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Water and thermal use characteristics of cowpea (*Vigna unguiculata* L. Walp.)

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ABSTRACT

The evapotranspiration rates of unstressed cowpea (*Vigna unguiculata* L. Walp. cv. *Charodi-1*) as measured from gravimetric lysimeters in the arid region of Jodhpur during 1999 to 2001 were 2.8-3.7 mm day^{-1} during early growth, 3.7-6.8 mm day^{-1} at vegetative stage, 4.1-6.6 mm day^{-1} at flowering/ pod filling stage and 3.1- 4.0 mm day^{-1} at maturity stage. The seasonal evapotranspiration of cowpea was 312 mm with an average yield of 1362 kg ha^{-1} resulting a water-use efficiency of 4.36 kg ha^{-1} mm^{-1}. The crop coefficients increased from 0.50 at early growth stage to 1.19 at vegetative stage and declined to 0.54 on maturity. The thermal time requirements, energy balance and advection were also quantified.

Key words : Cowpea, evapotranspiration, irrigation, water-use efficiency advection, arid region

Cowpea (*Vigna unguiculata* L. Walp) is an important crop of arid western Rajasthan and is grown in 0.1 million ha with an average productivity of 380 kg ha^{-1}, but the crop yields as high as 1500 kg ha^{-1} were reported (DOA, 1998). The seeds are used for human consumption whereas, the whole plant is used as fodder for livestock. The crop matures in 60 to 70 days and thus preferred to other long duration crops as it escapes the impact of recurring drought in the Indian arid region.

The cowpea requires adequate water at flowering and pod filling stage for higher production. The water stress at flowering reduced the seed yield by 44% and at pod filling stage by 29%, respectively (Labanauskas *et al.*, 1981; Turk *et al.*, 1980). Heavy rainfall at pre- and post-anthesis stages with poor sunshine hours adversely affected seed yield (Sinha and Mathur, 1994). Ramana Rao *et al.*, (1984) reported that the crop yield of cowpea was influenced by water availability at reproductive stage. Different cultivars of cowpea do not seem to differ in stomatal conductance or in net photosynthesis rates, but might differ in dry matter partition for seed and fodder yields (Sivakumar *et al.*, 1996). The cowpea can tolerate heat and dry conditions and can grow in areas where rainfall occurs in between 200 to 250 mm. Temperatures greater than 28°C leads to abnormal pollen development and anther indehiscence, and low temperatures (<20°C) reduce the yield of cowpeas (Warring and Hall, 1984) and the maximum yield was obtained when the cowpea was grown at 27/22°C day/night) temperatures (Bagnall and King, 1987). They also observed with high temperatures a decrease in pod number and with temperatures below 21°C a decrease in seed number and size. The present study was made to investigate the production potential, water and energy-use aspects of cowpea in an arid region.

MATERIALS AND METHODS

A field experiment on cowpea (*Vigna unguiculata* L. Walp. cv. *Charodi-1*) was conducted at Central Arid Zone Research Institute, Jodhpur (26° 18'N; 73° 01'E and 224 m above MSL) during 1999 to 2001. The area experiences an average rainfall of 310 mm and air temperatures between 24°C and 40°C during the cropping season. The soils of the area are 1 m deep and classified as coarse loam, mixed hyperthermic Haplocambids. The organic matter content according to Walkey and Blacks method was 0.4%, the available P using Olein's method was 17 kg ha^{-1} and the available K with ammonium acetate method was 190 kg ha^{-1}. The bulk density of the soil is 1.12-1.56 gm cm^{-3}, the field capacity is 12.0-13.5% and wilting point 5.5-6.5% (Rao and Saxton, 1995).

With the onset of monsoon, the crop was sown on 20th July during 1999, (late sown crop), 18th July during 2000 (late sown crop) and on 6th July during 2001 (normal sown crop) maintaining an inter and intra-row spacing of 45 cm and 10 cm, respectively in about 0.8 ha of field from which separate plots were ear marked for different treatments. The crop was harvested on 28th September in 1999, 26th September in 2000 and 6th September in 2001. The rainfall during the cropping season was 161 mm in 1999, 117 mm in 2000 and it was 250 mm during 2001..

