J. Agronomy and Crop Science 159, 192—198 (1987)

ISSN 0931-2250

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International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru P.O. Andhra Pradesh, 502 324, India (Journal Article No. JA462)

Effects of High Soil Temperature and Water Stresses on Malian Pearl Millet and Sorghum during Seedling Stage

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With 3 figures and 3 tables

Received October 1, 1986; accepted November 28, 1986

Abstract

Pearl millet (*Pennisetum americanum* [L.] Leeke) and sorghum (*Sorghum bicolor* [L.] Moench) can suffer from poor stand establishment under conditions of high soil temperature and water stresses. A line source sprinkler irrigation system and a charcoal pit technique were used to evaluate stand establishment and high correlations existed between the two methods. It may be possible to use the charcoal pit technique as a predictive tool in drought resistance breeding programs.

Key words: *Pennisetum americanum* (L.) Leeke, *Sorghum bicolor* (L.) Moench, drought stress, evapotranspiration, water use.

Drought and crop establishment are the two major priorities for millet and sorghum improvement in the low rainfall zones of West Africa (HOUSE 1982). This area is characterized by intermittent periods of moisture stress and high radiation loads which can have disastrous effects upon crop production, particularly when they occur during the seedling stage (GS-1). Yield reductions, caused by incomplete stand establishment due to high soil temperatures and moisture stress, are common (PEACOCK 1982).

The line source sprinkler irrigation system (LS), as developed by HANKS et al. (1976), has been used extensively to investigate various aspects of moisture stress effects on such diverse crops as sugarbeets (MILLER and HANG 1980), grain legumes (PANDEY et al. 1984), sorghum (O'NEILL et al. 1983), rice (O'TOOLE and NAMUCO 1983), and wheat (HANG and MILLER 1983). This technique provides the application of a continuously decreasing gradient of water from the LS to the extremities of the experimental plot, which enables researchers to better understand the development and effects of moisture stress.

The interactive effects of high soil temperature and moisture stresses upon germination and stand establishment are difficult to separate in the field. To investigate the effects of high soil temperatures during early growth, a technique has been developed at ICRISAT in which a thin layer of powdered charcoal or kaolin is spread evenly over the soil to modify soil temperatures (WILSON et al. 1982). They have demonstrated differential emergence of sorghum cultivars under high soil temperature stress.

The present study was conducted to test screening procedures used to evaluate the response of pearl millet and sorghum varieties to moisture and high soil temperature stresses during GS-1 in Mali. The LS system was chosen as a field screening method to subject

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Malian varieties of millet and sorghum to moisture stress and charcoal pits (CP) were used to subject the same varieties to high soil surface temperature stress. It was also proposed to investigate the correlation of results obtained in the pits with those obtained in the field.

Methods and Materials

The study was conducted at the Cinzana Agricultural Experiment Station (near Segou, Mali) during March and April, 1984, the period of the year with maximum solar radiation. The station, located between the Bani and Niger Rivers in the 700 mm mean annual rainfall zone (VIRMANI, REDDY, and BOSE 1980), was developed as the major research site for the Sahelian zone of Mali. There are five major soils on the station; that used in the present study was a loamy sand (83 % sand) of the Oxic Haplaustalf family with an average gravimetric water holding capacity of 13 % in the upper 30 cm. Cation exchange capacity was low (4.2 meq 100 g^{-1}) and pH averaged 5.6.

Two LS systems were installed, one each for millet and sorghum, after a uniform preplant irrigation of 13 mm. The systems were oriented in an east-west direction with eight replications of sixteen entries in a randomized block design. Rain gauges were located in each replication at 0, 1.5, 4.5, 7.5, 10.5, and 13.5 m from, and perpendicular to, the LS. These five positions represented the five water application treatments. Diammonium phosphate was banded at a rate of 42, 46 N, P kg ha^{-1} four days before planting. Five seeds of millet and sorghum were hand planted in pockets spaced every 20 cm on March 11 and 12, respectively, and Furadan (Carbofuran; 2, 3-dihydro-2, 2-dimethylbenzofuran-7-yl- methylcarbamate) was incorporated for insect control. Single entries were planted per row in rows spaced at 75 cm intervals. Pockets were thinned to one plant per pocket between growth stage 1 and 2 (VANDERLIP and REEVES 1972).

