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Prediction of water requirement for pea (*Pisum sativum*. L.) in mid-hill zone of Himachal Pradesh

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ABSTRACT
The water requirement of pea as predicted by Hargreaves equation is in close agreement (3.6 % deviation) with the actual water requirement, hence, the equation is the most suitable for predicting the water requirement of pea in mid hill zone of Himachal Pradesh.

Key words : Water Requirement and Pea.

INTRODUCTION

Knowledge of the water requirement of different crops is needed for scheduling of irrigations, in planning the farm irrigation systems, the design of irrigation projects and in resource development. The water requirement of a crop is the sum of crop evapotranspiration and percolation. Reference evapotranspiration approximates the evapotranspiration from tall cool season grass with adequate water supply to avoid moderately severe water stress and adequate fetch to minimize localized advection effects on evaporation. Actual evapotranspiration may be less than the potential evapotranspiration much of the time during the production of an agricultural crop. There are numerous approaches used to estimate evapotranspiration and potential evapotranspiration. Frequently used methods are mass transfer, energy budget, watershed water budget, soil water budget, ground water fluctuations and empirical formulae.

Various empirical methods have been developed by research workers considering various combinations of climatological parameters by correlating the data collected with actual evapotranspiration measured by lysimeters.

As the determination of water requirement of crops using lysimeter is laborious and quite expensive, efforts have been made to correlate the actual water requirements in the field with the agro meteorological data using different equations/methods for prediction of water requirement of crops (Doorenbos and Pruitt, 1997; Doss et al., 1962; Sharda and Bhushan, 1984; Chakraborty, 1985; Rao, 1985; Abdulmumin, 1988; Allen, 1993).

The present study had been undertaken to compute the evapotranspiration of commercially grown pea in the humid zone of the Himalayas for predicting the water requirement. The water requirement for pea was determined by multiplying the evapotranspiration calculated by each of the above methods by crop coefficients given by Doorenbos and Pruitt (1997). The potential evapotranspiration were computed using a computer programme written by Snyder and Pruitt (1992).

MATERIALS AND METHODS

The present study was conducted at the University of Horticulture and Forestry, Solan, Himachal Pradesh, receiving an annual average rainfall of 1100 mm with 70 per cent during Monsoon period. The maximum temperature does not exceed 35°C in summer and the minimum recorded is as low as –2°C in the month of January. The evapotranspiration (ET) requirements of pea for the region have been calculated using ten different empirical equations (Snyder and Pruitt, 1992) based on the meteorological data of the two crop growing seasons (Table 1). The computed potential evapotranspiration (PET) are presented in Table 3 and the equations used are:

1. FAO Penman Method

$$ET_{FAO} = R_{df} + A_{df}$$

ET_{FAO} = Potential Evapotranspiration, mmd^{-1}
R_{df} = Net Radiation term, mmd^{-1}

$$R_{df} = \frac{\Delta}{\Delta + ¥} R_{nf}$$

Δ = Slope of saturation vapour pressure
¥ = Psychrometric constant

$$R_{nf} = R_{ns} + R_L$$

R_{nf} = Net Solar Radiation, mmd^{-1}
R_L = Net terrestrial radiation, mmd^{-1}

$$A_{df} = \frac{\frac{¥}{\Delta + ¥}(e_{am} - e_d)(6.61)(1 + 0.864«)}{¥}$$

* Author for corrospondence.

A_{df} = Aerodynamic term, mmd^{-1}
e_{am} = Saturation vapour pressure at mean air temperature
e_d = Actual vapour pressure
« = Wind speed at 2.0 m, ms^{-1}

2. Preistley/Taylor Method :

$$ET_{PT} = 1.26 \frac{\Delta}{\Delta + ¥}\left(R_{no} - G\right)$$

ET_{PT} = Potential Evapotranspiration, mmd^{-1}

R_{no} = Net Radiation, mmd^{-1}

$$R_{no} = R_{ns} + R_L$$

G = Soil Air Flux, mmd^{-1}
R_{ns} = Short wave Net Radiation, mmd^{-1}
R_L = Net Terrestrial Radiation, mmd^{-1}

