	20.2
	5	10.8	22.9	5.1	6.3	36.5	20.5

Soil moisture

The amount of water applied from the line-source irrigation system decreased almost linearly with distance. The percentage water in the top 100 mm of soil, measured the day after irrigation, increased almost proportionally with the amount of applied water up to 25 mm but not beyond (Fig. 1). The relationship, which was the same for all years, was described by the equation $y = a - b\,e^{-cx}$ in which y is the moisture content by weight, x the amount of water applied and a, b and c are constants of 11.65, 0.45 and (−)0.093 respectively. The maximum moisture content of the surface soil was about 11.0% and an application of 25 mm water was sufficient to produce this in all trials. Soil water potentials, derived from pressure release curves on

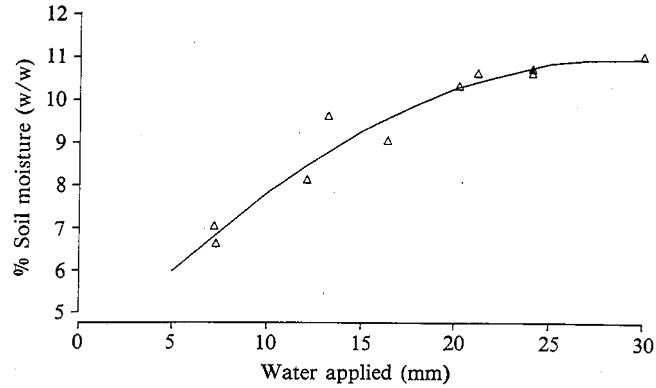

Fig. 1. Relationship between gravimetric moisture content (%) in the top 100 mm soil measured a day after irrigation and the amount of irrigation applied (mm), dry season, 1984. $y = 11.65 - 0.45e^{-0.093x}$.

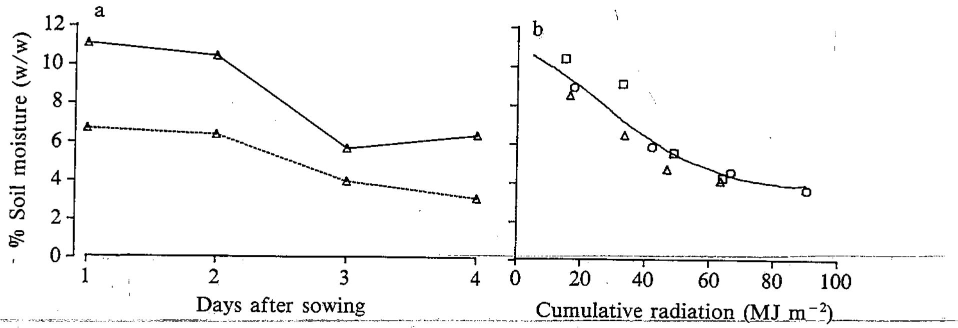

Fig. 2. a) Change in gravimetric moisture content (%) in seed-zone soil (25 – 50 mm deep) for the wet (———) and dry (---------) extremes of the irrigation treatments during the period from sowing to seedling emergence in 1984. Standard errors are smaller than the size of the symbols. b) Relationship between gravimetric moisture content of the soil and cumulative radiation for 1984 (□), 1986 (○), and 1987 (△). Points represent the different days after sowing in the wet treatment. $y = 12.34 - 0.193x + 0.0011x^2$, $R = 0.92$.

soil taken from seed depth (25-50 mm) from the wet and dry extremes of the irrigation treatment were −0.08 and −0.92 MPa, respectively.

The pattern of soil drying during 5 days between sowing and seedling emergence is shown for one year (1984) in Fig. 2a and plotted as a function of accumulated radiation for three years 1984, 1986 and 1987 in Fig. 2b. The relation between soil moisture content (y) and cumulative radiation x, $y = 12.34 - 0.193x + 0.0011x^2$, which was consistent between years and can therefore be used to predict available moisture in the top 100 mm of soil. The implication from this data that the incident radiation rather than soil moisture content predominantly controls the drying rate is consistent with the view of Hillel (1980).

