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Studies on Water–Use Efficiency and Energy Gain of Some Crops Grown in Sikar District

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Abstract : Relative suitability of six crops (maize, pearl millet, mung bean, gram, wheat and mustard/toria) grown at Neem Ka Thana tehsil of Sikar district were evaluated with respect to their consumptive water need, energy use scenario and water-use efficiency under rainfed conditions. Among Blaney-Criddle, Radiation and Thornthwaite methods, the first one agreed well with Mo-Penman method in all the seasons, except during summer and could be used for calculation of PET. The variability among different methods of calculating PET was less (cv = 16.51%) in *kharif* than in *rabi* crops (cv = 28.21%). Toria always had minimum water requirement while maize and pearl millet had comparatively higher water requirement with no definite order. In *kharif* season, mung bean was found to be the highest gainer of energy and harvested photosynthetically active radiation most efficiently, whereas, during *rabi*, all the crops had positive energy balance and gram was the highest energy gainer (+ 238 mm, average of four methods). Wheat had the highest water-use efficiency among *kharif* and *rabi* crops. Considering water requirement, energy gain and water-use efficiency, mung bean was the best selection during *kharif* and toria/mustard during *rabi* season.

Key words : Potential evapotranspiration, water-use efficiency, energy gain/loss, Mo-Penman, Blaney-Criddle, Thornthwaite, Radiation method.

The north eastern part of Rajasthan is characterised by arid to semi arid ecoclimate with limited crop growing period. Most of this region is having rainfed monocropping practice and the crop selection, as well as its time of sowing is decided by the onset of monsoon and socioeconomic profile. Meagre information is available regarding bioclimatic requirement of the crops for their ecological adaptibility. Major crops grown in this area are maize, pearl millet and mung bean during *kharif* and gram, toria/mustard and wheat during *rabi*. Out of these crops, only few are adapted to water limiting environment by virtue of drought escaping character, effective control of water loss and heat tolerance. However, in arid tracts, the high atmospheric evaporivity may lead to drastic yield reduction due to shortage of available soil moisture during critical phenological stages. This problem is further aggravated by erratic and uneven rainfall distribution mismatching with effective crop growing season. Since the actual measurement of PET or computation through physical formula like Mo-Penman is difficult due to limitation of getting all the climatic variables, simpler location specific models, which need only few parameters, are to be developed. The empirical formula was thus sorted which was in agreement with physical models, can be scaled or adjusted to reduce the systematic error from the actual value of PET. This process is likely to be of immense use for regular water budgeting, occurrence of drought or adjusting crop growing period, looking at the optimum/surplus moisture zone of the ombrothermic profile of the region. Keeping this in mind and for rational use of soil moisture, this study was undertaken to assess the relative performance of the above mentioned crops, with respect to their water requirement, water-use efficiency (WUE) and energy gain or loss

Table 2. Correlation matrix between Mo-Penman and other methods

Method	Summer (Mo-Penman)	*Kharif* (Mo-Penman)	*Rabi* (Mo-Penman)	Annual (Mo-Penman)
Blaney-Criddle	0.64	0.91	0.97	0.95
Thornthwaite	0.66	0.66	0.97	0.91
Radiation	0.45	0.36	0.97	0.93

Thornthwaite method

$$e = 1.6\ (10t/I)a \quad .....(4)$$

where,

e = unadjusted potential evaporation (cm/month)

t = mean air temperature (°C)

I = annual/seasonal heat index, the summation of 12 values of monthly heat indices (i), when $i = (t/5)^{1.514}$

a = empirical constant

$$= 67.5 \times 10^{-8} \times I^3 - 0.0000771\ I^2 + 0.01792\ I + 0.49239$$

'e' is uncorrected value based on a 12 hour day and 30 day month and is corrected by actual day length in hours, h, and days in a month, M, to give the adjusted PET.

$$PET = e(h/12)\ (M/30)$$

Energy gain/loss from crop canopy was calculated following Chakravarty and Shastri (1985) using the equation; energy gain/loss = Net radiation - Crop evapotranspiration.

WUE was calculated following the method of Misra and Ahmed (1987), where, WUE = (Crop yield in kg)/(ETc in ha^{-cm}).

