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Canopy-Air Temperature Differentials, Water Use and Yield of Chickpea in a Semi-Arid Environment *

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Summary. Stress degree days (SDD) and canopy-air temperature differential summation procedures were used to quantify the response of crops of chickpea (*Cicer arietinum* L.) to soil water availability and atmospheric demand over a four year period on a deep and medium-deep Vertisol in India using different irrigation treatments and planting dates. Canopy temperatures measured between 13.00–14.00 h provided a good index of the daily mean canopy temperature. Differences in the diurnal variation in the canopy-air temperature differentials between irrigated and non-irrigated chickpea reflected clearly the differential response of the crop to soil water availability. Total water use of chickpea decreased with increasing SDD. Data pooled over three growing seasons showed a close relationship between SDD and yield of chickpea. Calculated water stress index (WSI) which includes the vapor pressure deficit term showed a similar relationship with yield to that with SDD.

Chickpea (*Cicer arientinum* L.) is India's most important pulse crop and ranks second in the world after dry beans. In India and Pakistan, chickpea is cultivated during the *rabi* (postrainy) season on conserved soil moisture. Without adequate supplemental irrigation the crop at times suffers from drought stress and quantification of this stress in chickpea is important to evolve management strategies for drought. Measurement of leafwater potential is one of the methodologies to accomplish the objective of quantifying water stress in chickpea (Sivakumar and Virmani 1979), but there are other proven methods of quantifying drought stress such as leaf temperature (Hiler and Clark 1971) which have not been tested for chickpea so far.

Research over the last two decades on measurement of canopy temperatures with several crops showed that leaf temperatures are related to drought stress and could be used to differentiate between treatments which impose stress and

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* Approved for publication as ICRISAT Journal Article 580

** Present address: Principal Agroclimatologist, ICRISAT Sahelian Center, BP 12404, Niamey, Niger (Via Paris) those which relieve stress (Tanner 1963; Wiegand and Namken 1966; Ehrler and van Bavel 1967; and Bartholic et al. 1972). Leaf temperatures are determined by the energy exchange processes involving radiation, convection and transpiration. When soil moisture becomes limited, stomatal closure occurs resulting in reduced transpiration, increased heat load on the canopy and a consequent rise in leaf temperatures sometimes by as much as 10 °C above air temperature (Pearcy et al. 1971). However, a quantitative index of drought stress using canopy temperatures did not emerge until Jackson et al. (1977) showed that the difference between the temperature of a plant canopy and the temperature of the surrounding air could be used for this purpose. For durum wheat, a summation over the growing season of the canopy and air temperatures measured around solar noon each day was used to predict the yield (Idso et al. 1977). The importance of stage of growth in this summation procedure was demonstrated by Walker and Hatfield (1979) when they showed that the yield of red kidney beans was strongly dependent on the accumulation of stress-degree-days from flowering to maturity. Walker and Hatfield also suggested that future work on these lines should concentrate on determining whether a yield-SDD relationship is unique for a crop species or variety and on examining the variations in such relationships with different locations and environmental conditions.

Following the observation that canopy-air temperature differential, by itself, is too simple a parameter to adequately cope with significant environmental variability of either a temporal or spatial nature (Gardner 1979; Walker 1980), Idso et al. (1981) reformulated the SDD concept in the form of the plant water stress index (WSI) by introducing a vapor pressure deficit (VPD) term.

Although quantification of water stress for chickpea is considered essential in view of its importance in the seasonally dry semi-arid tropics, use of canopy temperature measurements for this purpose has not yet been studied. Hence the objective of this study were:

1. To evaluate the relationship between canopy and air temperatures in irrigated and non-irrigated chickpea in a semi-arid environment
2. To examine the feasibility of relating the canopy-air temperature differentials to the yield of chickpea using the SDD and WSI approaches.

Experimental Methods

The experimental work reported in this study was carried out at ICRISAT Research Center located at Patancheru (17°27'N, 78°28'E), India during the postrainy season (October–March) over four year period from 1978–1979 to 1981–1982. The experiment during 1978–1979 and 1979–1980 was conducted on a 180-cm deep Vertisol while during 1980–1981 and 1981–1982 the soil was a medium-deep Vertisol of 127 cm depth. These are fine, clayey, montmorillonitic, calcareous, hyperthermic members of the family of Typic Pallusterts. Available water holding capacity of the deep Vertisol was estimated as 230 mm while it was 160 mm for the medium-deep Vertisol.