Each LS system was run every third day during the evening when wind velocities were relatively low. The period of water application was sufficient to replace moisture lost through maximum evapotranspiration (DOORENBOS and KASSAM 1979) in the high water application treatment during the previous three days. Soil temperatures were measured at depths 1, 5, and 10 cm with an insertion probe thermocouple in each irrigation treatment and all replications between 13.00 and 15.00 h local time. Measurements were taken in the seedbed prior to, and on the day following, an irrigation at similar distances from the LS as the rain gauges. Plant populations in each of the five water application treatments were determined after thinning and final population counts were taken one day prior to harvest. Two plants per treatment were harvested 37 days after planting (DAP), dried in the sun to constant weight and dry weights were determined.

Concurrently, four pits were dug and cement floors and block walls were constructed with an inside dimension of 240 × 240 × 40 cm. The inside walls and floor were lined with plastic to enable accurate water application and prevent moisture loss. Each pit was then filled to 30 cm with the same soil used in the field test to a bulk density of 1.65 g cm^{-3}. The resulting pit soil surface was even with that of the surrounding field surface. Millet and sorghum of the same varieties used in the LS test were planted in 1-m rows, 3 cm deep in four replications of a randomized block design at a rate of 50 seeds per meter on April 2, 1984. Each block was irrigated with 45 mm of water, sufficient to bring the upper 15 cm of soil to field capacity, and a 0.5-cm covering of powdered charcoal was spread evenly over the surface. Data were taken of seed germination and vitriosity (endosperm corneousness) in the laboratory (HOUSE 1982), and of emergence, vigor (MAITI et al. 1981) at emergence, and survival at 10 DAP in the CP. There was a 3.7-mm rain during the evening of 10 DAP so vigor scores of recovered surviving plants were taken on 11 DAP (MAITI et al. 1981). Soil temperatures at 1, 5, and 10 cm were measured each day of the 11-day experiment between 13.30 and 14.30 h and maximum unshaded air temperature measured 10 cm above the soil surface was recorded at the agrometeorological station 0.5 km from the CP and LS test sites.

Results and Discussion

Environment

Environmental conditions during the 37-day study were extreme with maximum temperatures averaging 39 °C (Table 1). Pan evaporation ranged from 8.2 to 19.6 mm day^{-1} with a mean of 14.0 mm day^{-1}, rather high due to advection. Potential evapotranspiration (ETP) was calculated by the Penman method (GOMMES 1983) and by using pan coefficients as suggested by DOORENBOS and KASSAM (1979). The two methods differed by only 0.1 mm day^{-1} when averaged over the total experimental period, with similar maximum and minimum rates. Maximum evapotranspiration (ETmax), that quantity of water required by crops during various stages of growth, was calculated using ETP and crop coefficients ranging from 0.40 at planting to 0.84 for millet and 0.77 for sorghum at 37 DAP (DOORENBOS

Table 1. Daily temperature, pan evaporation, estimates of potential evapotranspiration (ETP), and maximum evapotranspiration (ETMax) from March 12—April 17, 1984

	Maximum	Minimum	Mean
Temp. Max. (°C)	42.9	26.9	39.3
Temp. Min. (°C)	27.5	9.5	19.2
Pan Evap. (mm day^{-1})	19.6	8.2	14.0
ETP[a] (mm day^{-1})	8.9	4.4	6.6
ETP[b] (mm day^{-1})	8.8	4.1	6.7
ETMax[c] (mm day^{-1})	6.0	1.9	4.2

[a] Penman equation (GOMMES 1983).
[b] Penman equation (DOORENBOS and KASSAM 1979).
[c] Penman equation and crop coefficients (DOORENBOS and KASSAM 1979).

and KASSAM 1979). This period represented approximately 30 and 25 % of crop development for the millet and sorghum, respectively. Maximum evapotranspiration ranged from 1.9 mm day^{-1} at planting to 6.0 mm day^{-1}.

Line Source Test

Total water application, regressed against distance from the line source, showed a very linear pattern. Coefficients of determination were greater than 0.96, but because of continual winds from the north, regression slopes on that side of the LS were much steeper than on the south. Total water applications in the lowest treatment on the north side of the LS were 50 and 69 mm for millet and sorghum, respectively. Of this total, 25 and 32 % were delivered during the last two irrigations to the millet and sorghum, respectively. Because severe water deficits prior to these last two irrigations resulted in drastically different growing conditions on either side of the LS, only the results from the south four replications are presented.

Soil temperatures were very similar for both sorghum and millet. Figure 1 illustrates the soil temperatures for sorghum in the high (1.5 m from LS) and low (13.5 m from LS) water application treatments at 1 and 5-cm depths. Mean daily maximum unshaded air temperature was 44 °C and surface soil temperatures in the low water treatment were similar. Soil temperatures were reduced following irrigation due to evaporative cooling, but rose on subsequent days (Fig. 1). Temperatures at the 5-cm depth remained about 5 °C cooler than surface temperatures. Although the higher water application treatment received substantially more water than the low treatment, surface soil temperatures reached nearly similar values on several occasions.

