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Evapotranspiration Rates and Water Utilization of Moth bean under two Soil Moisture Conditions

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Abstract: Moth bean (*Vigna aconitifolia* (Jacq.) Marechal) was grown under rainfed and 100% potential evapotranspiration (PET) irrigation (unstressed) conditions to quantify the influence of moisture availability on evapotranspiration (ET) rate, and water and heat use efficiencies. The experiment was carried out in gravimetric lysimeters, installed at Central Arid Zone Research Institute, Jodhpur, during 1991 and 1992. The evapotranspiration (ET) rate from 100% PET (unstressed) crop was maximum (6.6 mm day^{-1}) during 7th week after sowing, and lowest (2.2 mm day^{-1}) during crop emergence stage. The maximum evapotranspiration rate coincided with peak pod formation stage in the crop. Water use efficiency of the crop was 2.3 to 3.5 and 2.2 to 2.4 kg ha^{-1} mm^{-1} for unstressed and rainfed crop, respectively. At cardinal temperatures of 8°C (base temperature below which moth bean development ceases), 33°C (optimal temperature for development) and 45°C (maximum temperature at and above which no development takes place), the crop required 1351 to 1569°Cd growing degree days (thermal time) to reach physiological maturity. Linear relationship was developed between thermal time and leaf tip appearance. The leaf tip appearance on the main shoot of moth bean in relation to the thermal time was linear under both moisture conditions, requiring about 52 to 58°Cd $leaf^{-1}$. However, leaf tip appearance on primary branch was slightly faster and required 49 to 53°Cd for each new leaf. Appearance of first primary branch was earlier (at about 300°Cd after emergence) under the unstressed condition as compared to the rainfed crop under the potential ET (at 360°Cd). Hence, it may be concluded that despite low water requirements, the crop growth is considerably influenced by the moisture availability during crop growing period in the region.

Key words: Moth bean, evapotranspiration, moisture availability, crop development, thermal time, water use efficiency.

Agricultural production in general has undergone a rapid change since green revolution in India but, in particular, the performance of pulses is not satisfactory. The national pulse production revolves only around 12.5 to 13 million tonnes. The poor performance of the pulses in terms of area, production and yield is noticed in different parts of the country (Deshpande and Chandrashekar, 1982).

In arid regions, where water availability is a major constraint in crop production, the studies on evapotranspiration and water use become very essential for major crops of the region. Thermal time has long been recognized as one of the important environmental determinants of the rate at which plant development takes place (Bierhuizen, 1973; Landsberg, 1975). Thermal time is still calculated almost in

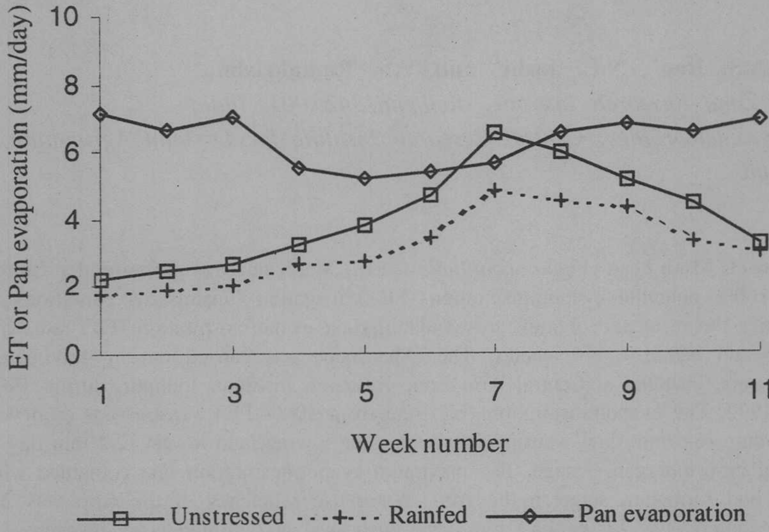

Fig. 1a. Variation in evapotranspiration rates of moth bean during different crop growth stages under unstressed and rainfed conditions.

its original form (summation of daily mean temperature minus base temperature) in some cases because it offers a better prediction in comparison to calender day for determining crop developmental stage, including crop physiological maturity.