During the 1978–1979 and 1979–1980 experiments the treatments consisted of three irrigation regimes i.e., no irrigation (I_0), two irrigations (I_1) and four irrigations (I_2), and were imposed in a randomized block design with three replications. During the 1980–1981 and 1981–1982 growing seasons the experiment was laid out in split-plot design with irrigation

Table 1. Irrigation amounts (mm) given on different dates in the three treatments during the first two growing seasons

Date	Treatment		
	I_0	I_1	I_2
	1978–79		
23 November	–	70	65
5 December	–	47	49
27 December	–	–	67
23 January	–	–	92
	1979–80		
4 December	–	39	37
18 December	–	–	32
4 January	–	58	62
15 January	–	–	50

regimes as the main plots and four dates of planting as subplots. Chickpea cv. Annigeri was sown in rows 30 cm apart on 23 October in 1978 and 26 October in 1979. The four dates of planting during 1980–1981 were 15 October, 30 October, 15 November and 30 November while in 1981–1982 they were 20 October, 4 November, 19 November and 4 December. The irrigation schedules and the amounts of water applied for the three treatments during the first two growing seasons are shown in Table 1. During 1980–1981 and 1981–1982 treatment I_1 received two irrigations of 40 mm each 30 and 70 days after sowing (DAS) in all planting dates and treatment I_2 was given four irrigations of 40 mm each 30, 50, 70 and 90 DAS. The treatment choice in 1980–1981 and 1981–1982 seasons was designed to provide a range of profile water depletion patterns and hence permit evaluation of the relationship between canopy-air temperature differentials and yield. Further details of the experiment were given by Sivakumar and Piara Singh (1986).

Canopy temperatures were measured on five plants (one measurement per plant) in each plot with a 2.8° field-of-view Barnes model 14-220-1 infrared thermometer. The instrument was held at an angle of about 45° to the crop surface at a distance of 50 cm so as to obtain a canopy temperature minimally influenced by the underlying soil. Air temperature was measured 1 m above the crop surface with an Assman psychrometer. Vapor pressure deficit (VPD) was determined from the psychrometric measurements from the information contained in the Smithsonian Meteorological Tables (List, 1971, Table 98).

Soil water measurements were made in all seasons except 1980–1981. Neutron probe observations were taken every tenth day (approximately) from two access tubes in each plot at 15 cm depth increments. A calibration equation developed from measurements made on the experimental site was used to convert the count ratios from the neutron probe to volumetric water contents. Water contents in the surface 10 cm and 10 to 22 cm layers were determined gravimetrically. Water use by the crop was calculated by the water balance method.

To evaluate the relationship between mean daily canopy temperature and canopy temperatures measured at 13.00–14.00 hours Indian standard time (IST), diurnal measurements were made during the first growing season (1978–1979) at weekly intervals from 07.00–18.00 hours on each measurement day. For the other three seasons measurements were taken each day at 13.00–14.00 hours from 30 days after emergence (when flowering commenced) to physiological maturity to enable calculation of stress-degree-days for different treatments. Final yield was obtained by harvesting 9×4 m strips in the middle of each plot.

The SDD index was calculated as defined by Idso et al. (1977) as:

$$SDD = \sum_{i=1}^{n} (T_c - T_a)_i$$

Where T_c is the canopy temperature, T_a is the air temperature, n is the number of measurement days.

Plant water stress index (WSI) was computed using the procedure outlined by Idso et al. (1981).

Results and Discussion

Average maximum and minimum air temperatures, wind speed, solar radiation, open pan evaporation and total rainfall during the four growing seasons are shown in Table 2. Lack of rainfall coupled with increasingly higher evaporation rates during the growing season could subject the crop to a high degree of drought stress. Because of chickpea's dependance for growth on the soil moisture left in the profile from the preceding rainy season, total rainfall during June to October could be an important parameter influencing the profile moisture content at sowing time. For the 1978–1979, 1979–1980, 1980–1981, and 1981–1982 growing seasons, total rainfall was 1077, 631, 733 and 1071 mm respectively.

