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A LABORATORY TECHNIQUE TO SCREEN SEEDLING EMERGENCE OF SORGHUM AND PEARL MILLET AT HIGH SOIL TEMPERATURE

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SUMMARY

Apparatus was built to screen sorghum and pearl millet for seedling emergence through a hot soil surface. Seeds were sown in soil in long clay pots arranged in a steel water tank so that the top 7 cm of the pots was above the water level. The soil in the pots was heated with infra-red lamps fitted to a frame above the tank. By adjusting the height of the frame the temperature of the soil could be changed. The system allows emerging plumules to be subjected to high soil temperatures (up to 50°C) but without water stress. Both crops exhibited genotypic differences in emergence.

In India, West Africa and southern Africa soil surface temperatures in farmers' fields commonly exceed 45°C and temperatures as high as 60°C have occasionally been measured (Soman *et al.*, 1981; ICRISAT, 1983; Peacock, 1977; Peacock and Ntshole, 1976). Soil temperatures above 45°C inhibit the emergence of seedlings in sorghum and pearl millet resulting in poor crop stands (Mustain, 1981; Soman, 1981; Garcia-Huidobro *et al.*, 1982; Peacock, 1982; Wilson *et al.*, 1982; Peacock and Heinrich, 1984). These experiments demonstrated considerable variability among sorghum and pearl millet lines for seedling emergence at high temperature. As emphasized by Wilson *et al.* (1982) it is important to identify lines of sorghum and pearl millet, two major cereals of semi-arid regions, that will emerge at high soil temperature.

Genotype response to temperature is difficult to study in the field because soil temperature varies with the moisture status of the soil and the system becomes even more complex if a crust develops on the soil (Soman *et al.*, 1984). Measurements of germination in constant temperature incubators are not necessarily relevant to the field where soil temperatures vary diurnally. Our observations with selected sorghum lines have shown that material which fails to germinate in incubators at 40°C will germinate and emerge when sown in soil of the same mean temperature.

Various techniques have been used to study the germination and emergence response of cereals to high soil temperature (Scheuring *et al.*, 1978; Wilson *et*

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al., 1982; Buckle and Grant, 1974). Scheuring *et al.* (1978) recorded germination of sorghum kept in wet sand in a warm water bath at a constant temperature for 72 hours; the seeds were thus exposed to a continuous high temperature (maximum of 40°C). Wilson *et al.* (1982) varied soil temperature using two different surface colourants, charcoal and kaolin, in small plots. Though the temperature regime obtained with their technique was adequate for screening for emergence, the water status of the soil could not be controlled. Similarly Buckle and Grant (1974), who grew maize seedlings in soil in dark incubators, did not replenish the soil moisture during the course of the experiment. Mustain (1981) observed an effect of differing moisture levels on germination at high temperatures. In all these experiments it was difficult to study the effect of temperature alone on seedling emergence because of interactions between water status and soil surface conditions. This paper describes a technique used to examine the effect of high soil surface temperature on selected lines of sorghum and pearl millet where soil water was not limiting and surface crusts absent.

MATERIALS AND METHODS

Apparatus

Porous clay pots, 30 cm in length and 10 cm in diameter, were filled with sieved top soil (0-20 cm depth) from an Alfisol field (Udic Rhodustalf, Patancheru series). The soil type was loamy sand, its principal components being coarse sand (particle size 200-2000 μm) 53%, fine sand (20-200 μm) 25% and clay (<2 μm) 16%. The pots were placed in a 183 x 92 x 38 cm steel water tank so that only the top 7 cm of the pots was above the water level. The soil surface was 2 cm below the mouth of the pot. Thirty-six pots were placed in the tank. The surface of the water was covered with floating white plastic balls to reduce evaporation.

The soil in the pots was heated with infra-red lamps (240-250 V, 250 W, Phillips, Type IRR) fitted to a frame above the tank. Ten lamps were placed in two rows, 40 cm apart. The temperature of the soil surface could be altered by varying the height of the frame above the soil surface, to obtain temperatures of 35, 40, 45 and 50°C measured at 2 cm below the soil surface. The design is simple and the total cost of the unit approximately one tenth that of a commercial growth chamber.

Operation

Seeds selected for uniformity in size were sown at precise depths (3 cm for millet and 5 cm for sorghum) at the rate of ten per pot.

