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Water and heat-use efficiency of mustard (*Brassica juncea* L. Czern. & Coss) and its yield response to evapotranspiration rates under arid conditions

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ABSTRACT

An experiment on mustard (*Brassica juncea* L. Czern. & coss) was conducted at Jodhpur during two *rabi* seasons (2002-03 and 2003-04) to study the crop response to evapotranspiration (ET) during different growth stages under three treatments of irrigation (viz., 100% potential evapotranspiration (PET), 50% of PET and control (three irrigations each of 60 mm depth). The mean ET rate of 100% PET (unstressed) mustard (cv. Bio 902) in arid region at Jodhpur was 1.2 mm day^{-1} during early growth, 3.3 mm day^{-1} at vegetative stage, 7.5 mm day^{-1} at flowering/pod formation stage, 7.1 mm day^{-1} at seed filling/development and 2.8 mm day^{-1} at maturity stage. The crop coefficient (ratio of evapotranspiration to evaporation) was 0.22 at early growth stage, 0.80 at vegetative stage, 2.13 at flowering/pod formation stages, 1.75 at seed filling and declined to 0.56 at maturity. Seed yield of mustard crop enhanced by 40% and 21% due to irrigation at 100% and 50% PET rate of water application, respectively from that of control crop. Low water availability causing reduced ET at seed filling stage reduced the yield under control crop. Water use efficiency in kg ha^{-1} $mm^{-1}$for 50% PET crop was more (6.93) in comparison to 100% PET (4.64) and control crop (6.61). Heat use efficiency was higher for 100% PET crop as compared to crop under other two treatments.

Key words: Mustard crop, arid zone, evapotranspiration crop coefficients, water and heat use efficiencies

Mustard (*Brassica juncea* L. Czern. & Coss) ranks second in area and production, among all oil seed crops and contribute around 27% of the total oilseed production in India. It is grown in 4.83 million ha in the country with a total production of 5.34 million tonnes with an average yield of 1106 kg ha^{-1} (Chakravarty and Gautam, 2002). Rajasthan contributes highest production followed by Uttar Pradesh, Haryana, Madhya Pradesh, Gujarat, Assam and Punjab and due to its low water requirement, mustard is preferred to other crops like wheat (Parihar *et al.,* 1981). Radiation and temperature concept for explaining the growth and yield of mustard

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Table 1: Soil, crop and weather details during two growing seasons.

Season	Soil type	F.C. (mm)	Variety Grown	Sowing Date	Emergence date	Maturity Date	Crop duration	Rainfall (mm)	Temp. range Min. (^{0}C)	Max. (^{0}C)
2002-03	Loamy sand	150	Bio-902	30.10.02	04.11.02	25.02.03	119	35.9	5.5	36.6
2003-04	Loamy sand	150	Bio-902	04.11.03	08.11.03	25.02.04	115	0.0	4.2	34.8

has been widely adopted (Kar and Chakravarty, 2000 and Singh *et al.*, 1996)

Water requirement of mustard varies with climatic conditions, management practices and length and period of growing season. This crop needs special attention because there is considerable gap between yield potential and harvest. Shortage of soil moisture during a particular stage may reduce yield more in comparison to other growth stages. Therefore, in arid Rajasthan, where limited ground water is available for irrigation, crop evapotranspiration and yield relationship become important. The present study aims at finding out the evapotranspiration rates during different growth stages, to optimize water and heat use efficiency of this crop under arid conditions.

MATERIALS AND METHODS

The study was conducted at Central Arid Zone Research Institute, Jodhpur (26^{0}18'N, 73^{0}01' E) in arid tracks of NW India. Available data for soil types, variety used, mean seasonal rainfall data of sowing/ harvesting etc. for two crop growing seasons are given in Table 1. The weather data were recorded at agrometeorological observatory located close to the crop field. The evapotranspiration (ET) was measured using three gravimetric lysimeters installed by IMD in the crop field. The evaporation (EP) values refer to those observed from a Class A mesh covered open pan evaporimeter. From the daily data, weekly totals/means of these parameters from the date of sowing to maturity were computed. The mustard crop (cv. Bio-902) was sown after 60 mm of pre-sowing irrigation, in the three lysimeters and surrounding field during two consecutive *rabi* (winter) seasons of 2002-03 and 2003-04. After three weeks of sowing, crop was maintained under three irrigation treatments, namely (a) irrigated daily with an amount equal to 100% of potential evapotranspiration (PET) of the previous day (b) irrigated every fourth day with an amount equal to 50% of PET of the previous 4 days, and (c) control irrigation three times each of 60 mm depth at monthly interval. Each of these three lysimeters were surrounded by field plots of size 5 x 2.5 m which were maintained with irrigation at the same level as in the lysimeters.