Daily evapotranspiration was recorded using 3 gravimetric lysimeters consisting of a sensitive type of weighing machine of 2 tones capacity (IMD, 1979) surrounded by 5 m x 15 m plots of crop with similar irrigation treatment to act as buffer. Separate field plots of size 5 m x 15 m were maintained under rainfed, 50% and 100% evapotranspiration. Growth and phenology from 7 tagged plants were monitored in each of 3 treatments, while the dry matter was sampled at 15 days interval. The tip of the leaf appearance was recorded on every alternate day to relate with thermal time (growing degree days). Fertilizer at 20 kg N ha^{-1} and 17.2 kg P ha^{-1} was applied.

Daily flood irrigation at 100% evapotranspiration rate was given to the crop after 20 days after emergence, based on the evapotranspiration during the previous day and irrigation at 50% rate was given once in 4 days. The irrigation time and quantity applied were the same both in the field plots as well as in the lysimeters. The weekly average evapotranspiration for the 3 cropping seasons for 100% rate of irrigated crop was used for working out the crop coefficients (ratio of actual to class A pan evaporation). The day time energy balance was calculated using the following equation;

Table 1 : Cowpea (Cv. *Charodi*-I) response to irrigation

Parameter	1999	2000	2001	Average
Plant height (cm)				
Irrigation at 100% ET rate	50	58	165	91
Irrigation at 50% ET rate	36	43	148	76
Rainfed	30	36	140	69
Number of leaves				
Irrigation at 100% ET rate	15	26	54	32
Irrigation at 50% ET rate	14	20	30	21
Rainfed	8	16	29	18
Leaf area index				
Irrigation at 100% ET rate	0.87	1.56	3.89	2.10
Irrigation at 50% ET rate	0.76	1.20	3.54	1.83
Rainfed	0.64	0.85	3.15	1.54
Biomass (kg ha^{-1}, SEm)				
Irrigation at 100% ET rate	3840 (43.0)	4020 (56.9)	4830 (58.5)	4230
Irrigation at 50% ET rate	1890 (23.1)	3654 (43.7)	4076 (47.3)	3207
Rainfed	710 (13.7)	3322(34.1)	2460 (32.6)	2164
Grain yield (kg ha^{-1} ,SEm)				
Irrigation at 100% ET rate	976 (45.5)	1228 (25.8)	1884 (55.8)	1363
Irrigation at 50% ET rate	621 (38.4)	1117 (23.9)	1590 (32.4)	1109
Rainfed	323 (33.2)	1015 (19.3)	961 (35.6)	766

$$R_n = LE + H + G$$

Net radiation (R_n) and soil heat flux (G) at different growth stages at hourly interval between 0600 and 1800 h IST on all plots were manually recorded on hourly basis. The latent heat of vaporization (LE) in MJ was indirectly calculated from the evapotranspiration (mm) measured from the lysimeters. Soil moisture upto 120 cm depth at 15 cm interval were measured using a TDR soil moisture (Model TRIME-FM). Water-use efficiency (kg ha^{-1} mm^{-1}) was worked out as a ratio of grain yield produced per unit of evapotranspiration used by the crop.

The thermal time (°Cd) was calculated using threshold temperature of 8°C (Singh *et al.*, 2000) from emergence to physiological maturity of the crop and also in relation to phenology and leaf tip initiation in the crop.