3. FAO Radiation Method :

$$ET_{FAORD} = B \frac{\Delta}{\Delta + ¥} \frac{R_s}{a} - 0.3$$

ET_{FAORD} = Potential Evapotranspiration, mmd^{-1}

B = Correction factor dependent on day time, wind speed and mean relative humidity

a = 2.45 mm/MJ m^{-2} d^{-1}
R_s = Solar Radiation, MJ m^{-2} d^{-1}

$$B = B_0 + B_1 H_m + B_2 U_d + B_3 H_m U_d + B_4 H_m^2 + B_5 U_d^2$$

Constants,
$B_0 = 1.066$ $B_1 = -0.0013$
$B_2 = 0.045$ $B_3 = -0.0002$,
$B_4 = -0.0000315$, $B_5 = -0.0011$

H_m = Mean Relative Humidity %
U_d = Day Time Wind Speed, ms^{-1}

4. FAO Blaney/Criddle Method :

$$ET_{FAOBC} = A + B\left(0.46T_m + 8.13\right)P$$

ET_{FAOBC} = Potential Evapotranspiration, mmd^{-1}
A = Constant dependent on relative humidity and sunshine hours

$$A = 0.0043H_n - \frac{n}{N} - 1.41$$

H_n = Minimum relative humidity, %

N

$$B = A_0 + A_1 H_n + A_2 \frac{n}{N} + A_3\left(\ln(U_d + 1)\right)^2 +$$
$$A_4 H_n \frac{n}{N} + A_5 H_n U_d + A_6 \ln\left(U_d + 1\right)\ln\left(\frac{n}{N} + 1\right)$$
$$+ A_7 \ln\left(U_d + 1\right)\left(\ln(H_n + 1\right)^2 \ln\left(\frac{n}{N} + 1\right)$$

B = Constant dependent on relative humidity, sunshine hours and day Time wind speed

Constants,
T_m = Mean monthly air temperature, ^{0}C

A_0 = 0.908, A_1 = -0.00483
P = Monthly percentage of annual sunshine hours in the year
A_2 = 0.7949 A_3 = 0.00768
A_4 = -0.0038 A_5 = -0.000443

