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RESPONSE OF SORGHUM TO MOISTURE STRESS USING LINE SOURCE SPRINKLER IRRIGATION
I. PLANT—WATER RELATIONS[1]

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ABSTRACT

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The response of sorghum (*Sorghum bicolor* L.) to moisture stress during the post-rainy season was studied at ICRISAT research center on a medium deep Alfisol using a line source sprinkler irrigation system. Changes in soil moisture content, stomatal conductance, leaf-water potential and leaf temperature of sorghum as a function of distance away from the line source sprinkler system were monitored throughout the season. Use of the line source technique facilitated the imposition of a range of moisture stress levels as indicated by increased water use by sorghum closer to the line source compared with the crop farther away from the line source. Canopy response measured in terms of stomatal conductance, leaf-water potential, and leaf temperature clearly reflected the gradient in moisture stress perpendicular to the line source.

INTRODUCTION

Crop production in the seasonally dry semi-arid tropics is often limited by the large variations in the amount and distribution of rainfall. Water deficits are frequent and these influence various physiological processes associated with crop growth, development, and final yield.

Sorghum (*Sorghum bicolor* L.) is one of the important post-rainy season crops in India. Crops grown in this season depend primarily on residual soil moisture which is influenced by the amount of rainfall in the preceding rainy season. In order to study the response of sorghum to available soil moisture during the post-rainy season, it is useful to create varying levels of soil moisture under field conditions.

Available literature indicates that measurements of leaf diffusion resistance (Ehrler and Van Bavel, 1967; Teare and Kanemasu, 1972), leaf-water potential (Sivakumar et al., 1979), and leaf temperature are useful in understanding the response of sorghum to plant-water deficits. Quantification of plant moisture stress under different soil moisture regimes was accomplished by means of such measurements (Sivakumar and Shaw, 1978; Sivakumar et al., 1979).

The objective of the current study is to present a quantitative evaluation of the efficacy of the line source irrigation system in imposing a gradient of water stress related to the distance from the sprinkler line. Measurements of soil moisture, stomatal conductance, leaf-water potential, and leaf temperature were used to describe the level of moisture available to sorghum at different distances from the line source.

MATERIALS AND METHODS

The experiment was conducted at the ICRISAT research center near Hyderabad, India (17°32′N 78°16′E) during the post-rainy season in 1978–1979. It was part of a more comprehensive experiment on the effect of differential moisture regimes on depletion patterns, root and shoot growth, transpiration and yield of sorghum. The experiment was conducted on a medium deep Alfisol with an estimated total moisture holding capacity of 254 mm in a 127 cm deep profile. The field was cultivated to a 150-cm wide broadbed-and-furrow system. All treatments were 18 m (12 broadbeds) wide in the North-South direction. Plots were laid out lengthwise in the East-West direction.

Sorghum hybrid (CSH-8-R) was planted in 75-cm rows on the beds on 1 November 1978. A basal fertiliser dose of 18-20-0 at 100 kg/ha was applied in the plant rows prior to planting. Carbofuron (at 40 kg/ha) was applied with the seed. After establishment the crop was thinned to 180,000 plants/ha. Urea was applied at the rate of 50, 60 and 20 kg/ha of N at 10, 14 and 20 days after sowing respectively. The entire area was given a light irrigation on 2 November and also immediately after each urea application.

Four differential moisture treatments were imposed as follows: no moisture stress (irrigation every 10 days); no initial moisture stress, differential moisture stress created by line source 40 days after planting and continued until maturity; no initial moisture stress, differential moisture stress created 40 days after planting and continued up to post-flowering stage whereupon the stress is released; and no moisture stress until post-flowering stage, differential moisture stress created at the post-flowering stage and continued until maturity.

Measurements reported here have been restricted to the second treatment, i.e., no initial moisture stress, differential moisture stress created by line source 40 days after planting and continued until maturity. There were 12 broadbeds, starting from the sprinkler line in the plot. Six neutron tubes were installed in each of beds 1, 4, 7, 9 and 12 for the measurement of moisture depletion from the soil throughout the growing season. Measurements with a neutron probe were made at 30-, 45-, 60-, 75-, 90-, 105-, 120-, 135-, 150-, 165-, and 180-cm depths in each bed. Gravimetric measurements were taken in the top 22 cm of soil.