RESULTS AND DISCUSSION

Water-use and yield attributes

With increasing moisture conditions, cowpea had performed well in its growth

Table 2. Weekly evapotranspiration and crop coefficient of *kharif* cowpea (cv. Charodi -1)

Week after sowing	Evapotranspiration (mm d^{-1})				Pan evaporation (mm d^{-1})				Crop coefficient			
	1999	2000	2001	Mean	1999	2000	2001	Mean	1999	2000	2001	Mean
1	3.0	4.2	3.8	3.7	6.9	4.9	4.3	5.4	0.43	0.85	0.88	0.68
2	2.9	3.9	2.7	3.2	5.8	8.5	3.8	6.0	0.50	0.45	0.71	0.53
3	3.1	2.1	3.2	2.8	4.2	8.4	4.1	5.6	0.74	0.25	0.78	0.50
4	3.0	4.5	3.5	3.7	5.4	7.6	4.2	5.7	0.56	0.59	0.83	0.65
5	3.7	5.3	5.0	4.7	6.6	4.2	5.8	5.5	0.56	1.26	0.86	0.85
6	6.2	7.6	4.7	6.2	5.5	6.6	4.2	5.4	1.12	1.07	1.25	1.19
7	7.8	7.1	5.6	6.8	6.1	6.6	4.5	5.7	1.27	1.07	1.25	1.19
8	8.9	4.3	6.7	6.6	7.5	6.3	5.6	6.5	1.18	0.68	1.19	1.01
9	3.5	3.5	5.4	4.1	7.6	7.1	5.8	6.8	0.46	0.49	0.93	0.60
10	1.2	2.8	5.2	3.1	4.0	6.9	6.2	5.7	0.30	0.40	0.84	0.54
Average	4.3	4.5	4.6	4.5	6.0	6.7	4.8	5.8	0.72	0.67	0.98	0.78

Table 3 : Seasonal evapotranspiration and water-use efficiency of unstressed *kharif* cowpea.

	1999	2000	2001	Mean
Seasonal rainfall (mm)	161	117	250	176
Seasonal evapotranspiration (mm)	301	315	322	312
Grain yeild (kg ha-1, SEm)	976(45.6)	1228(25.8)	1884(55.8)	1362
Water-use efficiency (kgha-1 mm-1)	3.24	3.90	5.85	4.36

as seen from the observations of plant height, leaf area index, biomass and grain yield (Table 1). The plant height was 50 to 165 cm in irrigated (100% ET rate) crop compared to 30 to 140 cm in rainfed crop The irrigated crop had 15 to 54 leaves plant^{-1} at peak vegetative stage and rainfed crop 8 to 27 leaves plant^{-1}. Rainfed cowpea sown on normal dates of onset and even distribution of rainfall in 2001 performed better than the crop sown under delayed and low rainfall conditions in 1999. Irrigation at 50% ET rate enhanced seed yield by 45% and irrigation at 100% rate by 78% and such increase due to irrigation was much higher during the low rainfall year 1999. The relative contribution of seed to biomass (Harvest index) varied between 0.25 and 0.40 by weight depending upon the moisture and other weather conditions.

Soil moisture variations in irrigated and rainfed crop conditions

The profile moisture contents both under irrigated (100%ET rate) and rainfed cowpea during the low rainfall year 2000 are shown in Figs.1&2. Both under irrigated and rainfed crop, the profile soil moisture contents were high beyond 15 cm depths as the moisture loss from surface layer was

