

## **INFLUENCE OF WATER DEFICIT ON TRANSPIRATION AND RADIATION USE EFFICIENCY OF CHICKPEA (*CICER ARIETINUM* L.)\***

PIARA SINGH and Y.V. SRI RAMA

*Resource Management Program, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh 502 324 (India)*

(Received November 10, 1988; revision accepted February 19, 1989)

### ABSTRACT

Piara Singh and Sri Rama, Y.V., 1989. Influence of water deficit on transpiration and radiation use efficiency of chickpea (*Cicer arietinum* L.). *Agric. For. Meteorol.*, 48: 317-330.

Information on the relationship between biomass production, radiation use and water use of chickpea (*Cicer arietinum* L.) is essential to estimate biomass production in different water regimes. Experiments were conducted during three post-rainy seasons on a Vertisol (a typic pallustert) to study the effect of water deficits on radiation use, radiation use efficiency (*RUE*), transpiration and transpiration efficiency (*TE*) of chickpea. Different levels of soil water availability were created, either by having irrigated and non-irrigated plots or using a line source. Biomass production was linearly related to both cumulative intercepted solar radiation and transpiration in both well watered and water deficit treatments. Soil water availability did not affect *RUE* (total dry matter produced per unit of solar radiation interception) when at least 30% of extractable soil water (*ESW*) was present in the rooting zone, but below 30% *ESW*, *RUE* decreased linearly with the decrease in soil water content. *RUE* was also significantly correlated ( $R^2 = 0.61$ ,  $P < 0.01$ ) with the ratio of actual to potential transpiration ( $T/T_p$ ) and it declined curvilinearly with the decrease in  $T/T_p$ . *TE* decreased with the increase in saturation deficit (*SD*) of air. Normalization of *TE* with *SD* gave a conservative value of 4.8 g kPa kg<sup>-1</sup>. To estimate biomass production of chickpea in different environments, we need to account for the effect of plant water deficits on *RUE* in a radiation-based model and the effect of *SD* on *TE* in a transpiration-based model.

### INTRODUCTION

In the semi-arid tropical areas of India, chickpea (*Cicer arietinum* L.) is grown as a winter crop mostly on stored soil water from the preceding rainy season. It may receive some rainfall during the season in some areas. As the crop advances towards maturity, it is subjected to increasing water deficits

\*Journal Article No. 841 of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

because of decreasing soil water availability and increasing evaporative demand. To model its final crop yields, the daily biomass production could be estimated either from the amount of solar radiation intercepted or from the amount of water used. It has been shown in several studies that under good agronomic management the amount of dry matter accumulated by a crop stand is often directly proportional to solar radiation intercepted, so that its efficiency of conversion to dry matter is a constant factor (Scott et al., 1973; Monteith, 1977; Gallagher and Biscoe, 1978). Over a season, the amount of radiation intercepted is determined by leaf area duration, plant morphology and transmission characteristics of leaves, which in turn are affected by soil and crop management. Conversion efficiency is reported to be influenced by water and nutrient availability (Monteith, 1977; Biscoe and Gallagher, 1977; Khurana and McLaren, 1982), and by air temperature (Squire et al., 1984). Thus under sub-optimal conditions, such as water deficits, dry matter production cannot be adequately modelled based upon solar radiation intercepted by a crop.

An alternative approach to crop productivity is the amount of water a crop stand loses through transpiration. Because carbon dioxide intake and water loss are both controlled by stomata, dry matter production is also directly proportional to the amount of water transpired. The proportionality between dry matter production and water transpired is defined as transpiration efficiency (Bierhuizen and Slatyer, 1965; Tanner and Sinclair, 1983). Transpiration from a crop is directly proportional to the evaporative demand of the environment, soil water availability and leaf area index, and inversely proportional to the resistance to water uptake offered by the soil-plant system. It is also reported that the transpiration efficiency of crops is almost inversely proportional to the saturation vapour pressure deficit of the air in all environments (Tanner, 1981; Tanner and Sinclair, 1983). Most studies relating dry matter production to radiation interception and water use under environmental stresses are on cereals; much less information is available on legumes such as chickpea. In this paper, we examine the influence of water deficits on (a) the relationship between total dry matter production, solar radiation interception and water use by a chickpea crop; and (b) on its transpiration and radiation use efficiency.

## MATERIALS AND METHODS

### *Site, experiments and management*

Three experiments were conducted during the post-rainy seasons of 1984, 1985 and 1986 on a Vertisol at the research farm of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), located at Patancheru (latitude 17° 30' N; longitude 78° 16' E; altitude 549 m), Andhra Pradesh, India. The soil is classified as a fine montmorillonitic isohyperthermic typic

pallustert. It retains  $\sim 200$  mm of plant-extractable water in the upper 1.5 m of the soil profile (Fig. 1).