Diurnal variation in the canopy temperature of chickpea on 3 different dates during the 1978–1979 growing season is shown in Fig. 1. Available soil water was

Table 2. Meteorological parameters during the four growing seasons et ICRISAT Research Center

Month	Average temp (°C)		Average wind (km/h)	Average solar radiation (MJ/m²/day)	Average pan evaporation (mm/day)	Total rainfall (mm)
	Max	Min				
				1978–79		
Nov	29.2	18.6	8.4	18.1	4.3	10
Dec	27.2	15.2	7.9	16.8	4.7	1
Jan	28.5	16.2	9.6	18.1	5.3	0
Feb	30.2	18.7	11.6	17.8	6.1	41
				1979–80		
Nov	28.7	19.3	9.7	15.8	4.1	80
Dec	27.7	14.9	7.3	16.8	4.4	0
Jan	28.9	15.0	8.0	18.3	5.3	0
Feb	32.4	17.9	7.8	20.0	7.1	4
				1980–81		
Nov	29.8	16.4	7.9	18.1	5.5	0
Dec	28.4	13.8	7.7	17.6	5.2	2
Jan	27.0	14.1	8.5	17.6	5.0	16
Feb	32.5	15.8	8.3	22.1	8.1	0
Mar	33.6	19.8	10.7	23.0	9.3	77
				1981–82		
Nov	28.3	15.0	5.2	19.5	4.5	2
Dec	26.9	13.9	7.4	17.2	4.6	0
Jan	28.5	15.6	8.6	18.4	5.4	0
Feb	32.0	18.4	7.6	19.4	7.1	0
Mar	35.0	20.9	7.8	22.8	9.2	0