N = Monthly mean maximum sunshine hours

A_6 = 0.281 A_7 = -0.00975

n = Actual sunshine hours

U_d = Day time wind speed, ms^{-1}

$$P = \frac{N_m}{N_a}$$

N_m = Day time wind speed, ms^{-1}

N_a = Monthly total max. sunshine hours

5. Jensen/Haise Method :

$$ET_{EJH} = \frac{0.87}{a}\left(C_T\left(T_m - T_{XJ}\right)R_s\right)$$

ET_{EJH} = Potential Evapotranspiration, mmd^{-1}

C_T = Factor dependent on e_{a2}, e_{a1} and e_1

$$T_{XJ} = -2.5 - 1.4\left(e_{a2} - e_{a1}\right) - \frac{E_L}{550}$$

T_m = Mean air temperature, ^{0}C

E_L = Elevation, m

$$e_{a2} = 0.6108e^{\frac{17.27T_{\max}}{T_{\max}+237.3}}$$

$T_{\max}$ = Max. Air Temperature, ^{0}C

$$e_{a1} = 0.6108e^{\frac{17.27T_{\min}}{T_{\min}+237.3}}$$

$T_{\min}$ = Min. Air Temperature, ^{0}C

6. SCS Blaney/Criddle Method :

$$ET_{SCSBC} = \frac{25.4}{100}K_T K_C T_F P$$

ET_{SCSBC} = Potential Evapotranspiration, mmd^{-1}

$$T_F = 1.8T_m + 32$$

K_T = Correction factor dependent upon mean temperature

$$K_C = 1.0$$

T_F = Temperature in ^{0}F

$$K_T = 0.0173T_F - 0.314$$

P = Monthly percentage of annual sunshine hours

7. Hargreaves Method :

$$ET_{HARG} = \frac{0.0023}{a}R_a\sqrt{T_d}\left(T_m + 17.8\right)$$

ET_{HARG} = Potential Evapotranspiration, mmd^{-1}

$$T_m = \frac{T_x + T_n}{2}$$

R_a = Extra terrestrial radiation, MJm^{-2}d^{-1}

$$T_d = T_x - T_n$$

T_d =Mean temperature range by month

T_x = Max. Air Temperature, ^{0}C

T_n = Min. Air Tempertaure, ^{0}C

a = Latent heat of evaporation 2.45 mm per, MJm^{-2}d^{-1}

8. FAO Evaporation Pan Method :

$$ET_{CPAN} = E_P P_C$$

ET_{CPAN} = potential Evapotranspiration, mmd^{-1}

E_P = Measured evaporation from pan, mmd^{-1}

P_C = Pan Evaporation correction factor

W_R = Wind run, Kmd^{-1}

Variable limits for use in correcting pan evaporation mean relative humidity (H_m , %)

$$30 \le H_m \le 84$$

F = Upward wind fetch, m daily wind run (Km/d)

$$84 \le W_{R\le} 700$$

Upwind fetch$^{(m)}$ of bare ground or low growing vegetation

$$1 \le \left|F\right| \le 1000$$

Pan evaporation correction when surrounded by vegetation (When F>0)

$$P_C = 0.108 - 0.000331 W_R + 0.0422 \ln(F) + 0.1434 \ln(H_m) - 0.000631 (\ln(F))^2 \ln(H_m)$$

Pan evaporation correction when surrounded by bare soil (When F<0)

$$P_C = 0.61 + 0.00341 H_m - 1.87 \times 10^{-6} W_R H_m - 1.11 \times 10^{-7} W_R F + 3.78 \times 10^{-5} W_R \ln(F) - 3.32 \times 10^{-5} W_R \ln(W_R) - 0.0106 \ln(W_R) \ln(F) + 0.00063 (\ln(F))^2 \ln(W_R)$$

9. Penman/Monteith FAO Method :

$$ET_{PENM} = R_{dp} + A_{dp}$$

ET_{PENM} = Potential Evapotranspiration, mmd^{-1}

$$R_{dp} = \frac{\Delta}{\Delta + ¥^*} (R_{np} - G)$$

R_{dp} = Radiation term, mmd^{-1}

A_{dp} = Aerodynamic term, mmd^{-1}

$$R_{np} = R_{ns} + R_L$$

R_{np} = Net radiation, mmd^{-1}

$$R_{ns} = 0.77 \frac{R_s}{a}$$

G = Soil heat flux, mmd^{-1}

R_{ns} = Shortwave net solar radiation, mmd^{-1}

?

$$A_d = \frac{\frac{¥}{\Delta + ¥^*} (e_{ap} - e_{dp})(900)«_2}{T_m + 275}$$

R_L = Longwave net radiation, mmd^{-1}

¥ = Psychrometric constant

$$e_{ap} = \frac{e_{ax} + e_{an}}{2}$$

$¥^*$ = Modified psychrometric constant

$$e_{dp} = \frac{e_{ax} \frac{H_n}{100} e_{an} \frac{H_x}{100}}{2}$$

e_{ap} = Mean daily saturation vapour pressure

$$e_{ax} = 0.6108 e^{\frac{17.27 T_{max}}{T_{max} + 237.3}}$$

e_{dp} = Mean saturation vapour pressure at dew point temperature

$$e_{an} = 0.6108 e^{\frac{17.27 T_{min}}{T_{min} + 237.3}}$$

T_m = Mean temperature range by month

10. Original Penman Method :

$$ET_{EPEN} = R_{do} + A_{do}$$

ET_{EPEN} = Potential Evapotranspiration, mmd^{-1}

$$R_{do} = \frac{\Delta}{\Delta + ¥} (R_{no} - G)$$

R_{do} = Radiation term, mmd^{-1}

A_{do} = Aerodynamic term, mmd^{-1}

R_{no} = Net radiation, mmd^{-1}

$$R_L = \left(\frac{-\pm T_k^4}{a} \right) \left(0.9 \frac{n}{N} + 0.1 \right) \left(0.34 - 0.14 \sqrt{e_d} \right)$$