The 1984 experiment had plots with irrigation and no irrigation as main treatments and three cultivars (Annigeri, K 850 and G 130) as sub-treatments. Main plots ( $21.6 \times 12.0$  m) were equally divided into three sub-plots, to which three cultivars were randomly assigned. The treatments were replicated four times. Before sowing, nitrogen at  $18 \text{ kg N ha}^{-1}$  and phosphorus at  $20 \text{ kg P ha}^{-1}$  (as diammonium phosphate) were applied. Seeds were sown on 5 November and seedlings emerged on 15 November 1984 after applying 45 mm of irrigation. A plant population of  $30 \text{ plants m}^{-2}$  was maintained.

In the 1985 and 1986 experiments, a line-source sprinkler irrigation system (Hanks et al., 1976) was used to impose gradients of irrigation, in order to achieve increasing levels of water deficit at different growth stages of chickpea. The main irrigation treatments were: (1) gradient irrigation at all growth stages; (2) gradient irrigation from emergence to 50% flowering and uniform irrigation at other growth stages; (3) gradient irrigation from 50% flowering to 50% beginning pod fill and uniform irrigation at other growth stages; (4) gradient irrigation from 50% beginning pod fill to physiological maturity and uniform irrigation at other growth stages.

In 1985, the main plots ( $18 \times 18$  m) were divided into two equal sub-plots ( $9 \times 18$  m), to which two levels of phosphorus ( $10$  and  $40 \text{ kg P ha}^{-1}$  as single superphosphate) were randomly assigned. A uniform application of nitrogen (as urea) at  $20 \text{ kg ha}^{-1}$  was also given before sowing. Row spacing was 0.3 m and plants were 10 cm apart within a row. Chickpea (cv. Annigeri) was sown on 5 November and emerged on 15 November 1985.

In 1986, the main plots ( $18 \times 18$  m) were divided into three equal sub-plots ( $6 \times 18$  m), to which three plant populations ( $20$ ,  $30$  and  $40 \text{ plants m}^{-2}$ ) were randomly assigned. Before sowing, nitrogen at  $18 \text{ kg N ha}^{-1}$  and phosphorus at  $20 \text{ kg N ha}^{-1}$  (as diammonium phosphate) were uniformly applied. Chickpea (cv. JG 74) sown on 30 October emerged on 7 November 1986. Row spacing

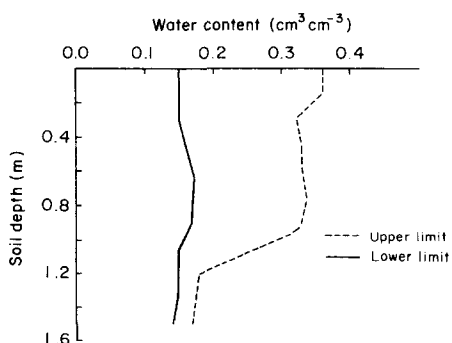


Fig. 1. Upper and lower limits of soil water extraction by chickpea crop on the Vertisol.

was 0.3 m and within-row spacing varied according to the plant population treatment.

### *Irrigation*

In 1984, irrigation was applied through perforated pipes at ~10-day intervals. Until ground cover was complete, the amount of water applied was equal to the soil water deficit in the root zone, as determined by the neutron probe. Later, the amount was 75% of cumulative open-pan evaporation minus rainfall, if any, since the previous irrigation.

In 1985 and 1986, gradient irrigations were given by the line-source sprinkler system and uniform irrigations with perforated pipes. Each gradient irrigation was applied in such a way that soil 3.6 m away from the line-source pipeline was brought to field capacity and beyond 3.6 m the irrigation received decreased linearly with increasing distance. The remaining procedure was the same as in 1984. The amount of water received at 3.6, 6.8, 10.0, 13.2 and 16.4 m from the line source was recorded using catch cans.

### *Radiation interception and saturation deficit of air*

Interception of photosynthetically active radiation (PAR) by chickpea foliage was measured twice a week with a line-quantum sensor (LI-COR, Nebraska, U.S.A.)\* and recorded on a polycorder (Omni-data, U.S.A.). To eliminate the effect of solar altitude on PAR interception, the measurements were confined to the mid-day period. Interception data were plotted and daily interception calculated for each treatment. Cumulative intercepted total solar radiation (0.3–3.0  $\mu\text{m}$ ) was calculated as the product of daily PAR interception and total daily solar radiation integrated over the season. In 1984, PAR interception was recorded in the middle of each sub-plot; in 1985 and 1986, the observations were taken in all sub-plots at 3.6, 10.0 and 16.4 m away from the line source.

To calculate the saturation deficit of air, wet- and dry-bulb temperatures were recorded very close to the surface of the crop canopy with an Assmann Psychrometer. These measurements were taken three times a week between 13.00 and 14.00 h in each plot at 3.6, 10.0 and 16.4 m away from the line source. Saturation deficit of air [defined as  $e_s(T) - e$ , where  $e_s(T)$  is the saturation vapour pressure of water vapour at dry bulb temperature and  $e$  is the partial pressure of water vapour] was obtained using the appropriate equations given by List (1971).