Soil temperature

The differential water treatments changed soil temperatures at 20 mm and 50 mm depth in all of the trials but daily soil temperatures could not be consistently related to soil moisture content (correlation coefficients were > 0.10 in all cases). Temperatures at 20 mm depth in

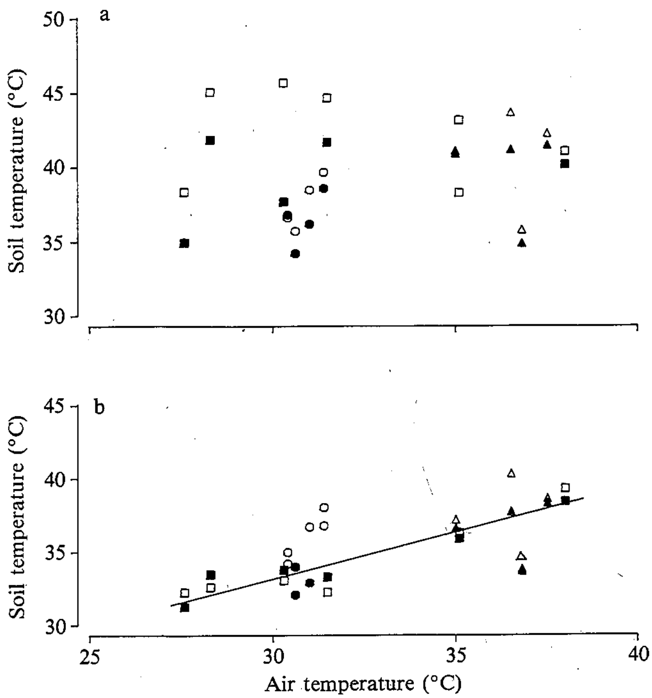

Fig. 3. The relationship between daily soil and air temperatures measured at 1400 h for the period between sowing and emergence. a) Soil temperature at 20 mm depth, and b) soil temperature at 50 mm depth. Open and closed symbols indicate the extreme dry and wet irrigation treatments, respectively for ○, 1984; △, 1985 and □, 1987. y = 18.84 + 0.50x, R = 0.68.

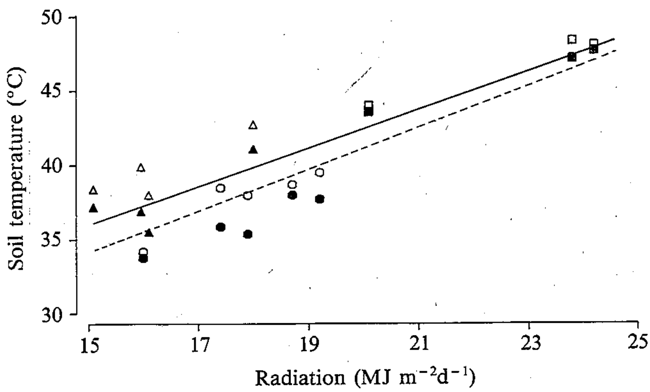

Fig. 4. The relationship between soil temperatures at 20 mm (solid symbols and line) and 50 mm (open symbols and hatched line) for the driest irrigation treatment and the accumulated total radiation between sowing and seedling emergence. For 20 mm depth, y = 16.21 + 1.31x, R = 0.88 and for 50 mm depth, y = 12.50 + 1.43x, R = 0.89.

the soil were not directly related to air temperature either (Fig. 3a) but there was a weak positive correlation between soil temperature at 50 mm depth and air temperature when all data from the three years 1984, 1985 and 1987 were pooled (Fig. 3b). Manrique (1986) has shown that the relationship between air and soil temperatures becomes weaker as the soil dries and less water is available for evaporation so that under hot conditions soil temperatures become increasingly regulated by the intrinsic thermal properties of the soil than by air temperature. The experiments reported here were conducted between March and May, during the hottest part of the year in this region, and soil temperatures at 20 mm soon became independent of air temperature as the upper layer of the soil rapidly dried but remained dependent on air temperature at 50 mm in soil, which retained the moisture longer.

Soil temperatures at 20 and 50 mm depth both were more strongly related to daily radiation than to air temperature (Fig. 4) and were not greatly influenced by the moisture contents of the soil at these depths. This agrees with the findings of Manrique (1986) for other tropical soils of very low moisture content. When the soil is exposed to direct sunlight the net energy input can be quite large. Because soils have high heat capacity (volumetric heat capacity of a dry soil = 1.2 MJ m^{-3} $°C^{-1}$) a considerable amount of energy is stored for a unit change in temperature. But as the heat conductivity (K) of the soil is low (e.g. K = 0.30 for dry sandy soil) much of the energy is stored in the surface soil; hence attaining very high temperatures independent of air temperature. This can change only by an increase in soil moisture which results in an increase of K (e.g. K changes from 0.30 to 1.80 when moisture content is 20%). Therefore when the soil is dry, as in these experiments, the temperature of the dry soil becomes independent of air temperature and soil moisture.