The infra-red lamps were automatically switched on at 0800 Indian Standard Time (IST) and switched off at 1800 IST by a time clock. Soil temperature was measured every two hours in each pot using copper-constantan thermocouples and a millivolt meter (Comark Instruments, UK). Temperature of the soil surface was difficult to measure accurately as the thermocouple junction was heated by radiation. The junctions were therefore buried at a depth of 2 cm in the soil and the output used to indicate the surface temperature. Soil temperatures at 5, 10 and 15 cm depths were also measured in a few cases.

Water was added to the tank daily to maintain a constant level, ensuring that the wet soil column (25 cm long) in the pots provided a steady water supply for the seedlings while allowing them to be affected by the temperature of the soil. The soil water content in the pots was determined gravimetrically. A small soil tube (2 cm diameter) was used to take 10 cm soil samples from two to four days after sowing (DAS). Samples were dried at 110°C and the percentage moisture estimated.

Experimental treatments

Three experiments using this technique are described. In Experiment I 24 sorghum entries (*Sorghum bicolor* (L.) Moench) comprising seventeen germplasm lines, two hybrids, one released variety and four experimental varieties were tested at four diurnal maximum temperatures: 35, 40, 45 and 50°C. In Experiment II 25 S_1 lines each from four different breeding composites of pearl millet (*Pennisetum americanum* (L.) Leeke) and in Experiment III 36 lines from a breeding population of sorghum were all evaluated at 45°C. The experimental design was a randomized block with four replicates.

RESULTS AND DISCUSSION

The soil surface temperature measured in the clay pots for a 24 hour period was compared with the temperature measured at the same depth in an Alfisol field, when the water content in the top 10 cm in the field was 5%; such conditions are characteristic of pre-sowing in the rainy season following a light rain (10-15 mm). In the pots, soil temperature increased curvilinearly after the lamps were switched on and reached a maximum between 1500 and 1800 IST (Fig. 1). Temperature then declined when the lamps were switched off. The diurnal temperature cycle in the soil surface closely followed the pattern observed in the field. The interval (1-2 h) during which the seeds or seedlings were exposed to the maximum daily temperature in the heater system was similar to that in the field. This is an improvement over the experimental technique used by Scheuring *et al.* (1978) where the soil temperature was kept constant.

A representative sample of soil temperature measurements for one run of the heater system for each temperature is shown in Fig. 2. There was very little variation between pots; for example the coefficients of variation were 2.4, 2.3 and 2.5% for temperatures of 40, 45 and 50°C, respectively.

Soil moisture content (0-10 cm depth) was measured at maximum temperatures (2 cm deep) of 40, 45 and 50°C and found to fall within the range 17.3 to 17.9% in each case. Analysis of variance of the water content from

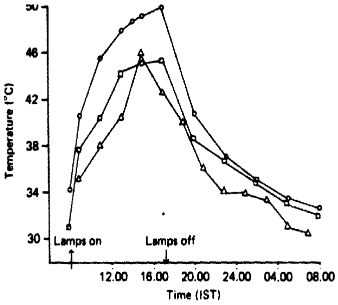

Fig. 1. Soil temperature measured in the pots and in the field at a depth of 2 cm: diurnal maximum in the pots in the 50°C (○) and 45°C (□) treatments and diurnal in the field (△). SE less than symbol size.

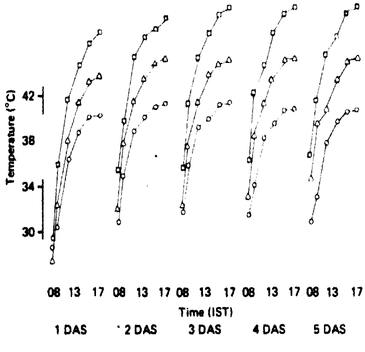

Fig. 2. Soil temperatures measured in the pots at a depth of 2 cm on five consecutive days after sowing (DAS); diurnal maximum in the 40°C (○), 45°C (△) and 50°C (□) treatments. SE less than symbol size.

each temperature treatment showed that this did not differ significantly on different days (1-4 DAS). However, as temperatures increased in each treatment the top centimetre of soil in the pots dried out, but this did not affect germination and emergence as moisture was available in the seed zone. In contrast to the field, there was no significant decline in soil moisture in the pots with increase in temperature; this was one of the problems encountered by

Wilson *et al.* (1982). Buckle and Grant (1974) did not report the water status of the soil in their experiments with maize.