---

\*Mention of commercial products or companies does not imply their endorsement or recommendation by ICRISAT.

### Growth analysis

In 1984, 10 plants from a 0.30-m<sup>2</sup> area were harvested twice a week from each sub-plot. Plant components were separated and the leaf area of each sample was determined with a leaf area meter (LI-COR, Inc. U.S.A.) and then dried at 60°C in an oven for a week and weighed to determine dry weight. In 1985 and 1986, samples were taken once a week from a 0.30-m<sup>2</sup> area at 3.4, 10.0 and 16.4 m away from the line source. The rest of the procedure for growth analysis was the same as in 1984.

### Soil water

In 1984, two neutron probe access tubes were installed in each sub-plot to monitor changes in soil moisture from emergence to maturity. Neutron probe (Didcot Instruments, Wallingford, U.K.) readings were taken at 0.15 m intervals from 0.3 to 1.5 m soil depth. Soil moisture in the 0–0.1 and 0.1–0.22-m layers was determined gravimetrically.

In 1985 and 1986, neutron probe access tubes were installed in each sub-plot at 3.6, 6.8, 10.0, 13.2 and 16.4 m away from the line source. Soil moisture was recorded weekly in the same manner as in the 1984 season. Water use (evapotranspiration) by the crop was computed by the water balance method, i.e.

$$ET = P + I \pm \Delta M$$

Where  $ET$  = evapotranspiration,  $P$  = rainfall,  $I$  = irrigation, and  $\Delta M$  = change in water content within the root zone (“–” for accretion and “+” for depletion). Because all the plots were diked to prevent runoff and the irrigation applied did not exceed soil water deficit or water loss from the crop, runoff and drainage were considered negligible. Soil evaporation ( $E$ ) and potential transpiration ( $Tp$ ) were calculated using the revised version of the soil water balance model of Ritchie (1972). Briefly, the estimation of soil evaporation in Ritchie’s model is separated into two stages – the constant rate stage (Stage 1) and the falling rate stage (Stage 2). Stage 1 evaporation is energy limited and starts after a recharging rainfall or irrigation and continues until the upper limit of Stage 1 cumulative evaporation ( $U$ ) is reached. Daily soil evaporation in Stage 1 was calculated from the following relationships

$$E = E_o (1 - 0.43 LAI) \quad \text{when } LAI < 1.0$$

$$E = E_o / 1.1 \bar{e}^{0.4 LAI} \quad \text{when } LAI \geq 1.0$$

where  $E_o$  is potential evapotranspiration and  $LAI$  is leaf area index.  $E_o$  was considered equal to 90% of class A open-pan evaporation and the value of  $U$  is 6.0 mm for the Vertisol. Daily soil evaporation in Stage 2, which is more dependant upon soil hydraulic properties, was calculated from the following relationship

$$E = Ct^{\frac{1}{2}} - C(t-1)^{\frac{1}{2}}$$

where  $t$  is the number of days after Stage 2 evaporation begins and  $C$  is a coefficient for soil water transmitting properties and equals  $3.5 \text{ mm d}^{-1}$  for the Vertisol.

Potential transpiration ( $T_p$ ) was calculated using the following relationships

$$T_p = E_o (1 - e^{-LAI}) \quad \text{when } LAI \leq 3.0$$

$$T_p = E_o \quad \text{when } LAI > 3.0$$

However, if  $T_p + E > E_o$  then  $T_p = E_o - E$ . The model was tested before use and gave good agreement between the observed and predicted changes in the soil water content under the chickpea crop. Actual transpiration ( $T$ ) was calculated as the difference between the observed evapotranspiration ( $ET$ ), calculated using the neutron probe data, and the soil evaporation ( $E$ ) estimated using Ritchie's model.

### *Analysis of data*

Over the range of sub-treatments applied, the chickpea crop did not respond to the levels of phosphorus in 1985 and the plant population levels in 1986. Therefore, the data were pooled over the sub-treatments of these two experiments for further analysis.

## RESULTS

### *The weather*

The three seasons differed mostly in the amount and timing of rainfall during growth (Table 1). In 1985, the crop received 96.6 mm of rain in January and February 1986; the saturation vapour pressure deficit of air ( $SD$ ) and open-pan evaporation for these 2 months were sub-normal. Some rain was received during early crop growth stages in the 1986 season and near maturity in the 1984 season. Incoming solar radiation increased after January in all seasons and was associated with higher maximum and minimum temperatures, faster open-pan evaporation and higher  $SD$  after flowering.