A complete description of seed-bed conditions should include soil aeration, but measurements were not made in the present study. Assuming a particle density of 2.65 Mg m^3 for the soil, the bulk densities that were measured (Table 2) indicate a mean total porosity between 43.8% and 45.3%. Such a porosity with the low water contents that prevailed during experiments (< 0.14 g/g) should have allowed sufficient aeration, so it is unlikely that soil aeration would have been limiting.

Table 2. *Soil bulk densities measured at different moisture treatments after a line source irrigation (1 = nearest to the sprinkler and 4 = furthest from the sprinkler) for two trials*

	Bulk density Mg m^{-3}					
Moisture regimes	1	2	3	4	Mean	S.E.
1986	1.49	1.43	1.45	1.42	1.45	±0.04
1987*	1.48	1.48	1.52	—	1.49	±0.03

*Only 3 moisture treatments were considered in the 1987 trial.

Seedling emergence

In all experiments (1984, 1985, 1986 and 1987) there were highly significant differences ($P < 0.001$) in seedling emergence due to genotype and moisture treatments. The genotypes showed a wide range of emergence response in each irrigation treatment. For example, in the 1984 experiment, the emergence percentage ranged from 93% to 36% in the wet and 50% to 0% in the dry extremes of irrigation. The responses of four genotypes from this experiment are shown in Fig. 5a along with the mean of all. This indicates that there were two main

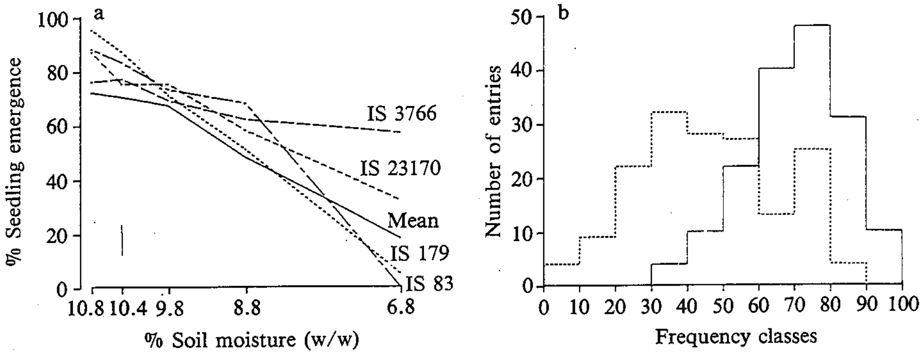

Fig. 5. a) Mean percent emergence of all 166 cultivars and of four individual sorghum cultivars in each moisture treatment along the line-source irrigation gradient in the dry season of 1984. The vertical bar represents the standard error of the mean of all genotypes. b) The distribution of percent emergence of 166 sorghum cultivars in the wet (10.8% soil moisture, ( ) and the dry (6.8% soil moisture, ( ) extremes of irrigation in the 1984 experiment.

types of responses, those that were linear (e.g. IS 179) and those that were curvilinear (e.g. IS 83). There were significant genotype $*$ treatment interactions ($P < 0.05$) also in these experiments. For example, IS 3766 maintained its emergence between 76% and 57% compared with IS 189 which achieved 95% in the wet treatment but fell steeply to 4% in the dry treatment, an example of extreme sensitivity to seed bed moisture stress.

The range of emergence obtained in the experiments suggest that it should be possible to select genotypes that are stress tolerant. For selection, however, testing in all the five moisture treatments may not be necessary. A minimum of two will show both the potential emergence (in the wet treatment) and the apparent tolerance to moisture deficit (in the dry treatment) in which case the land requirement could be reduced to 40%. Fig. 5b shows the relative shift in the emergence pattern of a set of sorghum genotypes from the wet to a dry treatment. The genetic difference for tolerance to dry soil conditions thus found in sorghum offers a useful attribute for use in crop improvement. This method to differentiate performance of sorghum was found to be repeatable (data not given in this paper) and can be recommended as a screening technique.

As far as germination is concerned, it is believed that the initial moisture level at the beginning of the germination process which influences imbibition is more critical. However for emergence, the rate of moisture depletion in the soil may be more important. The present technique does not distinguish between the specific effects of temperature or of water deficit *per se* on germination and subsequent seedling emergence. It merely offers an empirical method to group genotypes as tolerant or susceptible to hot and dry seed bed conditions. Such specific effects can, however, be investigated in separate studies by controlling temperature independent of moisture deficit, as described by Soman & Peacock (1985), or in the field by shading to decrease incident radiation or by changing surface colouring with kaolin to reduce radiation absorption by the soil.

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