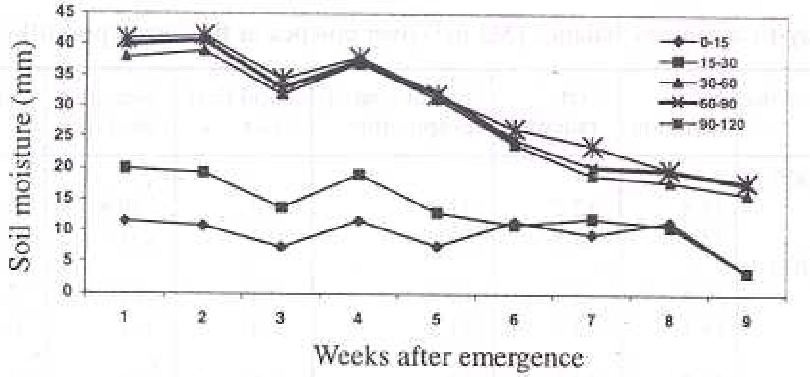

Fig. 1 : Soil moisture variations in irrigated cowpea during 2000

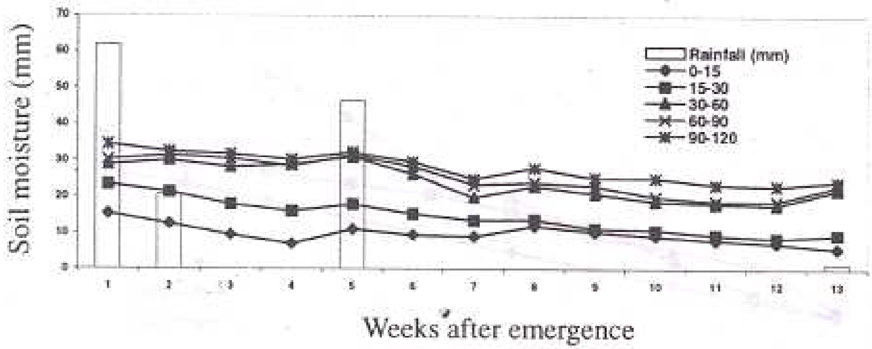

Fig. 2 : Soil moisture variations in rainfed cowpea during 2000

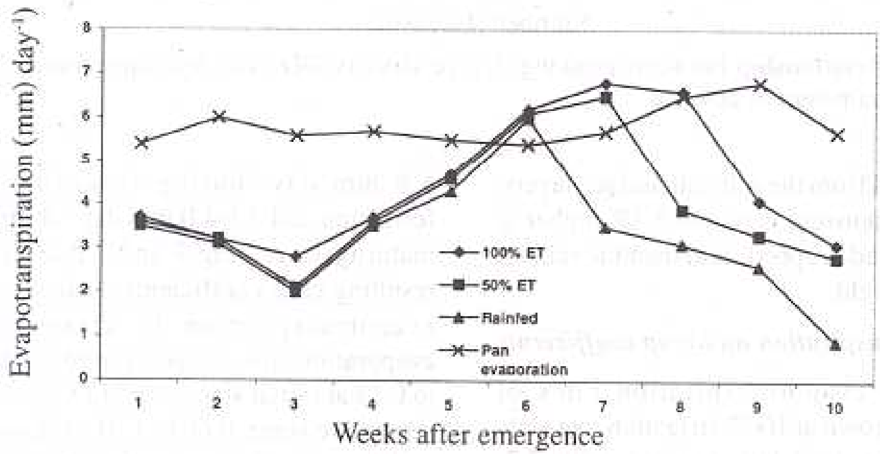

Fig. 3 : Class A pan evaporation and evapotranspiration rates of cowpea

Table 4 : Day-time emergy balance (MJ m^{-2}) over cowpea at flowering/pod filling stage.

Days after sowing	Solar radiation	Net radiation	Latent heat of evaporation	Soil heat flux	Sensible heat flux	Advection
Irrigated (100%)						
1999	18.8	12.2	41.4	0.2	-30.8	Yes
2000	13.2	12.8	29.2	0.8	2.3	Yes
Irrigated (50%)						
1999	20.4	12.4	19.5	0.8	-8.8	Yes
2000	14.1	13.6	24.3	1.4	1.4	Yes
Rainfed						
1999	21.7	12.5	4.9	3.6	6.0	No
2000	10.9	14.1	12.5	0.4	1.3	No