### *Radiation interception and radiation use efficiency*

As expected, a shortage of water restricted leaf expansion and thus decreased radiation interception by the crop over the season. The ratio of actual to potential transpiration ( $T/T_p$ ) was used as a measure of plant water deficit experienced by the crop, i.e., when  $T/T_p = 1.0$  the crop is not stressed and when

TABLE 1

Monthly mean values of various climatic elements during the three seasons. These observations are from the meteorological observatory, situated ~ 500 m away from the experimental site

Month	Year	Total rainfall (mm)	Open-pan evaporation (mm day <sup>-1</sup> )	Maximum temperature (°C)	Minimum temperature (°C)	Saturation deficit of air at 14 h (kPa)	Solar radiation (MJ m <sup>-2</sup> day <sup>-1</sup> )
Nov.	1984	6.4	5.7	28.2	13.5	2.4	17.4
	1985	0.0	5.5	29.0	13.4	2.5	17.5
	1986	36.8	4.8	29.9	17.2	2.4	16.1
Dec.	1984	0.0	5.0	29.1	13.7	2.5	15.2
	1985	8.1	5.1	28.6	13.3	2.5	15.8
	1986	6.3	5.0	28.5	15.3	2.2	15.5
Jan.	1985	1.8	5.5	29.0	16.5	2.3	15.9
	1986	53.0	4.9	27.0	13.4	2.1	16.2
	1987	4.4	5.1	28.6	15.0	2.3	17.1
Feb.	1985	0.0	7.5	32.9	16.4	3.7	19.2
	1986	43.6	6.6	30.3	17.4	2.6	19.1
	1987	0.0	7.7	30.6	15.6	3.2	18.8
Mar.	1985	20.4	9.4	36.8	20.2	4.6	19.5
	1986	0.0	9.4	35.1	20.1	4.2	22.3
	1987	2.0	9.0	34.2	19.3	3.9	20.5

$T/T_p < 1.0$  the crop is stressed and the magnitude of plant water deficit is inversely proportional to this ratio. Figure 2 shows the decrease in radiation intercepted (relative to the maximum observed during the season) in different treatments as a function of percent transpiration deficit  $[(1 - T/T_p) \times 100]$ . The slopes of these lines, which represent to relative sensitivity of radiation interception (or leaf growth) to water deficit, decreased as the crop advanced towards maturity. A greater reduction in radiation interception prior to 50% beginning pod fill is attributed to the greater reduction in new leaf appearance and growth; after 50% pod fill, leaf senescence or leaf fall is responsible. These results also show that when a reduction in leaf area occurs prior to pod filling, recovery in terms of radiation interception (or leaf growth) is minimal after stress is released and growth remains source limited.

Dry matter accumulation was linearly related to cumulative intercepted radiation in both the irrigated and non-irrigated treatments. As an example, the results obtained with cv. Annigeri are presented in Fig. 3. The slopes of these lines define radiation use efficiency (*RUE*). In the irrigated treatment, 0.67 g of dry matter was produced per MJ of solar radiation intercepted over the

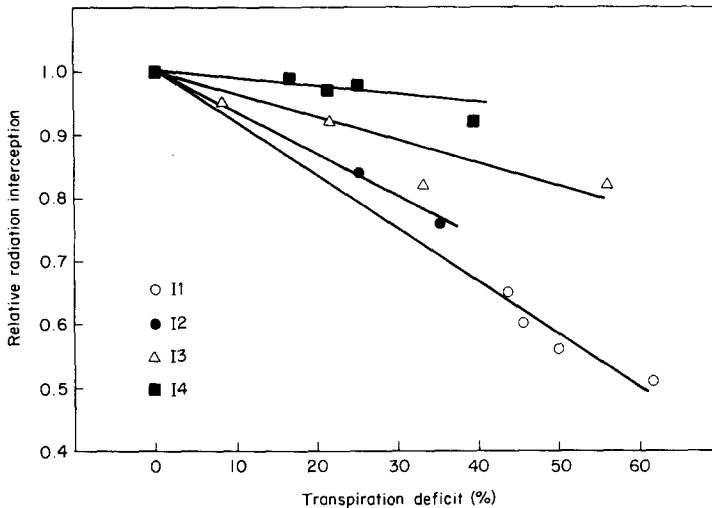


Fig. 2. Relationship between transpiration deficit and relative radiation interception in various irrigation treatments. Pooled data of 1986 and 1987 post-rainy seasons. For irrigation treatments I1-I4, see the text.

season. The plot of the data shows that *RUE* of non-irrigated chickpea maintained a fairly constant value close to the *RUE* of irrigated chickpea up to  $\sim 300$  MJ of solar radiation intercepted; it then declined with the decrease in extractable soil water and ultimately dropped to zero when all the extractable soil water was depleted. Over the season, the non-irrigated treatment produced 0.55 g of dry matter per MJ of solar radiation intercepted. These results also show that the decrease in *RUE* under stress induced by water deficit was not proportional to the decrease in soil water content in the major range of soil water availability.