Moth bean is an important drought tolerant legume in western Rajasthan (Kumar, 1996). The crop matures in 65-70 days, matching with the water availability period in the region. Various products of this crop have high food value and its demand is continuously increasing in both the national and international market. In spite of agricultural developments, its production remains low and unstable in the region. In the past, no study was reported on evapotranspiration (ET) as well as on the crop development in relation to growing degree days (thermal time). Therefore, in the present study an attempt has been made to describe the water requirement at different growth stages for optimum crop production in the region. Crop phenology and leaf

Table 1. Thermal time requirement for moth bean under two moisture availability conditions

Treatments	Year	Flowering		Physiological maturity	
		No. of days taken	Thermal time taken	No. of days taken	Thermal time taken
Unstressed	1991	44	936	66	1396
	1992	48	1012	76	1569
Rainfed	1991	41	873	64	1351
	1992	46	974	72	1487

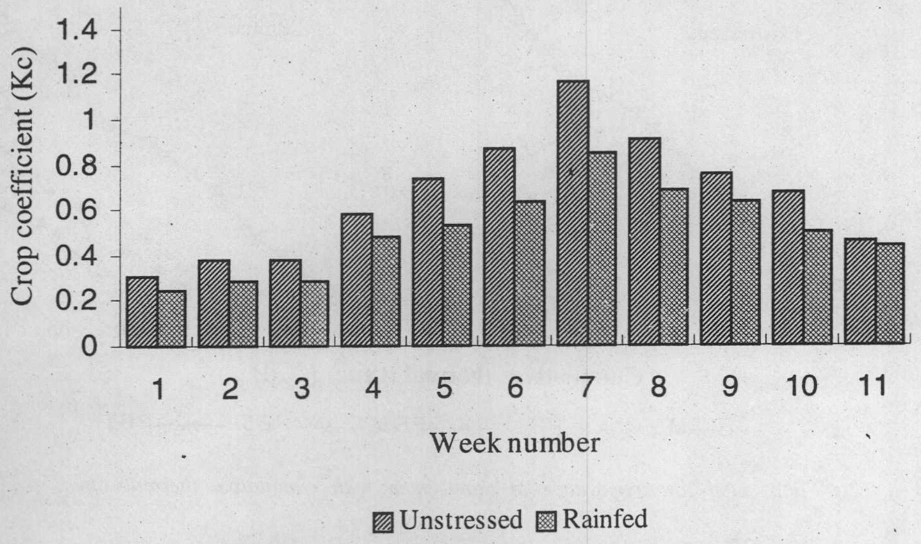

Fig. 1b. Crop coefficient of moth bean at different growth stages under unstressed and rainfed conditions.

tip appearance in relation to thermal time is described to estimate the crop development.

Materials and Methods

Field experiments on moth bean (cv. Maru moth) were conducted for two consecutive *kharif* seasons (July to September) in 1991 and 1992 at the Central Arid Zone Research Institute, Jodhpur (26.3°N, 73.02°E). Mean annual rainfall of Jodhpur is 368 mm, with the major part (90 to 95%) received during south west monsoon (*kharif*) season between end of June and September. The average annual global solar radiation on horizontal surface is 21.0 MJ m^{-2} day^{-1}, while during the crop season it varies from 16.6 to 19.4 MJ m^{-2} day^{-1}.

The soils in the experimental area have developed from rhyolite and modified by alluvial and aeolian activities and belong to the family of coarse loamy, mixed, hyperthermic of Camborthids as per soil taxonomy. The surface layer is fine sandy in texture with 6.55% clay and 0.52% silt.