Heat unit or growing degree days

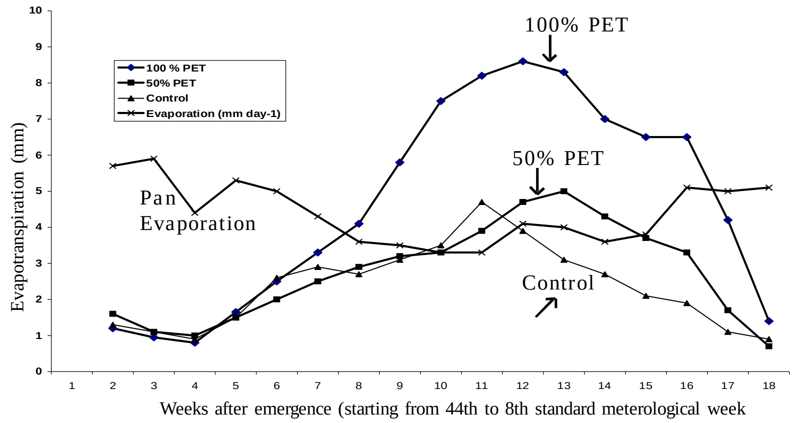

Fig. 1: Evapotranspiration rates of mustard crop

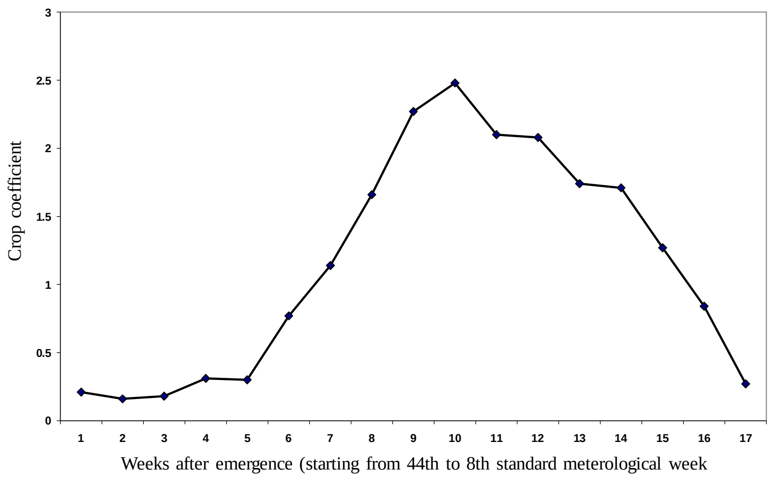

Fig. 2: The crop coefficients of mustard crop in an arid climate

(^{0}Cd) were computed with 5^{0}C as a threshold temperature following Nuttonson (1955) and Singh *et al.*, (1996). Heat use efficiency (HUE) of crop production (kg ha^{-1}) per unit of degree days (^{0}Cd) with respect to seed yield was computed following Sastry *et al.*, (1985). Water use efficiency (WUE) is computed as a ratio of seed yield (kg ha^{-1}) to consumptive water use (mm)

RESULTS AND DISCUSSION

Evapotranspiration (ET) rates and crop coefficients (K_c)

The highest ET of mustard (cv. Bio-902) crop during the study period was 8.6 mm day^{-1} during 11th week after sowing (pod formation and seed filling stage) under unstressed (100% PET) condition (Fig.1).

Table 2: Crop growth stage and mean daily ET (mm)

Irrigation level	Crop growth stages				
	Early growth	Vegetative	Flowering/ pod formation	Seed filling/ development	Maturity
100% PET	1.2	3.3	7.5	7.1	2.8
50% PET	1.3	2.5	3.8	4.1	1.2
Control	1.2	2.7	3.8	2.5	1.0
Evaporation	5.3	4.3	3.6	4.1	5.1

Table 3: Phase-wise variations in mustard crop coefficients (K_c) values (ET/EP ratio)

Growth Stage	100% PET
Early growth	0.22
Vegetative	0.80
Flowering/ pod formation	2.13
Seed filling/ development	1.75
Maturity	0.56
Seasonal	1.05

Similarly, peak ET rate of 5.0 mm day^{-1} during 12th week after sowing was observed under 50% PET treatment. On an average, the peak ET rate for control (three irrigations) crop was up to 4.7 mm day^{-1} during 10th week after sowing. Minimum ET rate was 0.8 to 1.6 mm day^{-1} during crop germination, emergence and early growth stage.