To determine the lower limit of soil water availability below which the *RUE* of chickpea declines, *RUE* was calculated for successive 10–15-day periods of crop growth and plotted against average extractable soil water during the corresponding period. These calculations were based on the irrigated and non-irrigated plots only of the three season experiments. Figure 4 suggests that the *RUE* was independent of soil water availability provided at least 30% of extractable water was present in the rooting zone, indicating that factors other than soil water govern *RUE* of chickpea. The scatter in the data points above 30% *ESW* may also be from errors in estimating *RUE* for shorter periods of crop growth. Below 30% extractable water, *RUE* declined with the decrease in soil water content. A statistical fit to the data explained 42% variation in *RUE* by soil water availability.

To examine the relationship of *RUE* with the water deficit experienced by the crop, *RUE* was plotted against  $T/T_p$  observed during the season. The *RUE*



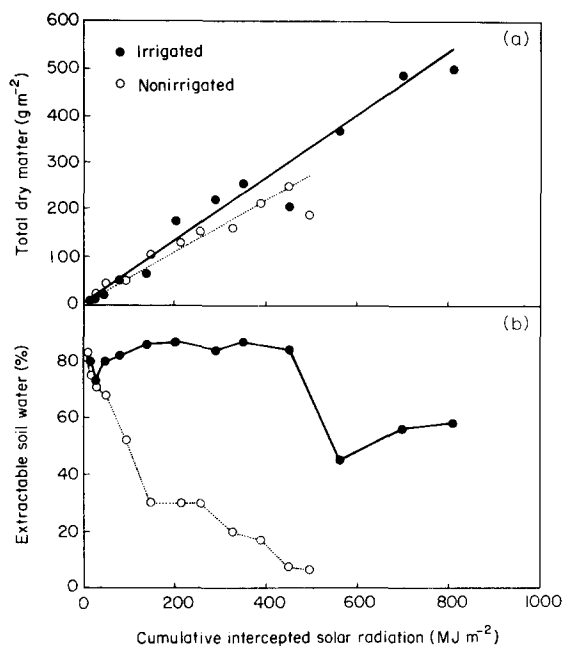


Fig. 3. Relationships between (a) dry matter production and cumulative intercepted solar radiation (irrigated:  $y=0.67X$ ,  $rse=23.8$ ,  $r^2=0.98$ ,  $P<0.01$ ; non-irrigated:  $y=0.55X$ ,  $rse=12.5$ ,  $r^2=0.98$ ,  $P<0.01$ ); and (b) percent extractable water and cumulative intercepted solar radiation by chickpea (cv. Annigeri), ICRISAT Centre, post-rainy season 1984.

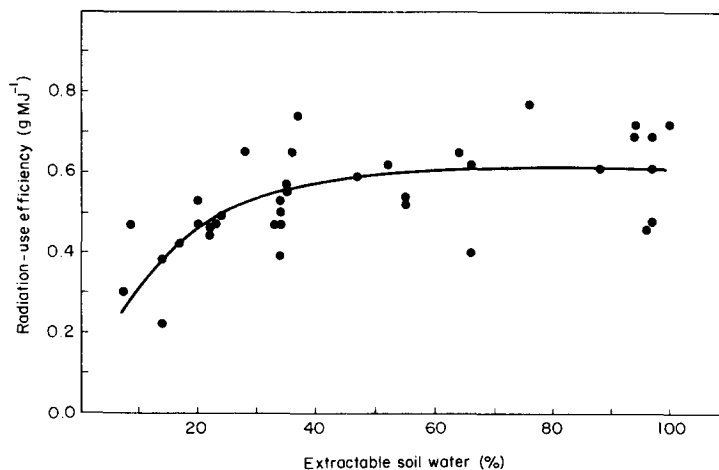


Fig. 4. Relationship between radiation use efficiency and extractable soil water content. Pooled data of 1984, 1985 and 1986 post-rainy seasons. Points represent average values for 10-15-day intervals ( $y=0.61(1-\exp(0.071X))$ ),  $rse=0.097$ ,  $r^2=0.42$ ,  $P<0.05$ ).

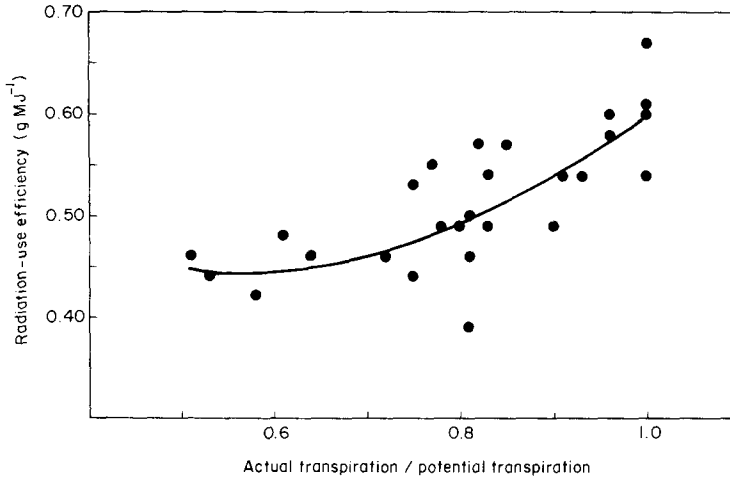


Fig. 5. Relationship between radiation use efficiency and the ratio of actual to potential transpiration observed in various irrigation treatments. Pooled data of 1984, 1985 and 1986 post-rainy seasons ( $y = 0.69 - 0.88X + 0.79X^2$ ,  $r_{se} = 0.043$ ,  $r^2 = 0.61$ ,  $P < 0.01$ ).