Table 2. WUE and HUE of moth bean

Year	Treatment	CU (mm)	Yield (kg ha^{-1})	WUE (kg ha^{-1} mm^{-1})	Thermal time (°Cd)	HUE (kg ha^{-1} °Cd)
1991	Unstressed	246	849	3.5	1396	0.61
	Rainfed	160	384	2.4	1351	0.28
1992	Unstressed	347	787	2.3	1569	0.50
	Rainfed	275	600	2.2	1487	0.40

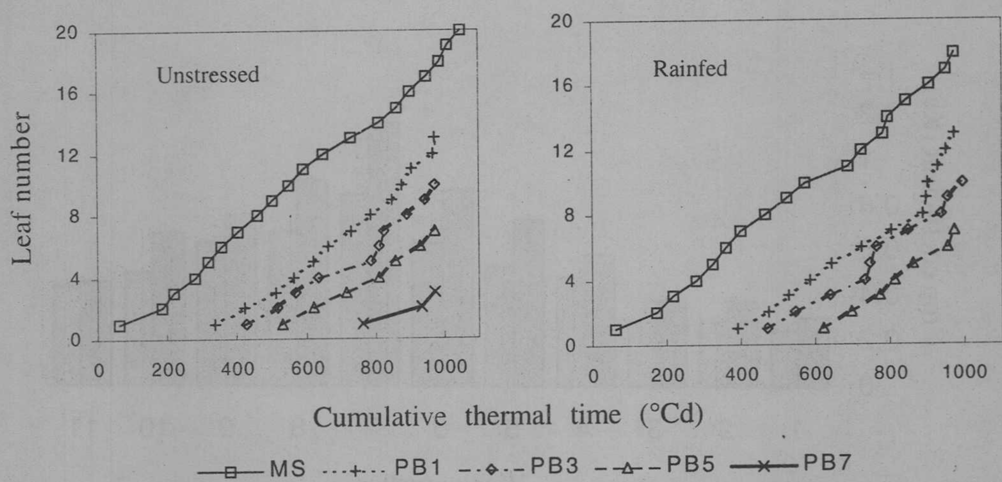

Fig.2. Leaf tip appearance in moth bean with cumulative thermal time.

The subsoil is a non-calcareous loamy sand. The soils are low in organic carbon (0.16%). Soil analyses showed the available P (Olsen's method) and K (ammonium acetate method) contents to be 17 and 180 kg ha^{-1}, respectively. The moisture contents at field capacity and at -15 bar tension were equivalent to 9.5 and 3.0% water content (w/w), respectively.

The crop was grown under two irrigation treatments, viz., (a) rainfed (control) and (b) unstressed (irrigated daily from 20 days onwards with an amount equal to 100% potential ET). The daily ET rates under these levels of soil moisture were measured using gravimetric lysimeters installed in the experimental plots. Field plots of 5.0 x 2.5 m were marked near lysimeters for various plant growth observations. The crop was sown after first sowing rains of greater than or equal to 20 mm of cumulative rainfall received in a week during the season. The inter- and intra-row spacings were maintained at 40 cm and 10 cm, respectively.

The thermal time (t_d) in °Cd of a phenophase was computed as given below:

$$t_d = \sum_{i=1}^{n} (T_a - T_b) \quad .....(1)$$

where,

T_a is daily mean air temperature, T_b is the base temperature below which development stops, and n is the number of days for the completion of the phenophase, used in the summation.

The T_a was calculated by averaging daily maximum and minimum temperatures which were recorded in an agrometeorological observatory located very near to the experimental site. A minimum temperature (threshold) of 8°C was taken as base temperature (T_b). The values of optimum temperature (T_p) for peak development and the maximum temperature (T_x) above which the development rate is zero were taken as 33°C and 45°C,