Soil crusting did not occur in any of the pots in the trials, probably because there was a continuous supply of water from the lower soil layers and no mechanical impact from raindrops (see Soman *et al.*, 1984).

Emergence by four DAS exceeded 80% in the 40°C treatment. The emergence response of the sorghum entries is shown in Table 1. The effect of both temperature and genotype, analysed after pooling the data for each temperature, was highly significant ($P < 0.001$) with considerable genotype x temperature interaction ($P < 0.01$). IS 6118 was the only entry which emerged well (60%) at 50°C. At 45°C only 40% of the entries achieved 60% emergence, while at temperatures of 40 and 35°C corresponding figures of emergence were 87 and 96%. The technique thus successfully differentiated sorghum material by ability to emerge as a function of temperature.

The technique provided repeatable results. For example, IS 1037 achieved

Table 1. *Emergence (%) of sorghum achieved at different diurnal maximum soil temperatures (measured at a depth of 2 cm)*

Entry name	Emergence (%)			
	35°C	40°C	45°C	50°C
IS 1037	100	87	100	10
IS 6118	80	90	70	60
IS 6087	60	50	60	30
IS 2282	100	90	80	20
IS 1034	100	100	30	0
IS 9867	90	70	80	0
IS 10022	90	80	50	0
IS 2146	100	60	0	0
IS 1054	100	70	20	0
IS 4821	90	30	30	0
IS 4817	90	80	0	0
IS 83	100	100	0	0
IS 2705	80	60	0	0
IS 7235	100	80	30	0
IS 7752	100	90	50	0
IS 17595	100	85	80	0
IS 17605	100	83	75	0
CSH 1	46	27	20	0
CSH 8	73	63	40	0
CSV 5	73	93	80	0
SPV 351	85	†	73	0
SPV 354	85	70	67	0
SPV 386	50	60	55	0
SPV 387	90	65	50	0
Mean	86.8	73.2	47.5	5.0
SE	3.2	3.9	6.1	2.8

† Not tested at 40°C.

92 ± 3%, 86 ± 4%, and 86 ± 3% emergence in three preliminary tests at 40°C, and CSH 6, an entry with poor emergence at 40°C, achieved 40 ± 7% and 36 ± 4% emergence in two tests at this temperature (Soman, 1981).

Soil temperature rises above 40°C in the semi-arid tropics during the sowing season and inhibits emergence in a number of lines. Initial experiments showed that a temperature maximum of 45°C gave the best selection pressure and very few lines emerged at 50°C. The genetic differences among the lines from four pearl millet and a sorghum population measured at 45°C are shown in Fig. 3.

High soil temperature affects germination and emergence in several ways. The soil temperature in the seed zone can inhibit germination itself and plumule extension can be halted at any time after germination. In these experiments, when the topsoil in the clay pots was removed, many ungerminated seeds and seedlings with damaged plumules which had failed to emerge were observed. Buckle and Grant (1974) recorded similar abnormalities with maize seedlings grown at an average soil temperature of 40°C. In addition differences in the rate of plumule extension were observed when sorghum was grown at a range of temperatures (Soman, 1981).

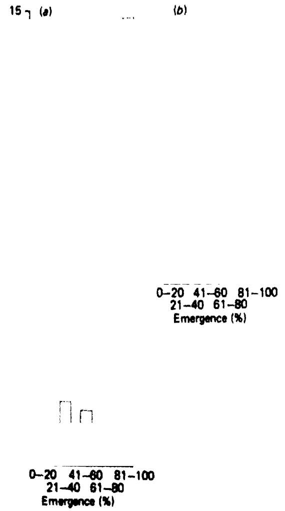

Fig. 3. Classification of entries from four pearl millet (a, b, c, d) and one sorghum population (e) c the basis of emergence at a soil surface temperature of 45°C.

This technique has been used to classify germplasm and breeders' lines according to their performance at high (up to 50°C) soil surface temperatures and shows that genotypic variation clearly exists among sorghum and pearl millet lines. Further studies using this system coupled with a more detailed biochemical analysis are required to understand better the mechanisms of inhibition of emergence by high temperature. Such studies are reported by Ougham and Stoddart (1985) in the following paper.

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