decreased curvilinearly with the decrease in  $T/T_p$  (Fig. 5). The main decrease occurred when  $T/T_p$  decreased from 1.0 to  $\sim 0.75$ , and below 0.75 it gradually levelled off. A quadratic fit to the data explained  $\sim 61\%$  variation in  $RUE$  by  $T/T_p$ . The factor  $T/T_p$  could, therefore, be used to estimate  $RUE$  as a function of water deficits in chickpea.

#### *Transpiration and transpiration efficiency*

Dry-matter production was linearly related to transpiration in all treatments and in all years; but the slopes of these curves, which represent transpiration efficiency ( $TE$ ) of chickpea, were different. In 1986, for example, cv. JG 74 produced 2.54 g of dry matter per kg of transpiration in the irrigated treatment, whereas in the non-irrigated treatment it produced 1.66 g of dry matter per kg of transpiration (Fig. 6). Differences in  $TE$  observed between seasons could be attributed to differences in saturation deficit ( $SD$ ) of air observed above the crop canopy (Table 2). Squire et al. (1987) reported similar relationships between  $TE$  and  $SD$  for pearl millet grown in a semi-arid tropical environment. They found that when  $TE$  is normalized by multiplying by the mean  $SD$  of air, the product is a conservative quantity with units  $g\ kPa\ kg^{-1}$ . Normalization of  $TE$  of chickpea with  $SD$  of air reduced the coefficient of variation ( $CV$ ) in the  $TE$  data of the three seasons from 14.4 to 10.8%, and a mean normalized  $TE$  value of  $4.8\ g\ kPa\ kg^{-1}$  was obtained.

To further study the relative advantage of normalization of  $TE$  with  $SD$  in the irrigated and non-irrigated environments, the data of fully irrigated and non-irrigated plots of the three experiments were considered separately (Table

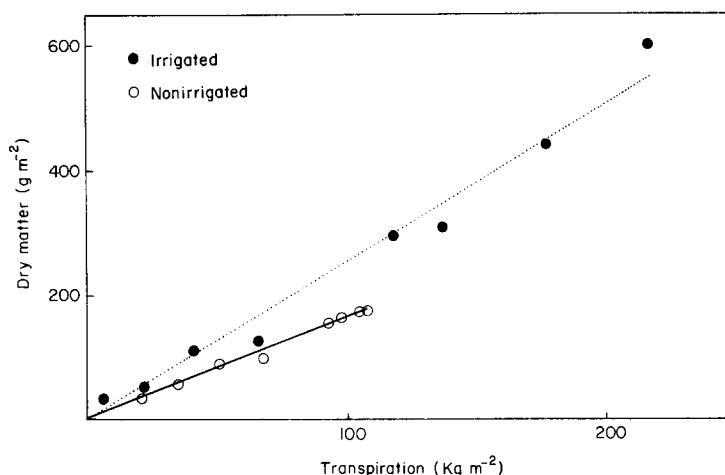


Fig. 6. Relationship between dry matter production and transpiration, post-rainy season 1986 (irrigated:  $y=2.54X$ ,  $rse=31.8$ ,  $r^2=0.98$ ,  $P<0.01$ ; non-irrigated:  $y=1.66X$ ,  $rse=6.2$ ,  $r^2=0.99$ ,  $P<0.01$ ).

TABLE 2

Range in transpiration efficiency ( $TE$ ), saturation deficit of air ( $SD$ ) and normalized  $TE$  of chickpea observed during three seasons

	$TE$ ( $g\ kg^{-1}$ )	$SD$ ( $kPa$ )	Normalized $TE$ ( $g\ kPa\ kg^{-1}$ )
1984 season ( $n=6$ )			
Range	2.16-1.42	2.78-2.44	5.27-3.95
Mean	1.9	2.6	4.9
CV (%)	14.5	7.1	9.8
1985 season ( $n=9$ )			
Range	2.78-1.91	2.29-2.17	6.31-4.14
Mean	2.2	2.2	4.8
CV (%)	11.4	1.68	12.2
1986 season ( $n=12$ )			
Range	2.60-1.66	2.15-1.94	5.31-3.6
Mean	2.3	2.1	4.8
CV (%)	11.6	4.2	10.6
All seasons ( $n=27$ )			
Range	2.78-1.42	2.78-1.91	6.31-4.1
Mean	2.2	2.2	4.8
CV (%)	14.4	10.8	10.8