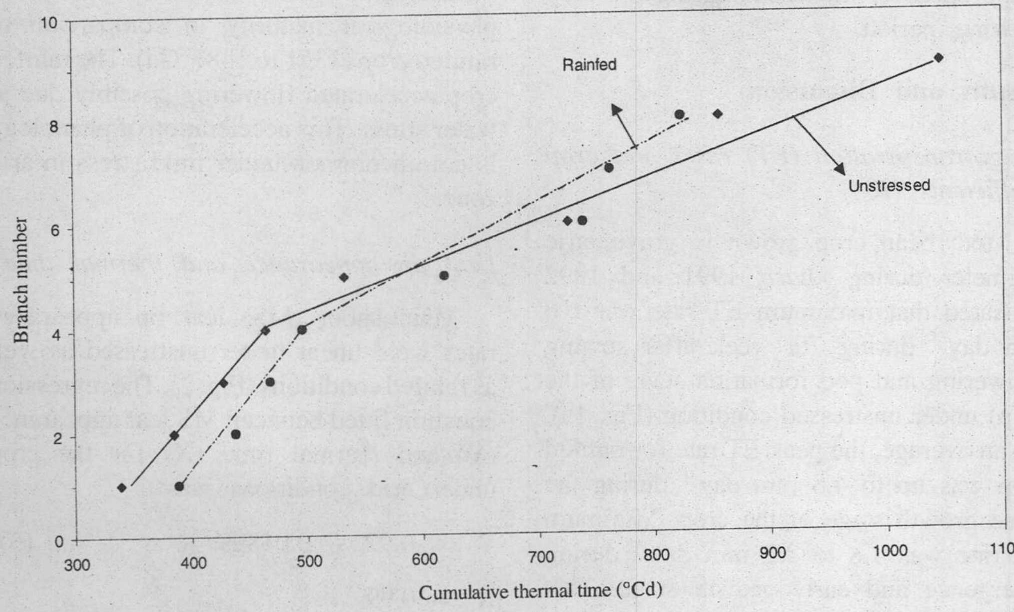

Fig. 3. Branch appearance in moth bean with cumulative thermal time.

respectively (Ong, 1983a, 1983b; Ritchie and Nesmith, 1991). If daily mean temperature (T_a) was between T_p (33°C) and T_x (45°C), thermal time (t_d) was calculated as follows:

$$t_d = (T_p-T_b)*(1-(T_a-T_p)/(T_x-T_p)) \quad ....(2)$$

When daily mean temperature (T_a) equalled to T_x, the calculated thermal time (t_d), using the equation 2, was computed as zero to represent no crop development. Negative thermal time computed for any day was also considered zero.

At the beginning of the growing season, 10 representative plants were marked in each (unstressed and rainfed) plot (5.0 x 2.5 m) to collect the detailed phenological and growth data. Leaf tip appearance data, on the main shoot (MS) and on the primary branch (PB), were collected every alternate day.

Heat-use efficiency (HUE), which measures crop production (kg ha^{-1}) per unit degree day (°Cd) with respect to grain yield, was calculated following Sastry *et al.* (1985) for studying production pattern in relation to ambient temperature. Water-use efficiency (WUE; kg ha^{-1} mm^{-1}) was calculated using the data on grain yield and accumulated values of ET during the cropping period for both the years. Pan evaporation data recorded through Class A open pan evaporimeter kept in the agrometeorological observatory adjacent to the lysimeter field were also used in the study. The weekly mean of ET and pan evaporation were used to compute the crop coefficients (K_c) as the ratio of ET to pan evaporation for all weeks during the crop growing period.

Results and Discussion

Evapotranspiration (ET) rates and crop coefficients (K_C)

Moth bean crop grown in gravimetric lysimeter during *kharif* 1991 and 1992 indicated that maximum ET rate was 6.6 mm day^{-1} during 7th week after sowing (flowering and pod formation stage of the crop) under unstressed condition (Fig. 1a). On an average, the peak ET rate for rainfed crop was up to 4.8 mm day^{-1} during the same growth stage of the crop. Minimum ET rate was 1.8 to 2.2 mm day^{-1} during emergence and early growth stage. This ET rate was mainly due to evaporation from top soil as the crop did not cover the surface fully at this stage of growth.

Crop coefficient, a basic tool for making irrigation scheduling, was computed as the ratio of crop ET to the open pan evaporation. Crop coefficient ranged between 0.3 and 1.2 for unstressed crop and between 0.24 and 0.85 for rainfed crop (Fig. 1b). Low crop coefficient values coincided with emergence stage of the crop whereas high crop coefficient values were found during 6th to 8th week for the crop under both the treatments, coinciding with peak pod formation and grain filling stages of the crop.

Crop phenology and thermal time requirements

In general, unstressed crop took 936 to 1012°Cd to reach flowering against 873 to 974°Cd under rainfed condition (Table 1). Similarly, unstressed crop took more thermal time (1396 to 1569°Cd) to reach physiological maturity in comparison to rainfed crop (1351 to 1487°Cd). The rainfed crop accelerated flowering possibly due to water stress. This acceleration of phenology is not uncommon under mild stress in arid zone.