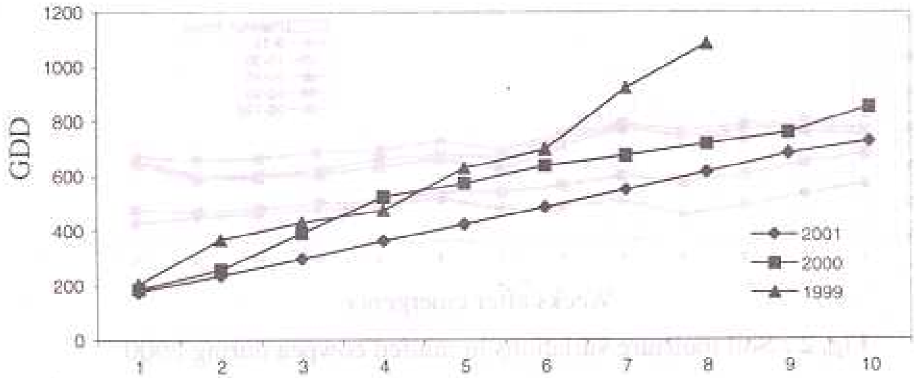

Fig 4 : Relationship between growing degree days (GDD) and leaf appearance in the mainstem of cowpea

faster than from the sub-sub-surface layers. The soil moisture was upto 3.1% higher in the irrigated cropped field than the rainfed cropped field.

Evapotranspiration and crop coefficients

The evapotranspiration rates of cowpea grown at 100% irrigation rate were 2.8-3.7 mm day^{-1} during early growth, 3.7-6.8 mm day^{-1} during vegetative stage, 4.1-6.6 mm day^{-1} during flowering/ pod formation and 3.1-4.0 mm day^{-1} during the maturity stage (Fig.3 and Table 2). The resulting crop coefficients (ratio of actual evapotranspiration to class A pan evaporation) for cowpea varied from 0.50 to 0.68 at initial stage, 0.65 to 1.19 at peak vegetative stage, 0.60 to 1.01 at flowering/ pod formation stage and 0.54 to 0.60 at maturity with a mean coefficient of 0.78

for the entire cropping season. The crop had highest evapotranspiration during 6th to 8th weeks after emergence.

The seasonal evapotranspiration for unstressed cowpea was 312 mm compared to 408 mm of class A pan evaporation. The seasonal evapotranspiration for 50% ET and rainfed crop was 286 mm and 260 mm, respectively (Table 3).

Crop phenology and degree days

The flowering in cowpea was delayed due to extended rainfall conditions in 2001 and took degree days of 918°Cd to reach flowering as compared to 856°Cd under low rainfall condition of 2000. Similarly, the crop took more accumulated temperature 1470°Cd to reach physiological maturity in 2001 in comparison to 1390°Cd in 2000.

Leaf tip initiation in relation to degree days

Leaf tip appearance on main stem (MS) of cowpea grown during different years in relation to thermal time (degree days) from days after emergence was worked out and presented in Fig.4. A linear relationship exists in all years among these variables. On an average, the thermal time required for each leaf production on MS was about 64°Cd during good rainfall year (2001) compared to 88°Cd for the crop grown in a low rainfall year (2000) indicating that leaf appearance was slower in low rainfall years compared to extended rainfall years.

Day-time energy balance

The day-time energy balance (MJ m^{-2}) conditions over cowpea at flowering/pod filling stage showing net radiation, latent heat of vapourization, soil heat flux, sensible heat flux and advection are presented in Table 4. The net radiation was low in rainfed crop compared to the one in irrigated crop. Latent heat of vapourization was high in irrigated crop compared to the rainfed crop. Advective conditions were present in both irrigation treatments in both seasons giving rise to high latent heat of evaporation.

CONCLUSIONS

Based on the measured evapotranspiration rates of unstressed cowpea which varied from 2.8 to 6.8 mm day^{-1} during a season, the crop coefficients for scheduling irrigation were worked out as 0.5 for initial stage to 1.19 for vegetative stage. The water-use efficiency was highest for 50%ET rate irrigated cowpea and hence suggested for irrigation scheduling at this level of evapotranspiration for achieving optimum yields from cowpea in the arid region.

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