3). The mean  $TE$  values of irrigated and non-irrigated plots were 2.18 and 1.76  $g\ kg^{-1}$ , respectively. Normalization of  $TE$  decreased the CV from 10.1 to 4.4% for the irrigated treatment, and from 15.2 to 14.7% for the non-irrigated treat-

TABLE 3

Effect of water supply on transpiration efficiency ( $TE$ ) of chickpea and its normalization with saturation deficit of air ( $SD$ ) for irrigated (I) and non-irrigated (NI) plots of the three experiments

Season <sup>a</sup>	Cultivar	$TE$ (g kg <sup>-1</sup> )		$SD$ (kPa)		Normalized $TE$ (g kPa kg <sup>-1</sup> )	
		I	NI	I	NI	I	NI
		1984	Annigeri	2.16	1.77	2.46	2.81
	K 850	2.11	1.79	2.46	2.81	5.2	5.0
	G 130	1.94	1.42	2.46	2.81	4.8	4.0
1985	Annigeri	2.16	2.16	2.26	2.32	4.9	5.0
1986	JG 74	2.54	1.66	1.96	2.19	5.0	3.6
Mean		2.18	1.76			5.0	4.5
CV (%)		10.1	15.2			4.4	14.7
Grand mean		1.97				4.8	
CV (%)		16.3				11.2	

<sup>a</sup>For the 1985 and 1986 season experiments, irrigated and non-irrigated plots refer to the area 3.6 and 16.4 m away from the line source, respectively, for the I1 treatment.

ment. This shows that normalization of  $TE$  with  $SD$  is more effective under well watered conditions than under water-deficit conditions. Normalization of the pooled data decreased the CV from 16.3 to 11.2% and gave a mean normalized  $TE$  of 4.8 g kPa kg<sup>-1</sup>.

## DISCUSSION

Water deficits decreased the rate of dry-matter production of chickpea by influencing both the amount of solar radiation intercepted and the efficiency with which it was used. A greater reduction in radiation interception with water deficits occurred during the growth stages prior to pod filling, implying greater sensitivity of leaf growth to stress. Water deficits during pod filling decreased radiation interception primarily because of increased leaf senescence. The maximum  $RUE$  observed in this study was 0.67 g MJ<sup>-1</sup> of solar radiation. Hughes et al. (1987) reported  $RUE$  values ranging from 0.30 to 0.93 g MJ<sup>-1</sup> for various varieties of kabuli chickpea in the relatively cooler climate of northern Syria. These results show that  $RUE$  of chickpea is less than for other legumes. For example, well watered pigeonpea had a  $RUE$  of 1.23 g MJ<sup>-1</sup> solar (Hughes and Keatinge, 1983), 1.25 g MJ<sup>-1</sup> solar (2.5 g MJ<sup>-1</sup> PAR) for groundnut (Marshall and Willey, 1983) and 2.05 g MJ<sup>-1</sup> solar (4.1 g MJ<sup>-1</sup>

PAR) for field beans (Fasheun and Dennett, 1982). Therefore, increasing total radiation interception by the chickpea during the season provides a better alternative for increasing its biomass production than increasing *RUE*.

A shortage of water decreased the *RUE* of chickpea, as observed in other crops such as barley and wheat (Biscoe and Gallagher, 1977; Monteith, 1977) and in pigeonpea (Hughes and Keatinge, 1983). Over the season, the non-irrigated chickpea intercepted 40% less radiation and had 18% less *RUE* than the irrigated chickpea (Fig. 3). This suggests that the main loss in dry matter of non-irrigated chickpea is in the fraction of radiation intercepted and not in the *RUE*. Although *RUE* decreased below 30% ESW in the root zone,  $T/T_p$  rather than soil water availability was better correlated with *RUE*, which explained only 61% variation in *RUE*. This indicates the need to investigate the influence of other factors (soil or climatic) on *RUE* of chickpea. For example, Squire et al. (1984) observed the maximum *RUE* of pearl millet to be at 25 °C and it decreased at other temperatures.

Transpiration efficiency was greater in those treatments and years where the saturation deficit of air was less. These results on the influence of *SD* on *TE* are similar to those observed in potato crop (Tanner, 1981) and in herbaceous dicots (Ford and Thorne, 1974; Nagarajah and Schulze, 1983). Normalization of *TE* with *SD* of air yielded a conservative value of 4.8 g kPa kg<sup>-1</sup> of transpiration, which could be used to estimate dry matter production in different chickpea-growing environments. Tanner and Sinclair (1983) reported normalized *TE* of soybean crop as 4.0 g kPa kg<sup>-1</sup>. The differences in *TE* of these two crops could be attributed to the differences in dry matter allocation to roots and the chemical composition of reproductive organs. The greater effectiveness of *SD* in reducing variability in the *TE* under irrigated than under non-irrigated conditions indicates that factors other than the *SD* of air also influence *TE* of chickpea under severe drought; this needs to be investigated.