Leaf tip appearance and thermal time

Main shoot (MS) leaf tip appearance rates were linear under unstressed as well as rainfed conditions (Fig. 2). The regression equation fitted between MS leaf appearance (Y) and thermal time (X) for the crop under arid conditions was:

$$Y = -0.92 + 0.01899\ X \qquad .....(3)$$

$$R^2 = 0.99$$

On an average, the rate of leaf production on MS was 52 to 58°Cd $leaf^{-1}$ (about 0.02 leaf per °C day) irrespective of soil moisture adequacy. Leaf appearance on primary branches (PB1 to PB7) remained faster and took a little less (49 to 53°Cd) thermal time as compared to leaf appearance on the main shoot. However, among the branches, branch 1 (PB_1) displayed slightly faster rate of leaf appearance under rainfed crop than unstressed condition. The production of fully expanded leaves on the branch axes was compared with that for the main shoot for two moisture treatments. The main shoot always produced more leaves than other axes within the plant. Also, number of leaves produced by the branch axes were less under rainfed crop in comparison to unstressed condition. This suggests that though moisture availability has no significant effect on the leaf appearance rate, the soil water stress could limit the leaf number per shoot. The less number of leaf in the rainfed crop may also be responsible for earlier flowering.

Branch appearance and thermal time

The appearance of the first primary branch on the MS required about 300 and 360°Cd after emergence under the unstressed and the rainfed conditions, respectively (Fig. 3). Thereafter, the crop under both moisture conditions displayed a linear rate of branch production, 40°Cd and 34°Cd per branch up to the appearance of primary branch number 4 on the main shoot for the unstressed and the rainfed crop, respectively. Thereafter, branch appearance is again at linear rate with different slope than earlier (Fig. 3). After fourth branch every next branch took about 115°Cd and 90°Cd for the unstressed and rainfed crop, respectively. The first branch was estimated to have appeared when there were five to six leaves on the main shoot. Four primary branches were common on each plant, irrespective of moisture availability. Generally, only 83% of plants under unstressed and 50% of plants under rainfed conditions bore branch 7. Branch 8 or 9, which was generally the last branch, appeared only in 15 to 50% of the plants maintained under unstressed condition.

Yield, water use and heat use relationships of moth bean

Consumptive use (CU), grain yield, WUE, thermal time (°Cd) and HUE of the crop were worked out for the two years (Table 2). The crop maintained under unstressed conditions utilized 246 and 347 mm of water during 1991 and 1992, respectively, providing grain yield of 849 and 787 kg ha^{-1}, respectively. In contrast, the rainfed crop produced 384 kg ha^{-1} with a CU of 160 mm during 1991 and 600 kg ha^{-1} with a CU of 275 mm during 1992. The WUE of moth bean varied between 2.3 and 3.5 for unstressed crop and between 2.2 and 2.4 for rainfed crop (Table 2). The HUE ranged between 0.50 and 0.61 for unstressed crop, and between 0.28 and 0.40 kg ha^{-1} °Cd^{-1} for rainfed crop. In general, HUE was higher for unstressed crop as compared to rainfed crop, irrespective of rainfall and other microclimatic conditions during the cropping season (July-September).

However, WUE for both unstressed and rainfed conditions were more during the low rainfall (182.1 mm) year of 1991 in comparison to high rainfall (383.1 mm) year of 1992. This indicates that WUE decreased during the high rainfall year, irrespective of moisture treatments. This is because increase in yield is not linear with increase in moisture availability condition after certain critical amount of rainfall and its distribution (rainy days) over the region. This conforms to the low water requirement of the crop (about 250 mm rainfall) during the cropping season for its optimum WUE.

Conclusions

ET rates for moth bean crop varied between 1.8 to 6.6 mm day^{-1} depending upon the soil moisture availability, crop growth stages and micro-meteorological conditions in the region. Crop maintained under unstressed conditions required more thermal time to reach flowering and physiological maturity in comparison to the rainfed crop. It is also concluded that WUE and crop production may decrease due to high rainfall (more than 250 mm) during the cropping period in the region.

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