G = Soil heat flux, mmd^{-1}

$$R_{ns} = 0.77 \frac{R_s}{a}$$

a = Latent heat of vaporization

e_{am} = Saturation vapour pressure at mean temperature

$$A_{do} = \frac{\frac{¥}{\Delta + ¥} (e_{am} - e_d)(6.43)(1 + 0.536 «_2)}{a}$$

e_d = Actual vapour pressure using mean temperature and humidity

Table 1 : Climatic data of the experimental site (Nauni, Solan)

Month	Sunshine Hrs	Max Temp	Min Temp	Max Hum	Min Hum	Wind Run*	D/N Wind	Evap Pan
	Hrs	^0C	^0C	%	%	Km/d		Mm/d
Oct	9.3	25.7	10.3	72.2	39.4	5.27	1.1	3.2
Nov	7.9	21.9	6.0	73.8	41.0	5.38	1.1	2.5
Dec	6.6	18.4	3.4	71.2	41.5	5.39	1.0	1.9
Jan	6.6	17.3	3.0	70.2	42.1	120.	1.1	1.5
Feb	6.3	16.9	4.2	74.2	42.8	6.10	1.1	2.5
Mar	6.5	20.6	7.4	68.5	41.8	6.69	1.1	3.2
Apr	8.6	25.9	11.3	52.4	41.3	6.75	1.3	4.9

D/N – Ratio of Day and night wind speed
Km/d – Kilometers per day
* - Total distance traveled by air in one day (Average wind speed per day)

The water requirement of pea has been determined by conducting field experiments at the departmental farm for two years. The irrigation treatments selected for determination of water requirement of pea were based on irrigation water (IW) and cumulative pan evaporation (CPE) ratios.

The water requirement of pea, thus, observed was 54.8 cm (Table 2).

values determined by Penman-Monteith FAO method, Original Penman, Corrected FAO Penman, Preistley/Taylor, FAO radiation and Jensen/Haise methods are considerably higher than those estimated by FAO Blaney/Criddle method, SCS Blaney/Criddle method, Hargreaves method and FAO Pan methods.

In the absence of solar radiation data, the solar radiation values used in Penman type equations, Preistley/ Taylor and FAO radiation methods were estimated using sunshine hours which is a ratio of actual monthly mean sunshine hours and monthly mean maximum sunshine

Table 2 : Field water requirement (mm) and yield (q/ha) of Pea

Year	Rainfall during the crop season (mm)		Depth of water applied (mm)	Av. Water requirement (mm)	Av. Yield (q/ha)	
	Total	Effective*			Green Pod Yield	Seed Yield
Ist Year	625	438	120	548	113.5	19.5
IInd Year	597	418	120			

*Effective rainfall was computed using balance sheet method

RESULTS AND DISCUSSION

The monthly reference/potential evapotranspiration (PET) values estimated by various methods have been presented in Table 3. The monthly as well as annual PET

Table 3 : Potential evapotranspiration rates (mm/day) of the experimental site

Month	EPEN	PENM	CFAO	EPT	EJH	FAORD	FAOBC	SCSBC	HARG	CPAN
Oct	9.57	8.49	10.45	10.26	8.77	11.70	3.80	3.38	3.67	2.49
Nov	6.60	5.85	7.32	6.82	5.59	7.99	2.56	2.33	2.64	1.96
Dec	5.02	4.40	5.52	4.96	3.86	5.94	1.79	1.73	2.01	1.49
Jan	5.20	4.51	5.73	5.24	3.92	6.18	1.74	1.65	2.05	1.18
Feb	6.36	5.39	7.05	6.58	4.68	7.36	2.04	1.84	2.43	1.94
Mar	8.49	7.19	9.20	8.82	6.64	9.87	2.91	2.64	3.41	2.43
Apr	12.19	10.43	12.51	12.73	10.54	15.02	4.49	3.96	4.80	3.60