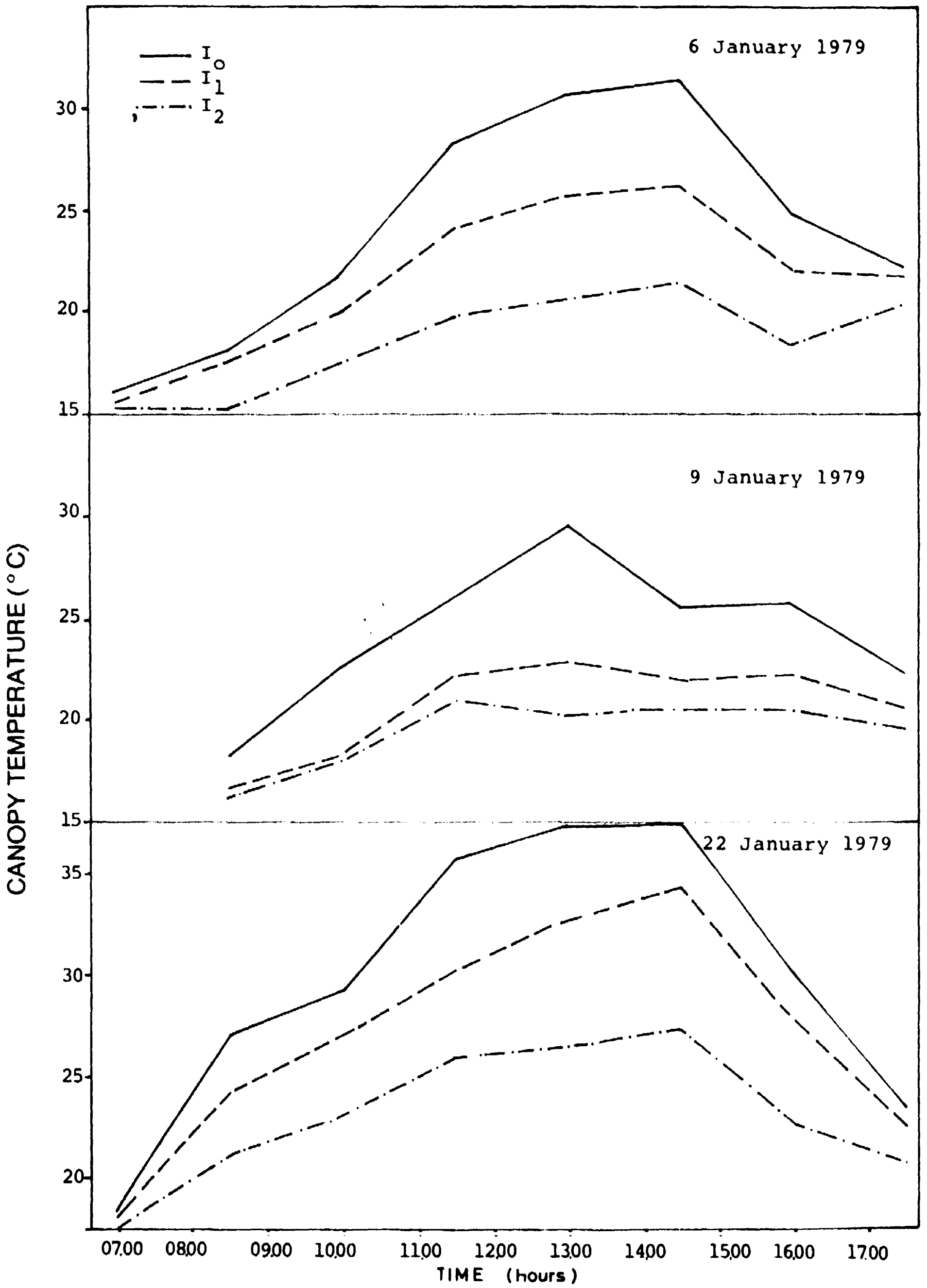

Fig. 1. Diurnal variation in the canopy temperature of chickpea under different water regimes on three selected days

124, 180 and 200 mm respectively in the I_0, I_1 and I_2 treatments on 6 January 1979. Three days later soil water contents in the I_2 and I_1 treatments were more or less unchanged at 204 and 180 mm respectively while in I_0 available soil water decreased to 112 mm. By 22 January soil water contents decreased in all treatments, but most significantly in the I_0 treatment and were 190, 120 and 96 mm in the I_2, I_1 and I_0 treatments respectively. These changes in soil water affected the canopy temperatures specifically in treatment I_0 where the maximum temperatures

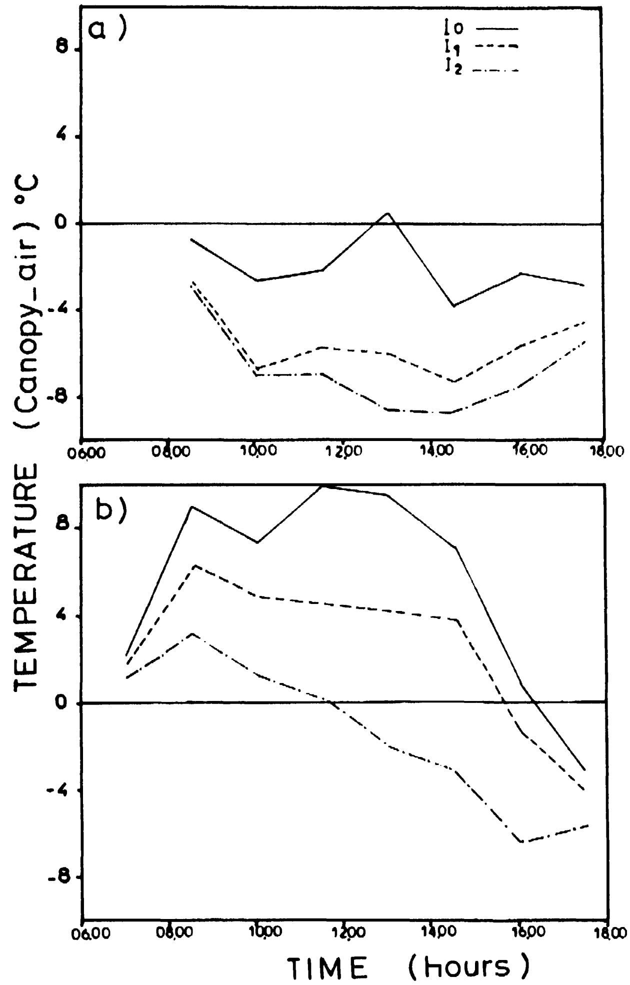

Fig. 2. Diurnal variation in the canopy-air temperature differential on a) 9 Jan. 1979 and b) 22 Jan. 1979

increased from 31.4 °C on 6 January to 37.9 °C on 22 January. In all cases the canopy temperatures were low in the morning, but showed a steady increase with time and by 13.00–14.00 hours in all the treatments they reached the maximum. For the I_2 treatment, the rate of increase in the canopy temperature was slow whereas for the I_0 treatment there was a steep increase presumably due to partial stomatal closure and less evaporative cooling. By late afternoon the canopy temperatures decreased. Greatest absolute difference in the canopy temperatures of I_0 and I_2 treatments occurred between 13.00–14.00 hours.