Results and Discussion

The ranges of ETo values were 2.0 to 7.9 mm day^{-1}, 0.41 to 11.86 mm day^{-1}, 1.66 to 6.22 mm day^{-1}, and 1.09 to 8.89 mm day^{-1} by Blaney-Criddle, Thornthwaite, Radiation and Mo-Penman method, respectively (Table 1). Among the four methods, Thornthwaite showed extreme values with lowest 0.41 mm day^{-1} to highest 11.86 mm day^{-1} during 1st and 12th fortnight, respectively. Thornthwaite also showed lowest values upto 7th fortnight and again 19th fortnight onwards; however, Radiation method showed lowest ETo between 8th to 19th fortnight. The values obtained by Mo-Penman method occupied an intermediate position among four methods (Fig. 1). In case of Mo-Penman, the ETo maxima value assumed a plateau shape as compared to

Table 3. Linear regression between Mo-Penman and other methods

Season	Regression equation	Corr. coeff. (r)
Kharif	P = 0.804 BC + 1.503	+ 0.913**
	P = 0.431 Th + 3.039	+ 0.661*
	P = 1.350 Ra + 0.677	+ 0.367
Rabi	P = 1.249 BC + 1.440	+ 0.969**
	P = 1.425 Th + 0.501	+ 0.968**
	P = 1.338 Ra + 0.748	+ 0.993**
Summer	P = 1.138 BC + 0.055	+ 0.645*
	P = 0.296 Th + 5.516	+ 0.668*
	P = 1.384 Ra + 0.212	+ 0.453
Annual	P = 1.302 BC + 1.215	+ 0.957**
	P = 0.671 Th + 1.754	+ 0.908**
	P = 1.557 Ra + 0.770	+ 0.993**

Where, P = Mo-Penman, BC = Blaney-Criddle, TH = Thornthwaite, RA = Radiation.
* Significant at 5% level. ** Significant at 1% level.

Table 4. Phenophasic consumptive water use by kharif and rabi crops

Crop	Stage	Mo-Penman	Blaney-Criddle	Thornthwaite	Radiation
Maize	1	68.01	50.02	46.77	35.80
	2	137.92	108.31	136.21	92.63
	3	107.90	92.07	84.48	71.06
	4	133.41	116.50	104.48	107.89
	Total	447.24	336.90	371.94	307.38
Pearl millet	1	41.90	37.37	55.18	23.17
	2	113.68	106.42	117.26	58.29
	3	153.83	124.80	148.52	91.25
	4	71.37	67.20	66.20	52.03
	Total	380.78	335.79	387.13	224.74
Mung bean	1	19.46	19.22	14.70	18.05
	2	63.35	61.27	41.19	51.02
	3	157.14	145.42	146.52	125.78
	4	120.35	100.30	122.46	83.36
	Total	360.30	326.21	324.87	278.21
Gram	1	13.38	11.46	9.76	13.92
	2	27.22	44.03	18.06	36.46
	3	137.20	208.17	135.71	132.82
	4	142.59	144.72	121.98	121.91
	Total	320.39	408.38	285.51	305.11
Wheat	1	9.78	11.76	9.27	10.79
	2	32.45	44.73	22.60	37.90
	3	105.20	177.64	41.19	105.65
	4	97.12	104.93	54.72	87.22
	Total	244.55	339.06	127.78	241.56
Toria/Mustard	1	18.58	18.11	14.59	16.51
	2	37.67	45.54	25.77	40.38
	3	58.86	87.11	34.78	69.16
	4	19.37	40.50	8.20	21.40
	Total	134.48	191.26	83.34	147.45

1 = establishment, 2 = vegetative, 3 = reproductive, 4 = maturity.

others. Between 19th to 24th fortnight, not much differences were observed among four methods. The variability was maximum from 8th fortnight onwards upto 15th fortnight. Correlation matrix was computed (Table 2) to compare the degree of relationship of other methods with Mo-Penman method. During *rabi* season, all the methods gave very high positive correlation with Mo-Penman. In contrast, during summer and *kharif* season, relations were considerably poor, especially Radiation method gave non significant correlation value with Mo-Penman method and other methods were found to be considerably high (av, 0.93**). The linear regression equation between ETo calculated by Mo-Penman and other methods are as follows (Table 3).

Crop water requirement (CWR) of important kharif and rabi crops of Neem Ka Thana tehsil of Sikar district were computed by different methods using appropriate crop calendar (Table 4).