Measurements of stomatal resistance, leaf-water potential, and leaf temperature were made on sorghum on beds 2, 4, 6, 8, 10, and 12. Stomatal resistance measurements were made with a diffusion porometer that was calibrated before each set of measurements. Resistance measurements were taken four times during the growing season, from 06.00 to 18.00 h at 90-min intervals. At each time interval, measurements were taken in each bed on four sorghum plants. Adaxial (R_{ad}) and abaxial (R_{ab}) stomatal resistance was measured on four fully expanded, completely exposed sorghum leaves. Stomatal conductance is expressed as the reciprocal of leaf stomatal resistance.

Leaf temperature was measured with a 2.8° field-of-view Barnes 14-220-1 model IR thermometer with a band pass of 6.5—20 μm. Leaf-water potential was measured with a pressure chamber (Scholander et al., 1965).

On selected days, two SWISSTECO net radiometers were mounted 1 m above the sorghum canopy at 3 and 15 m from the sprinkler line. Daily values of incoming solar and net radiation were obtained by integrating 10-min values obtained from printing integrators (LAMBDA Instruments Corporation, Lincoln, Nebraska, U.S.A.).

RESULTS

Seasonal trends

During the months of November, December, and January only 11 mm of rainfall were recorded (Table I). Because no irrigations were given after the day of the sprinkler line irrigation, there was a monotonic depletion of soil water and the crop faced an increased degree of stress with time. After the line source irrigation, the soil water measurements on beds 1, 4, 7, 9, and 12 indicated that the profile was fully recharged up to bed 4. Measurements on

TABLE I

Meteorological parameters during the growing season at ICRISAT research center

Month	Average temp.		Average 24-h winds (km/h)	Average solar radiation (ly/day)	Average pan evaporation (cm/day)	Rainfall (cm)
	Max. (°C)	Min. (°C)				
Nov.	29.2	18.6	8.4	433	0.43	1.0
Dec.	27.2	15.2	7.9	401	0.47	0.1
Jan.	28.5	16.2	9.6	431	0.53	0.0
Feb.	30.2	18.7	11.6	425	0.61	4.1

beds 9 and 12 indicated no appreciable addition of water. The soil water loss from beds 4 and 7, and the average of beds 9 and 12 were taken to represent the depletion from beds 1—4, 5—8 and 9—12, respectively. Data collected on leaf conductance, leaf temperature and leaf-water potential were also pooled for beds 1—4, 5—8, and 9—12.

Using the data from the neutron probes, cumulative water use was calculated at 6, 10.5, and 16 m from the line source (Fig. 1). Water use was always higher in the first four beds from the line source except for one measurement made on day 49. The rate of water use was always the lowest in beds 9—12, which were the farthest from the line source. Sorghum grown on beds 5—8 showed intermediate water use patterns. The maximum difference in water depletion (34 mm) was attained 65 days after planting.

Leaf conductance decreased continuously throughout the season in all cases (Fig. 2). The sorghum closest to the line source received more water and hence maintained higher leaf conductance compared with the crop farther away from the line source. There were only small differences in the leaf conductance of sorghum grown on beds 5—8 compared with that on beds 9—12. Maximum differences in leaf conductance were observed immediately after the line source was operated and the magnitude of differences showed a decline later. This trend is similar to the rates of water loss.

The seasonal changes in the mean daily leaf temperature of sorghum, as related to the distance from the line source, are shown in Fig. 3. As in the case of leaf conductance, the leaf temperature showed a steady increase in all cases until about 75 days after planting. Differences in sorghum leaf

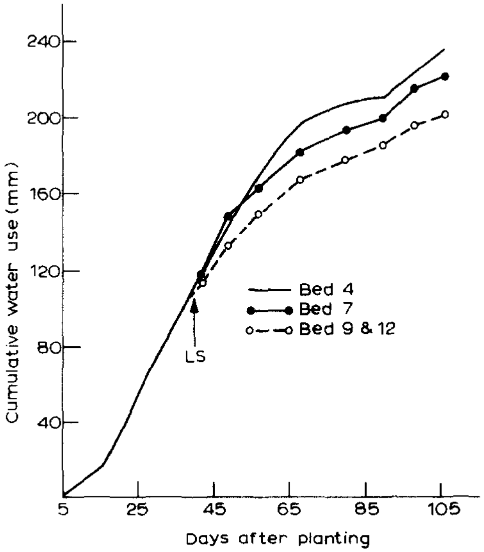


Fig. 1. Cumulative water loss during the season for sorghum.