In order to test whether the canopy temperatures measured between 13.00–14.00 hours (Y) were representative of the daily mean canopy temperatures (X), a regression equation was fitted to the available data. The resulting equation was:

$Y = 1.14\,(X);\ r = 0.99;\ t$ value 62.69^{**}

The standard error of estimate of mid-day canopy temperature was 1.84 °C. Hence it can be concluded that mid-day canopy temperature provided a good index of the daily mean temperature as shown by Ehrler et al. (1978) with wheat.

Diurnal variation in the canopy-air temperature differential for two days during the 1978–1979 growing season for the three treatments is shown in Fig. 2. Jackson

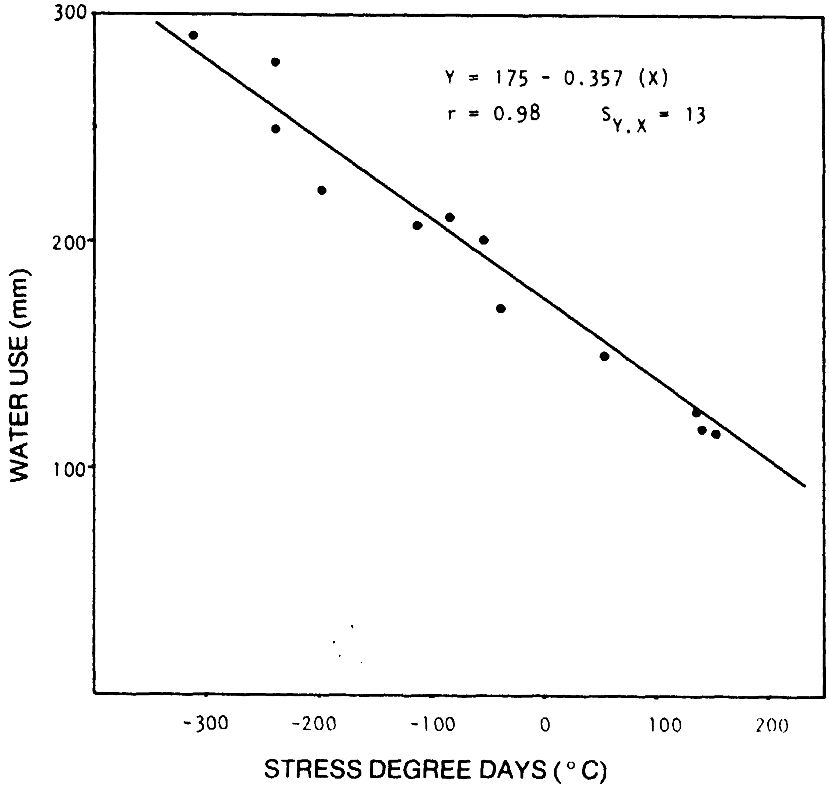

Fig. 3. Relationship between total water use and stress degree days (SDD) of chickpea var. Annigeri grown during 1981–1982 growing season

et al. (1977) found that in a plant with adequate water supply the temperature differential will be near zero or negative, but if it is stressed by lack of water the differential will be positive. As mentioned earlier, on 9 January available soil water was 204, 180 and 112 mm respectively in I_2, I_1 and I_0. These differences in profile water influenced the measured canopy-air temperature differentials. On this day both I_2 and I_1 treatments showed differentials much lower than those in I_0 indicating that the crop was able to extract enough water to maintain transpirational cooling. On the other hand canopy-air temperature differentials in I_0 show that the crop was under drought stress by mid-afternoon presumably due to partial stomatal closure reducing evaporative cooling.

But by 22 January, available soil water decreased to 190, 120 and 96 mm respectively in I_2, I_1 and I_0 and under these reduced soil water contents the temperature differentials were positive up to 16.00 hours in I_0 and I_1 treatments and upto solar noon in I_2.