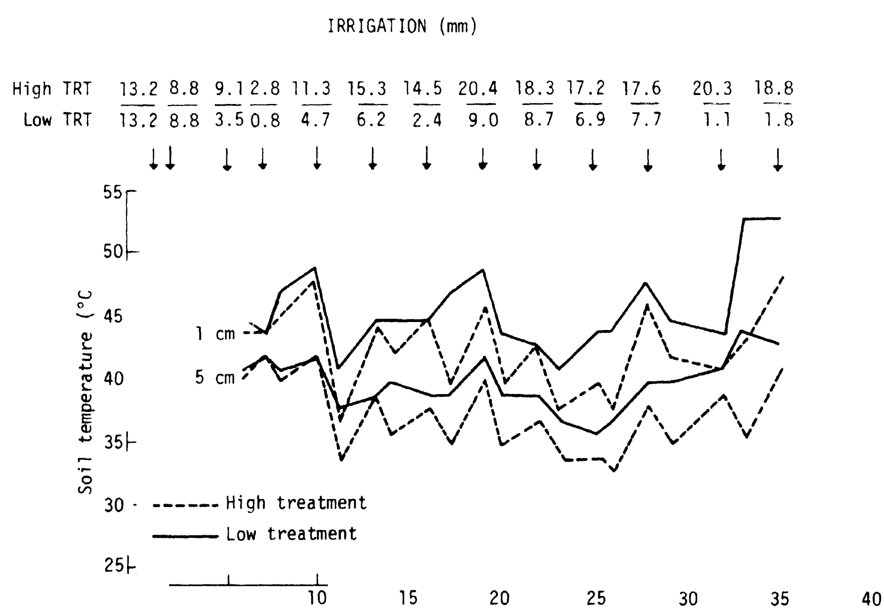

Fig. 1. Mean soil temperatures taken between 13.00 and 15.00 h at 1 and 5 cm as a function time for the high and low water application treatments in the sorghum line source test. Arrows at the top of the graph represent irrigation events and quantities applied to each treatment are given above the arrows

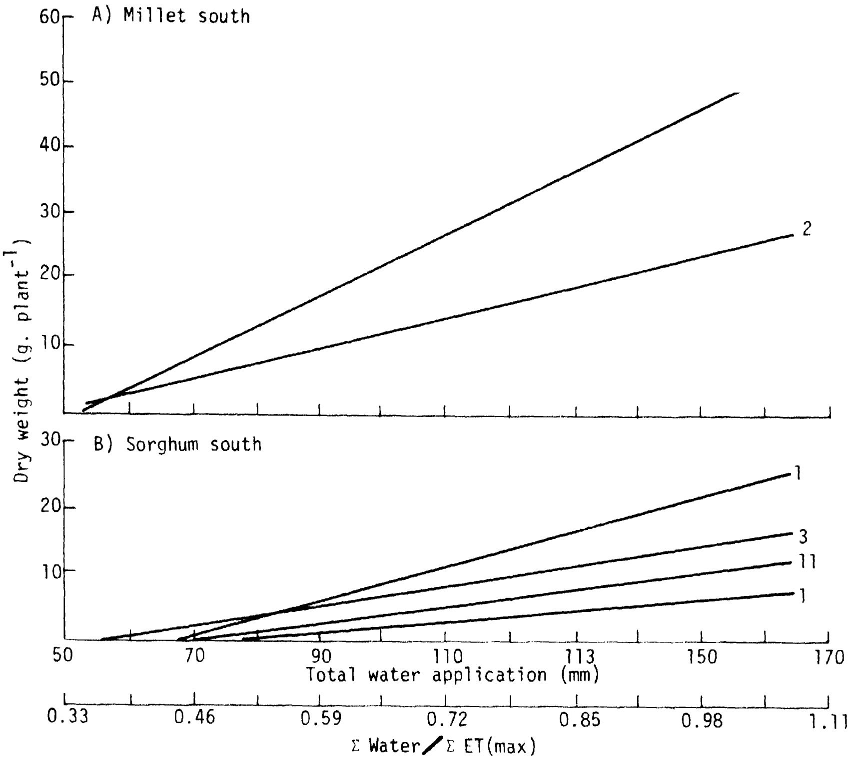

Fig. 2. Grouped regression lines of mean dry weight of: A) millet and B) sorghum as a function of total water applied during the 37-day study and the ratio of total water applied to cumulative maximum evapotranspiration. Number of varieties out of 16 which each line represents is given at the right of the line