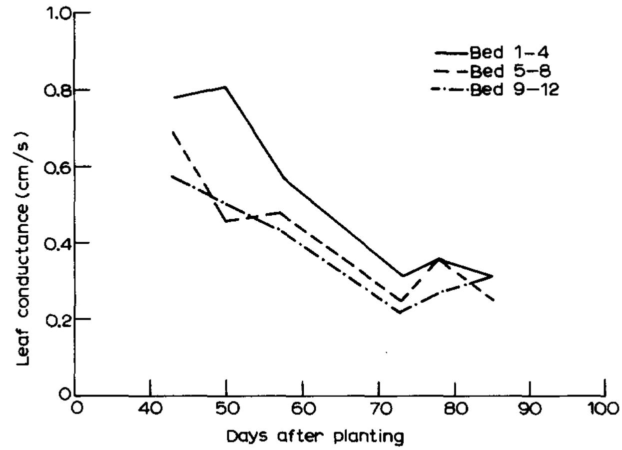


Fig. 2. Seasonal changes in leaf conductance of sorghum planted on beds. Beds 1—4 are closest to the line source and beds 9—12 are farthest away.

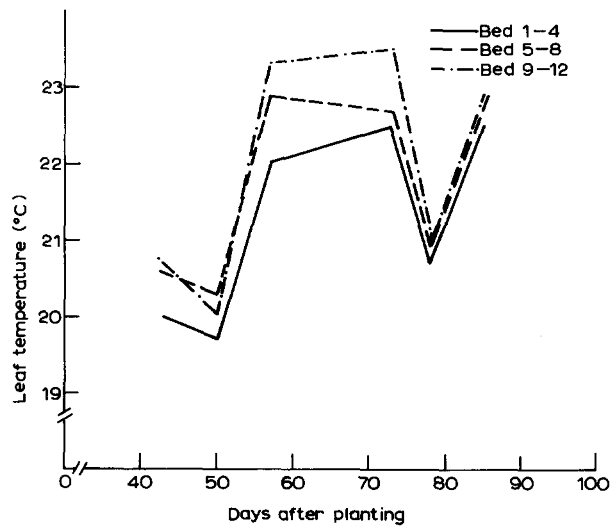


Fig. 3. Seasonal changes in leaf temperature of sorghum planted on beds. Beds 1—4 are closest to the line source and beds 9—12 are farthest away.

temperature were larger between beds 1—4 and 9—12 and were smaller between beds 5—8 and 9—12. The differences between different beds were greatest between 55 and 75 days after planting, when the air temperatures were also higher.

Changes in the mean daily leaf-water potential of sorghum, measured periodically at varying distances away from the line source, are shown in Fig. 4. As in the case of leaf conductance and leaf temperature, leaf-water potential data also show that sorghum grown on beds 1—4 was able to maintain higher leaf-water potentials because of greater water availability.

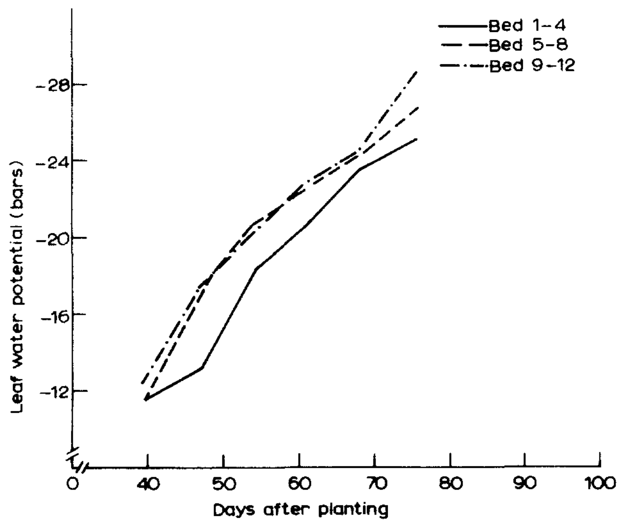
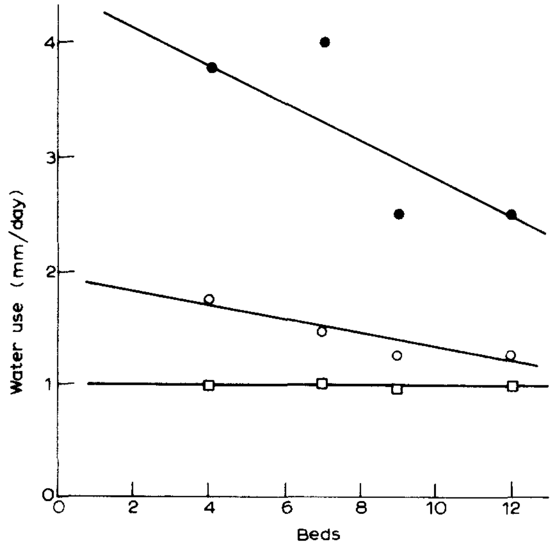