In order to evaluate the relationship between seasonal water use and canopy-air temperature differentials, stress degree days (SDD) computed from 30 DAE to maturity during 1981–1982 growing season were plotted against total water use (Fig. 3). Water use was negatively correlated with SDD. The *t*-test for regression

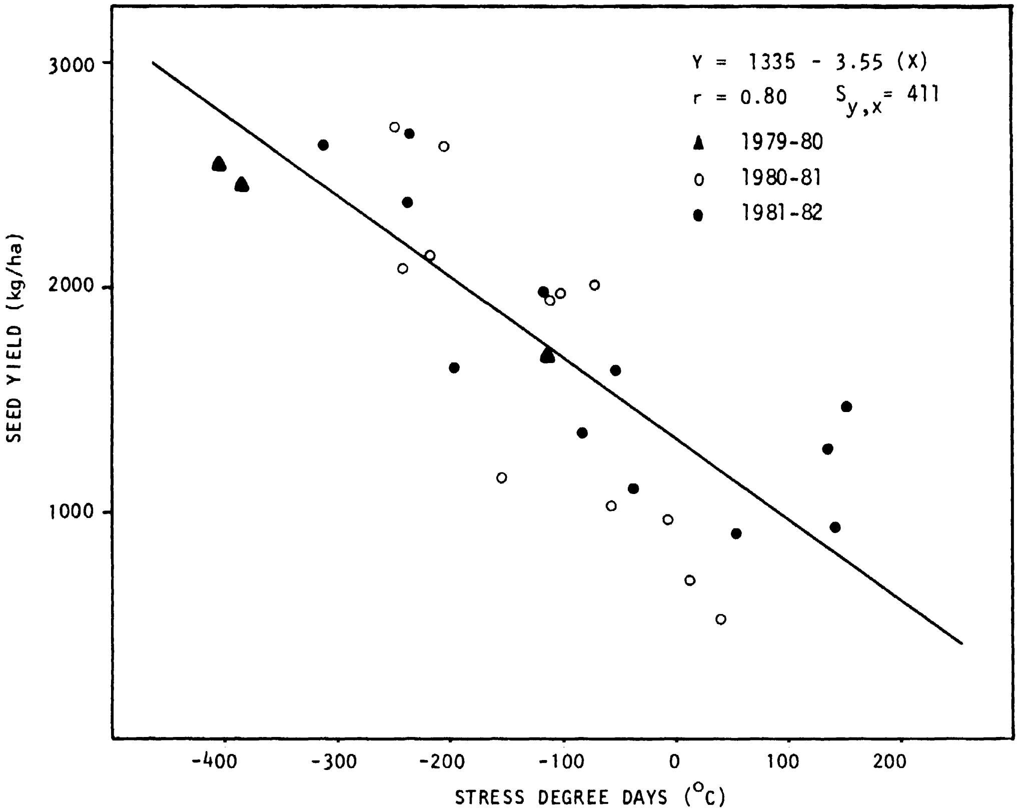

Fig. 4. Relationship between seed yield and stress degree days (SDD) of chickpea cv Annigeri grown at ICRISAT Center during three seasons