The results show that CWR by different methods differed significantly in *kharif* and *rabi* crops; but the variability was less (CVav = 28.21%). The CWR computed by Mo-Penman method was found to be highest in case of maize (447 mm) and lowest in case of toria (134 mm). Irrespective of the method, crop and season, water need appeared to be highest during reproductive stage, except in maize and gram, and lowest during crop establishment due to poor

Table 6. Water-use efficiency of different crops in kg ha^{-1} cm^{-1}

Season	Crop	Mo-Penman	Blaney-Criddle	Thornthwaite	Radiation
Kharif	Maize	3.35	4.03	4.03	4.88
	Pearl millet	10.50	11.91	10.33	17.80
	Moong bean	12.48	13.79	13.85	16.17
Rabi	Gram	15.61	12.24	17.51	16.38
	Toria	44.64	31.38	72.02	40.70
	Wheat	49.07	35.59	93.97	49.68

balance. On the contrary, *rabi* crops were efficient in energy use. Gram showed all along positive energy balance by all four methods possibly due to transfer of sensible heat from the surroundings except for the first few days. Similar observation was also recorded in toria. Wheat crop showed a positive energy balance upto reproductive stage and negative during its maturity (Fig. 2). During the *kharif* and *rabi* seasons, Radiation and Thornthwaite methods gave lowest energy use, respectively, when compared among four methods. Mo-Penman occupied an overall mean position. In general, all the crops initially had a negative energy balance, i.e., crop canopy lost some energy to surroundings (crop ET) till it was well established. However, with advancing growth, energy gain becomes positive due to higher leaf area index. In summer and *kharif* seasons, energy balance is negative because more incoming radiation is used as latent heat of evaporation (ETcRn) in order to keep the canopy cooler so long soil moisture is nonlimiting. Total energy balance during growing period of six crops by four methods were as follows:

Mo-Pen gram (+253 mm) > mung bean (+163 mm) > maize (+128 mm) > toria (+127) > wheat (+56 mm) > pearl millet (+28 mm)

Blan-Crid gram (+334 mm) > toria (+197 mm) > wheat (+150mm) > mung bean (+119mm) > maize (+49mm) > pearl millet (-6mm)

Thornth gram (+135mm) > mung bean (+119mm) > toria (+67mm) > maize (+54mm) > pearl millet (+51 mm) > wheat (-58mm)

Radin gram (+232mm) > toria (+139mm) > mung bean (+70mm) > wheat (+58 mm) > maize (-8mm) > pearl millet (-104mm)

Water-use efficiency (WUE)

Wheat was found to be the most efficient crop with respect to WUE by all methods, except Radiation, followed by toria and gram during the *rabi* season. Overall WUE was quite less during *kharif* season where mung bean showed highest value and least by pearl millet (Table 6).

All the methods of calculation showed similar trend with respect to CWR, energy gain and WUE, except in Radiation method. To generalize, during *kharif* mung bean is the most efficient crop with regard to water use, energy gain and water-use efficiency (Table 7). Moreover, the

Table 7. Listing of crops with respect to CWR, energy gain and WUE in decreasing order

Season	CWR	Energy gain	WUE
Kharif	Maize	Mung bean*	Mung bean*
	Pearl millet	Maize	Pearl millet
	Mung bean*	Pearl millet	Maize
Rabi	Gram	Gram	Wheat
	Wheat	Toria/Mustard*	Toria/Mustard*
	Toria/Mustard*	Wheat	Gram

* Best selection of crop..

crop gives good economic return and this should be the first choice in a given cropping pattern.

Pearl millet can be followed by mung bean which requires moderate water for consumptive use and WUE is also medium.

During *rabi* season toria fits well with less water required for consumptive use and moderate energy gain and WUE. Alternatively, wheat can also be grown which needs moderate amount of water with high WUE.

Conclusion

Six different crops grown in Neem Ka Thana tehsil of Sikar district, Rajasthan, were evaluated with respect to consumptive water use, energy gain/loss and water-use efficiency. Depending upon the annual rainfall, and its distribution pattern, crop water requirement, energy gain/loss and water use efficiency, mung bean was found to be the most efficient crop during *kharif*/summer and toria during *rabi* without sacrificing the yield.

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