Fig. 4. Seasonal changes in the leaf water potential of sorghum planted on 150-cm wide beds. Beds 1—4 are closest to the line source and beds 9—12 are farthest away.

These seasonal changes indicate that use of the line source sprinkler irrigation system facilitated the imposition of differential moisture stress levels as a function of distance from the line source.

Daily trends

To illustrate the uniformity in the gradient of water stress brought about by the use of line source sprinkler irrigation systems, three dates — 13 December, 27 December and 12 January — were chosen. Straight lines were fitted



to the data points to show that there was a gradient as a function of distance from the line source in the case of daily water use, leaf conductance, leaf temperature and leaf-water potential.

Water loss from the top 127 cm of soil from beds 4 and 7, and the average of beds 9 and 12 are shown in Fig. 5. On 13 December, 3 days after the application of water, the water loss was higher in all beds compared with the data collected on 27 December and 12 January. The gradient in water loss as a function of distance from the line source was at a maximum on 13 December and had declined considerably by 27 December. By 12 January (73 days

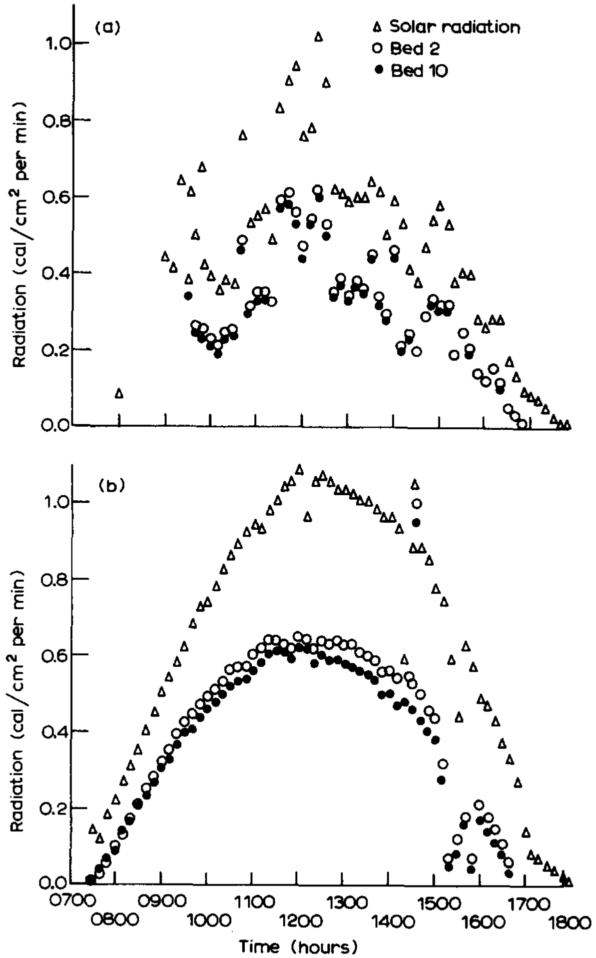


Fig. 6. Diurnal variation in the incoming solar radiation and net radiation for sorghum planted on beds 2 and 10 from the line source on (a) 28 Dec. 1978 and (b) 4 Jan. 1979.