EPEN – Original Penman
PENM – Penman/Monteith
CFAO – Corrected FAO Penman
EPT - Preistley/Taylor
EJH - Jensen/Haise
FAORD- FAO radiation
FAOBC – FAO Blaney/Criddle
SCSBC – SCS Blaney/Criddle, kc = 1.0
HARG - Hargreaves
CPAN - FAO ETo- Pan Method

hours. The monthly mean maximum sunshine hours have been determined from the sun rise hour angle. The experimental farm is surrounded by hills but the Eastern and North-Eastern hills are comparatively of higher altitudes. So, the actual monthly mean maximum sunshine hours are lower than those determined by using sunrise hour angle due to shading by hills at sunrise. Thus, the PET estimated by the above referred methods is bound to be higher than the actual and the latter is realistic for a flat topography only.

In FAO Blaney/Criddle method, the ratio of actual monthly mean sunshine hours and the monthly mean maximum sunshine hours is used as a natural logarithm and its effect is marginally on higher side in estimating the PET values. That is why PET estimated by this method are, comparatively, much lower. In the remaining three methods, viz. SCS Blaney/Criddle method, Hargreaves and FAO Pan method, the solar radiation parameter is not required; hence, they estimated lower PET values.

The predicted water requirement for pea estimated by different methods using crop coefficients given in Table 4 (Doorenbos and Pruitt, 1977) are presented in Table 6 and the actual water requirement for pea was observed to be 548 mm (Table 2). The deviation of water requirement of pea estimated by Hargreaves method from that of actual requirement was negligible and minimum i.e. -19.9 mm. Thus, we can use Hargreaves method for estimating the water requirement of pea with precision using meteorological data.

The suitability of other PET equations decrease in the order of FAO Blaney/Criddle and FAO Pan equations with deviations of –77.2 mm, -117.6 mm and –165.0 mm, respectively, estimating lower water requirements than the actual. All other methods/equations in which radiation parameter is involved show deviations towards the higher side i.e. predicting high water requirement than the actual and, hence, are not suitable for mid hill zone of Himachal Pradesh.

Table 4 : Month wise crop coefficient for pea

Month	October	November	December	January	February	March	April
Crop Coefficient	0.85	0.85	0.89	1.10	1.10	1.08	1.00

Table 5 : Reference evapotranspiration for pea (mm/month)

Month	EPEN	PENM	CFAO	EPT	EJH	FAORD	FAOBC	SCSBC	HARG	CPAN
Nov	198	175	220	205	168	240	77	70	79	60
Dec	156	136	171	154	120	184	55	54	62	46
Jan	161	140	178	162	122	192	54	51	64	37
Feb	178	151	197	184	131	206	57	52	68	54
Mar	263	223	285	373	206	306	90	82	106	75
Apr	366	313	375	382	316	451	135	119	144	108

Table 6 : Estimated water requirement for pea (mm/month)

Month	EPEN	PENM	CFAO	EPT	EJH	FAORD	FAOBC	SCSBC	HARG	CPAN
Nov	168.30	1480.70	187.00	174.20	142.80	204.00	65.60	54.50	67.20	51.00
Dec	168.80	121.00	152.20	137.10	106.80	163.70	49.00	48.10	55.20	40.90
Jan	177.10	154.00	195.80	178.20	134.20	211.20	59.40	56.10	70.40	40.70
Feb	195.80	166.10	216.70	202.40	144.10	226.60	62.70	57.20	74.80	59.40
Mar	284.00	240.80	307.80	402.80	225.50	330.50	97.20	88.50	114.50	81.00
Apr	366.00	313.00	375.00	382.00	316.00	451.00	135.00	119.00	144.00	108.00
Estimated water requirement	1330	1143.60	1434.50	1476.70	1066.40	1587.00	468.80	428.40	526.10	381.00

Table 7 : Deviation of the estimated water requirement by different equations from field experimental values (mm)

Crop	EPEN	PENM	CFAO	EPT	EJH	FAORD	FAOBC	SCSBC	HARG	CPAN
Pea	782.00	595.60	886.50	928.70	518.40	1039.00	-77.20	-117.60	-19.90	-165.00

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