Mean dry weight of two plants from each treatment was regressed against total water applied during the 37 days of the study (Fig. 2). An indication of the degree of moisture stress is given on the secondary abcissa as the ratio of total water applied to cumulated ETmax. Differences in plant populations, which could affect water utilization by individual plants, was initially included in the analysis. There was no significant improvement of the analysis when percent population was used so all calculations were done with dry plant weight. Two separate response groups for millet and four for sorghum were identified by combining entries with lines of similar slopes and intercepts (Fig. 2). Growth of 14 of the 16 millet varieties was similar with respect to water application. The response of sorghum was more diverse; there was one superior sorghum variety, three others above average, and one below (Fig. 2). Millet generally produced more dry matter than sorghum at all levels of water application. At a water application rate of 50 % cumulative ETmax, millet dry matter was three times greater than that of the best sorghum entries. All entries were Malian varieties but millets have tended to do better in similar sandy soils whereas the reverse has been true on heavier soils (Serafini 1983).

Charcoal Pit Test

Daily soil temperatures for millet at 1, 5, and 10 cm with charcoal applications are represented in Figure 3. Initial soil temperatures were lower than unshaded air temperatures because of evaporative cooling after irrigation. Surface temperatures rose to 60 °C at 7 DAP and remained near there until a rain occurred at the end of the period (Fig. 3). Temperatures at 5 cm (2 cm deeper than planting depth) reached 47 °C at emergence and temperatures in the planting zone must have been around 50 °C at that time. Temperatures at 5 cm and maximum unscreened air temperature reached similar values at 3 DAP.

Maximum percent emergence for millet in the CP was 59 %, not significantly different from the local check (CMM 374) or the mean (Table 2). There was a 17 and 19 % loss of population between emergence and day 10 for the check and best millet entry, respectively. The stand of the poorest entry decreased by

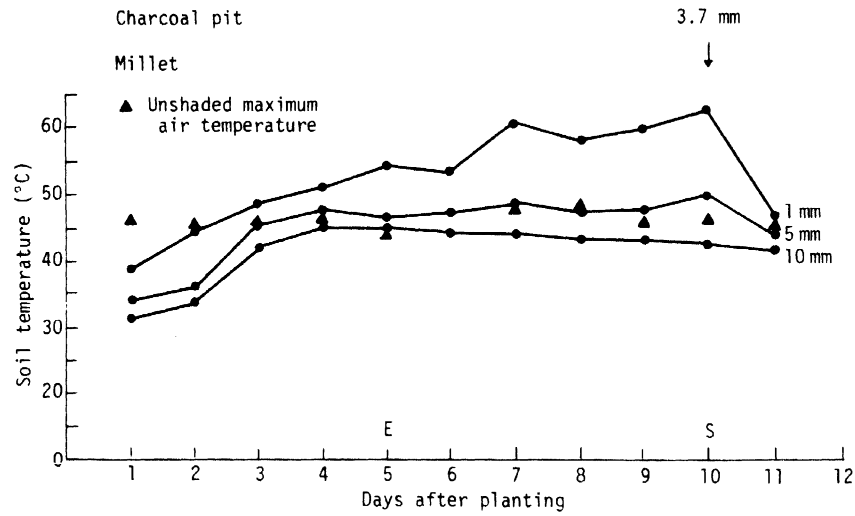

Fig. 3. Mean soil temperatures taken between 13.30 and 14.30 h at 1, 5, and 10 cm and unshaded maxim air temperature as a function of time in the millet charcoal pit. Emergence (E) was at 5 DAP, final survival vigor was determined after 3.7 mm of rain during the evening of 10 DAP

36 % compared to the mean reduction of 22 %. Both the local check and the best entry recovered and appeared vigorous after 3.6 mm of rain during the evening of 10 DAP. The local sorghum check (CSM 205) and best entry had a very good percent emergence and vigor scores, both significantly better than the mean and worst entry (laboratory germination for worst sorghum entry: 59 %) but their stand was reduced 29 and 30 %, respectively. Their survival vigor score was good, especially when compared to the mean or the worst entry.