Fig. 5. Water use by sorghum from the top 127 cm of soil as related to distance from line source on 13 Dec. 1978 (•—•), 27 Dec. 1978 (o—o), and 12 Jan. 1979 (□—□).

after planting) all the beds showed equal water loss, indicating that sorghum grown on beds closer to the sprinkler line had already used all the additionally provided water.

Diurnal variation in the net radiation over the sorghum canopy in beds 2 and 10, and the incoming solar radiation recorded at 10-min intervals for two contrasting days (28 December and 4 January) are shown in Fig. 6. December 28 was a cloudy day with clear and cloudy skies alternating at random; hence, the diurnal patterns in the incoming solar radiation and net radiation show a wide scatter.

From the individual data points it is clear, however, that net radiation over sorghum on bed 10 was always slightly lower than the net radiation over sorghum on bed 2. Incoming solar radiation integrated over the whole day was 300 langleys.

The sky was comparatively clear on 4 January. Incoming solar radiation recorded on this day was 432 langleys. Net radiation closely followed the variations in solar radiation and again was higher throughout the day over bed 2 than over bed 10. Integrated over the whole day, net radiation over bed 2 was 230 langleys whereas over bed 10 it was 213 langleys. These differences appear to confirm that water use of sorghum closer to the line source was higher than that farther from the line source (as indicated earlier in Fig. 5).

Mean daily leaf conductance of sorghum grown on beds 2, 4, 6, 8, 10, and 12, measured on the same dates as considered for water loss, are shown in Fig. 7. On each of the three days the leaf conductance showed relatively uniform gradient, with conductance decreasing with distance from the sprinkler line. Leaf conductance at all positions decreased as the season progressed, indicating that they are intimately related to water loss or transpiration. When the sorghum plants had an adequate supply of water, as near

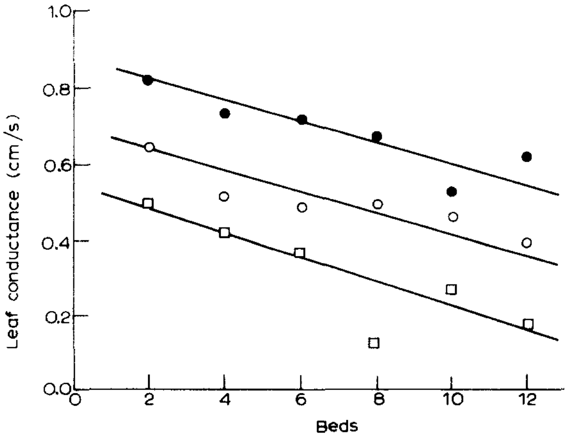


Fig. 7. Leaf conductance of sorghum as related to distance from the line source on 13 Dec. 1978 (•—•), 27 Dec. 1978 (○—○), and 12 Jan. 1979 (□—□).

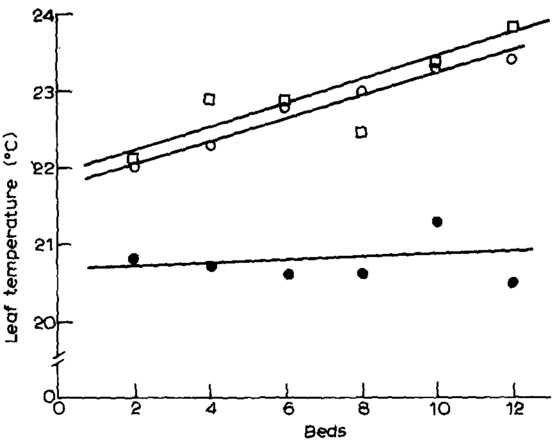


Fig. 8. Leaf temperature of sorghum as related to distance from the line source on 13 Dec. 1978 (●—●), 27 Dec. 1978 (○—○), and 12 Jan. 1979 (□—□).