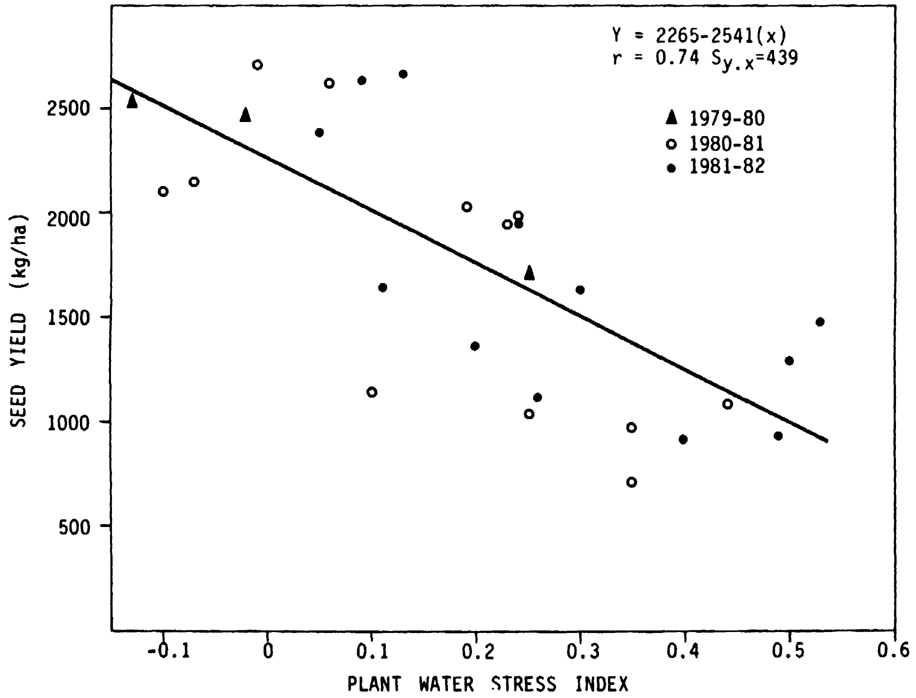

Fig. 5. Seed yield of chickpea as a function of plant water stress index

coefficient was significant at 1% level. These results show that canopy-air temperature differences are indicative of the general water use by chickpea and are similar to those reported by Walker and Hatfield (1979) and Hatfield (1983 a) with other crops.

The relationship between SDD and yield of chickpea was evaluated using the data from 1979–1980, 1980–1981 and 1981–1982. As shown in Fig. 4, the yield decrease was linear with increasing SDD. The *t*-test or regression coefficient was significant at the 1% level. The intercept term in the regression equation for Fig. 4 is lower than those reported from Davis, California for sorghum and wheat by Hatfield (1983 b) and for kidney beans by Walker and Hatfield (1979). The intercept term, which represents the environmental potential in terms of yield at zero SDD, is higher since Davis, California is a temperate location, while Patancheru is in the semi-arid tropics. The slope of −3.55 in the regression equation in Fig. 4 is lower than the value of −0.74 reported for kidney beans by Walker and Hatfield and considerable lower than the value −33.4 for sorghum and −54.2 for wheat given by Hatfield. The slope term is similar for kidney beans and chickpea which are both grain legumes indicating that they respond similarly to the intensity of drought stress.

The above relationship provided a valid test of the utility of SDD in quantifying the effects of water stress in chickpea as the data used covered three different growing seasons and in two of these the crop was planted in four different planting dates. These results are in agreement with the conclusions of Walker and Hatfield (1979) that the SDD concept is valid over a range of planting dates.

In order to establish the lower limit for the computation of WSI, the diurnal measurements of canopy-air temperature differentials made in the well-watered treatment (I_2) during 1978–1979 were used according to the procedure given by Idso et al. (1981). The regression equation established for the computation of the lower limit was:

$$(T_c - T_a) = -1.626 - 0.46\,(\mathrm{VPD}) \quad r = 0.66$$

The *t*-value for the regression coefficient was significant at the 1% level. The upper limit was established from the measurements made in I_0. Both the intercept and the slope terms given in the equation above are lower than those given by Idso et al. (1981) for wheat grown at Phoenix, Arizona and from Davis, California by Hatfield (1983 a) for sorghum. Lower VPD values at Patancheru than those at Phoenix and Davis could be a major factor for the differences in the terms of the regression equation between the two locations. Data for 22 January were excluded in establishing the regression equation given above since the plants were slightly stressed on that day as shown in Fig. 2.

Using the measurements of VPD and canopy-air temperature differentials taken at 13.00–14.00 hours each day, WSI was calculated for three growing seasons i.e., 1979–1980, 1980–1981 and 1981–1982. Final seed yield plotted as a function of WSI is shown in Fig. 5. The *t*-test for regression coefficient was significant at 1% level. Howell et al. (1984) also demonstrated a linear relationship (negative correlation) between lint cotton yield and seasonal mean WSI. The statistics of the observed relationship of yield to WSI was similar to that with SDD.

Conclusions

In this study a combination of irrigations and planting dates was used to create a range of profile water contents under varying atmospheric evaporative demand conditions to quantify the interactions between soil water availability, transpiration and energy exchange in chickpea in terms of canopy-air temperature differentials. The diurnal and seasonal measurements of canopy-air temperature differentials in different irrigation treatments showed the effect of changing soil water contents on canopy transpiration and consequently on canopy temperatures. Total water use of chickpea was closely related to canopy-air temperature differentials summed over the season or SDD. Data pooled over different irrigation regimes and planting dates in three growing seasons to study the relationship between SDD, WSI and chickpea yield showed that canopy-air temperature differentials could be used to quantify the response of chickpea to soil water availability.

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