Crop coefficients for unstressed mustard crop ranged between 0.16 and 2.40 (Fig. 2). The high crop coefficient values are due to advection that normally takes place under irrigated crops under the arid environment besides the water loving nature of the mustard crop. Low crop coefficient values coincided with the emergence stage of the crop, whereas, high crop coefficient values were found during 9th to 12th week, coinciding with peak pod formation and seed filling stages of the crop.

Crop growth stages and ET requirements

Under unstressed (100% ET rate) mustard crop, the peak water requirement of the crop was observed during flowering and pod formation stage (up to 7.5 mm day^{-1}) followed by seed filling and development stage (up to 7.1 mm day^{-1}) under all the treatments (Table 2). Similarly, phase-wise variations in crop coefficients (Table 3) also revealed that the mean value of K_c was at maximum 2.13 during flowering and pod formation stage followed by seed filling (1.75) and vegetative (0.80) stage. Low soil moisture availability causing poor ET rate (2.5 mm day^{-1}) during critical seed filling stage is responsible for more reduction in the seed yield under control treatment in comparison to both 50% PET and 100% PET treatments.

Table 4: WUE and HUE of mustard (cv. Bio-902) crop

Year	Treatment	CU (mm)	Yield (kg ha^{-1})	WUE (kg ha^{-1} mm^{-1})	Thermal Time (^{o}Cd)	HUE (kg ha^{-1} ^{o}Cd^{-1})
2002 -03	100 % PET	570.1	2574	4.51	1814.4	1.42
	50 % PET	333.6	2090	6.26	1814.4	1.15
	Control	278.7	1780	6.39	1814.4	0.98
2003 -04	100 % PET	533.1	2540	4.76	1708.3	1.49
	50% PET	308.6	2360	7.65	1708.3	1.38
	Control	277.8	1900	6.84	1708.3	1.12
Mean	100 % PET	552.2	2557	4.64	1714.4	1.45
	50 % PET	321.1	2225	6.93	1761.4	1.26
	Control	278.3	1840	6.61	1761.4	1.04

Yield, water use and heat use relationships of mustard crop

Consumptive use (CU), seed yield, water-use efficiency (WUE), thermal time (^{0}Cd) and heat-use efficiency (HUE) of the crop were worked out for the two years (Table 4). The crop maintained under unstressed conditions utilized 570 and 533 mm of water during 2002-03 and 2003-04, respectively, producing seed yield of 2574 and 2540 kg ha^{-1}, respectively. In contrast, the control crop produced 1780 kg ha^{-1} with a water use of 278 mm during 2002-03 and 1900 kg ha^{-1} with a CU of 277 mm during 2003-04. The WUE of mustard varied from 4.51 to 4.76 for unstressed crop, from 6.26 to 7.65 for 50% PET crop and from 6.39 to 6.84 kg ha^{-1}mm^{-1} for control crop during the period of study. The HUE ranged between 1.42 and 1.49 kg ha^{-1} ^{0}Cd^{-1} for unstressed (100% PET) crop, between 1.15 and 1.38 kg ha^{-1} ^{0}Cd^{-1} for 50% PET crop and between 0.98 and 1.12 kg ha^{-1} ^{0}Cd^{-1} for control crop. In general, HUE was higher for 100% PET crop as compared to other crop, irrespective of rainfall and other microclimatic conditions during the cropping season (November-February).

However, WUE for 50% PET crop in both the years were more in comparison to 100% PET and control crop. This indicates that WUE decreases with availability of high moisture regime. This is because increase in the seed yield is not linear with increase in soil moisture availability condition above certain critical amount of soil moisture in the region. This conforms to the medium water requirement of the crop during the cropping season for its optimum WUE.

CONCLUSIONS

High evapotranspiration rates from mustard was noticed during flowering/pod formation phase followed by seed filling/ development stage. The ET/EP ratio (crop coefficient) generally rises till the flowering/ pod formation phase and thereafter declines gradually. A linear relationship exists between WUE and irrigation up to 50% PET level. Irrigation beyond 50% PET declines WUE gradually. Low ET rate during critical seed filling/development stage may be responsible for reduction in the seed yield of mustard crop under control treatment.

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