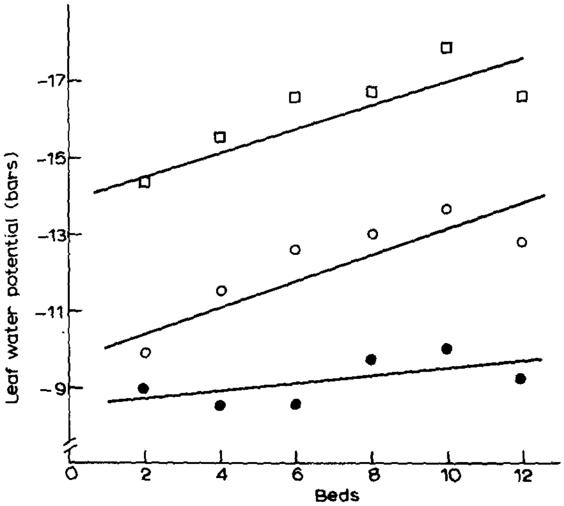


Fig. 9. Leaf-water potential of sorghum as a function of distance from the line source on 13 Dec. 1978 (●—●), 27 Dec. 1978 (○—○), and 12 Jan. 1979 (□—□).

the irrigation line on 13 December, the stomata were probably fully open and leaf conductance was high. But as the season progressed and as the soil water was depleted, the stomata started to close and leaf conductance decreased.

Available literature indicates that when the rate of water supply to the leaves is too low to maintain full transpiration, leaf temperatures increase rapidly. Mean daily leaf temperatures of sorghum for 13 December, 27 December and 12 January are shown in Fig. 8 for different beds. On 13 December, sorghum leaf temperatures were the same at all distances from the line source but increased with distance from it on 27 December and 12 January.

As in the case of leaf conductance and leaf temperature, mean daily leaf-water potential data collected on different beds also showed a clear gradient (Fig. 9). It is interesting to observe a close resemblance in the patterns of water stress gradients as reflected by leaf temperature and leaf-water potential. This probably points to the importance of maintenance of adequate leaf-water potential levels in order to attain transpirational cooling and the consequent effects on leaf temperature.

The preceding data show that the intensity and duration of water stress increased with distance from the sprinkler line. Average sorghum yields on beds 1—4 were 2509 kg/ha whereas they were 1829 kg/ha on beds 5—8 and 1545 kg/ha on beds 9—12.

DISCUSSION

The data presented so far indicate that studies on the response of sorghum to varying levels of moisture stress could be facilitated by using a line source sprinkler irrigation system. The advantage of the system lies in the level of uniformity of water application that can be achieved by giving adequate attention to the time of application and the appropriate direction with respect to the prevailing winds.

Data on water use indicate that sorghum grown on beds closer to the line source could extract more water compared with the crop farther away from the line source. The effect of these increased extraction rates is also reflected in the seasonal changes in leaf conductance, leaf-water potential, and leaf temperature. Leaf conductance data, especially for the first 25 days after the sprinkler line was operated, indicate that increased water availability in the beds closer to the line source resulted in open stomata for a longer time; a decreased water supply would produce the opposite effect. This ability of sorghum to close stomata and reduce transpiration under conditions of a water deficit has been documented earlier by Teare and Kanemasu (1972). The magnitude of differences in the sorghum leaf-water potential between the beds closer to the line source and those farther away also illustrates the reasons for earlier stomatal closure of sorghum in the beds farther from the line source. Sivakumar et al. (1979) showed that in the case of non-irrigated sorghum, reduced leaf turgidity, as reflected by decreased leaf-water potential, resulted in frequent stomatal closure and lower yields.

It is also known that when the rate of water supply to the leaves is inadequate for transpirational cooling, leaf temperatures increase (Pearcy et al., 1971). As Miller et al. (1971) reported, the difference in temperatures of leaves similarly exposed is a sensitive indicator of plant water stress. The sorghum leaf temperature data collected in the present study, taken in beds at different distances away from the line source, show that different levels of moisture stress can be effectively imposed using the line source technique.

The data on plant—water relations discussed are closely related to differences in the growth of sorghum. The sorghum plants nearest to the line source attained a larger leaf area index and greater dry matter accumulation compared with the plants grown farther from the line source (Sachan and Gill, 1979). More elaborate experiments are under way using the line source technique and associated plant measurements to evolve a realistic means of predicting plant response and also the resulting yields of sorghum as result of moisture stress.

CONCLUSIONS

Studies on the response of sorghum to different levels of moisture stress can be facilitated by the use of a line source sprinkler irrigation system that can produce a water application pattern which varies uniformly across the plot. Data collected on water use, stomatal conductance, leaf-water potential, and leaf temperature throughout the season indicated a range of water stress as a function of distance from the line source imposed by the use of a line system.

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