Table 2. Responses of various parameters of 16 millet and sorghum varieties to high temperature stress in charcoal pits

Entry	Emergence (%)	Emergence vigor (1—5)[a]	Survival day 10 (%)	Survival vigor day 11	Vitri-osity (1—5)[b]
Millets					
Check					
(CMM 374)	47.0	1.0	38.8	1.3	3.0
Maximum	59.0	1.0	48.8	1.0	2.3
Minimum	29.0	3.0	18.5	4.3	4.3
S.E. ±	8.53	0.29	7.10	0.32	0.53
Mean	42.9	1.8	33.3	2.5	3.3
Sorghum					
Check					
(CSM 205)	71.0	1.0	50.8	1.3	2.3
Maximum	74.0	1.0	51.8	1.0	1.5
Minimum	6.5[c]	3.8	0.0[c]	5.0	4.8
S.E. ±	7.90	0.32	5.73	0.37	0.43
Mean	46.3	2.3	26.4	3.2	3.1

[a] Ranking 1 to 5 with 1 being superior (MAITI, RAJU, and BIDINGER 1981).
[b] Ranking 1 to 5 with 1 being superior (HOUSE 1982).
[c] S.E. does not refer to these values.

Table 3. Correlations for various parameters of 16 millet and sorghum varieties between responses in charcoal pits and in the low water application treatment of a field line source irrigation gradient

Field / Pits	Emergence (%)	Survival (%)	Dry Weight (g plant^{-1})
Millet			
Emergence (%)	0.28*	−0.01	−0.29*
Emergence vigor	0.16	0.14	0.22
Survival (%)	0.27*	0.00	−0.27*
Survival vigor	0.12	0.14	0.18
Vitriosity	0.00	0.20	−0.67**
Sorghum			
Emergence (%)	0.81**	0.74**	0.32*
Emergence vigor	−0.70**	−0.66**	−0.45**
Survival (%)	0.87**	0.82**	0.46**
Survival vigor	−0.75**	−0.71**	−0.44**
Vitriosity	−0.44**	−0.41**	−0.12

$0.01 < P < 0.05$
$P < 0.01$

Charcoal Pits vs. Line Source

Correlations of entry responses in the CP to those of the LS in the low water application treatment are presented in Table 3. Except for the highly significant correlation for vitriosity vs. dry weight, there are no biologically significant relationships for the millet entries. This is not surprising given the lack of differences among millet varieties in the field (Fig. 1) and the high mean survival in the CP (Table 2). The millet varieties were selected from local material adapted to heat and moisture stresses. rghum, on the other hand, selected from a)re diverse range of germplasm, demonstra- l highly significant correlations ($p < 0.01$) ..tween the two tests for all responses except percent emergence vs. dry weight, which was significant at the 5 % level, and vitriosity vs. dry weight. Negative correlations for vigor and vitriosity were expected because they were ranked from 1 to 5 with 1 being superior.

The very high correlation of sorghum survival in the CP verses field emergence, survival, and dry weight production suggest the CP may be used as a screening method for the combined effects of high soil temperature and moisture stress. The method is rapid; several runs can be made during the hot season from early March through late May. The method is easy; given the high temperatures during the hot season, no sophisticated equipment is needed to increase soil temperatures. And finally, the method reasonably evaluates the probable field performance during GS-1 of a range of material given an adequate potential range of responses to high soil temperature and moisture stress.

Zusammenfassung

Die Einflüsse hoher Bodentemperaturen und von Wasserstreß auf malianische Perlhirse und Sorghum während des Sämlingsstadiums

Perlhirse (*Pennisetum americanum* [L.] Leeke) und Sorghum (*Sorghum bicolor* [L.] Moench) können unter schlechtem Aufgang unter den Bedingungen hoher Bodentemperatur und Wasserstreß leiden. Ein Beregnersystem und eine Kohle-Abdeck-Technik wurden verwendet, um den Aufgang des Bestandes zu beurteilen; es war eine straffe Korrelation zwischen den beiden Methoden nachzuweisen. Es könnte möglich sein, die Kohle-Abdeck-Technik als ein Vorhersageverfahren in Züchtungsprogrammen für Dürreresistenz zu verwenden.

Acknowledgements

The authors would like to express their thanks to Drs. O. NIONGADO, SRCVO/Mali Millet Breeder;

J. F. SCHEURING, ICRISAT/Mali Cereal Breeder; and K. V. RAMAIAH, ICRISAT/Burkina Faso Striga Physiologist for providing germplasm and to Messrs. DIBY DIAKITÉ and MAKANO COULIBALY, SRCVO/Mali Ingenieur and Moniteur, respectively, without whose able work, this project would not have been completed. This research was made possible by a grant to ICRISAT/Mali by USAID.

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