It is concluded from this study that water deficits reduce solar radiation interception, transpiration and their use efficiencies in chickpea. If dry matter production is to be estimated from radiation interception, radiation use efficiencies must be related to plant water status. In transpiration-based models, *TE* must be normalized with the *SD* of air for better estimation of dry matter production of chickpeas. Although the seed yield of a cultivar will depend on its biomass production and harvest index, the results also show that greater and stable chickpea yields in the central and southern Indian environments could be obtained by adopting cultural practices and varieties that will provide greater growth during periods of low saturation deficits of the air and cooler temperatures, to make the most efficient use of water and radiation. This study also provides an explanation as to why the short-duration variety Annigeri is the best-adapted cultivar in penninsular India.

## ACKNOWLEDGEMENTS

We thank Messrs. S. Ramakrishna, P.V.V. Satyanarayana and R. Mukunda Reddy for their assistance in the field, and Mr. K.P.C.S. Raju for typing the manuscript.

## REFERENCES

- Bierhuizen, J.F. and Slatyer, R.O., 1965. Effect of atmospheric concentration of water vapour and CO<sub>2</sub> in determining transpiration-photosynthesis relationships of cotton leaves. *Agric. Meteorol.*, 2: 259-270.
- Biscoe, P.V. and Gallagher, J.N., 1977. Weather, dry matter production and yield. In: J.J. Landsberg and C.V. Cutting (Editors), *Environmental Effects on Crop Physiology*. Academic Press, London, pp. 75-100.
- Fasheun, A. and Dennett, M.D., 1982. Interception of radiation and growth efficiency in field beans (*Vicia faba* L.). *Agric. Meteorol.*, 26: 221-229.
- Ford, M.A. and Thorne, G.N., 1974. Effects of atmospheric humidity on plant growth. *Ann. Bot.*, 38: 441-452.
- Gallagher, J.N. and Biscoe, P.V., 1978. Radiation absorption, growth and yield of cereals. *J. Agric. Sci.*, 91: 47-60.
- Hanks, R.J., Keller, J., Rasmussen, V.P. and Wilson, G.D., 1976. Line-source sprinkler for continuous variable irrigation in crop production studies. *Soil Sci. Soc. Am. J.*, 40: 426-429.
- Hughes, G. and Keatinge, J.D.H., 1983. Solar radiation interception, dry matter production and yield of pigeonpea (*Cajanus cajan* (L.) Millspaugh). *Field Crops Res.*, 6: 171-178.
- Hughes, G., Keatinge, J.D.H., Cooper, P.J.M. and Dee, N.F., 1987. Solar radiation interception and utilization by chickpea (*Cicer arietinum* L.) crops in northern Syria. *J. Agric. Sci.*, 108: 419-424.
- Khurana, S.C. and McLaren, J.S., 1982. The influence of leaf area, light interception and season on potato growth and yield. *Potato Res.*, 25: 329-342.
- List, R.J., 1971. Hygrometric and psychrometric tables. *Smithson. Misc. Collect.*, Vol. 114. Smithsonian Meteorological Tables, 6th Revised Edn. Smithsonian Inst., Washington, DC.
- Marshall, B. and Willey, R.W., 1983. Radiation interception and growth in an intercrop of pearl millet/groundnut. *Field Crops Res.*, 7: 141-160.
- Monteith, J.L., 1977. Climate and the efficiency of crop production in Britain. *Phil. Trans. R. Soc. London, Ser. B*, 281: 277-294.
- Nagarajah, S. and Schulze, E.D., 1983. Response of *Vigna unguiculata* (L.) Walp. to atmospheric and soil drought. *Aust. J. Plant Physiol.*, 10: 385-394.
- Ritchie, J.T., 1972. Model for predicting evaporation from a row crop with incomplete cover. *Water Resour. Res.*, 8: 1204-1213.
- Scott, R.K., English, S.D., Wood, D.W. and Unsworth, M.H., 1973. The yield of sugar beet in relation to weather and length of growing season. *J. Agric. Sci.*, 81: 339-347.
- Squire, G.R., Marshall, B., Terry, A.C. and Monteith, J.L., 1984. Response to temperature in a stand of pearl millet. VI. Light interception and dry matter production. *J. Exp. Bot.*, 35: 599-610.
- Squire, G.R., Ong, C.K. and Monteith, J.L., 1987. Crop growth in semi-arid environments. In: J.R. Witcombe and Seth R. Beckerman (Editors), *Proceedings of the International Pearl Millet Workshop*, 7-11 April 1986, at ICRISAT, Patancheru, A.P. 502 324, India, pp. 219-231.
- Tanner, C.B., 1981. Transpiration efficiency of potato. *Agron. J.*, 73: 59-64.
- Tanner, C.B. and Sinclair, T.R., 1983. Efficient water use in crop production: research or research. In: H.M. Taylor, R. Wayne, Jordan and T.R. Sinclair (Editors), *Limitation to Efficient Water Use in Crop Production*. American Society of Agronomy, Madison, WI, pp. 1-28.