RESEARCH PAPER:

Utility of empirical models and pan evaporation method to estimate chickpea evapotranspiration in mollisol of *Tarai* region of Uttrakhand

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SUMMARY

The experiments were conducted at the Crop Research Centre of G.B. Pant University of Agriculture and Technology, Pantnagar, Uttrakhand with the objectives for quantifying evapotranspiration (ET) losses of chickpea under *Tarai* conditions, and to select some suitable empirical methods based on meteorological parameters for estimating ET from chickpea. Evapotranspiration of chickpea was measured with weighing type lysimeter. Data on pan evaporation measured with USWB class A pan evaporimeter and chickpea parameters for the corresponding period were collected from Meteorological observatory of G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand. Evapotranspiration from chickpea was also estimated by using empirical methods of Thornthwaite, Turc, Stephens-Stewar, Jensen-Haise, Blaney-Criddle and modified Penman. Evapotranspiration of chickpea during 2005-06 and 2006-07 were about 416.5 and 475.6 mm, respectively. The average total rainfall during 2005-06 and 2006-07 were 18.2 and 275 mm, respectively. Thus, supplementary irrigation was required during crop season due to low rainfall. The pan evaporation did not give accurate estimate of ET, both on seasonal and as well as weekly basis. Thus, the pan evaporation does not seem to be good criterion for the estimation of ET. Modified Penman method was found to be most very suitable for estimation of ET in *Tarai* region of Uttarakhand

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Pulses have been the mainstay of Indian agriculture, enabling the land to restore fertility so as to produce reasonable yields of succeeding crops and providing proteineous grain and nutritive fodder. Chickpea (*Cicer arietinum* L.) is one of the important pulse crops of *Tarai* and other regions of Uttarakhand. It is an essentially a winter season crop grown from November to April of this region. In this season supplementary irrigation is essential for successful completion of the life cycle of crop and higher yields. For economizing the water, irrigation should be given as per needs of the crop. Evapotranspiration (ET) is a complex phenomenon which depends on the extremely complicated interactions of soil, plant and meteorological factors. The best estimation of evapotranspiration was achieved through measurement of water used by well watered crops which exert minimal canopy resistance. Lysimeter offers not only the advantage of sensitivity and precision but also an accuracy. However, the technique is expensive and involves various complexities. Pan evaporation measured with standard pan (*viz.* USWB class A) can be related to ET or consumptive use but the technique has to be standardized for different crops under different soils and agroclimatic conditions. A large number of empirical and semi-empirical methods have been proposed and used by various workers for estimating evapotranspiration from various meteorological parameters. However, these methods are not equally applicable and suitable for all the locations and situations. Water is one of most important factors required by a crop or diversified pattern of crops for their normal growth under field conditions. Water is needed mainly to meet the demands of evaporanspiration and the metabolic activities of plants, both together known as consumptive use. Evapotranspiration is an important feature in microclimatic studies related to crop production, due to its largely successful application in the economic utilization and application of irrigation water as per actual requirement of crops (Rosenberg *et al.,* 1983). Environment is another important factor which effects the growth and development of chickpea. A rapid rise in temperature and desiccative power of the atmosphere cut short the vegetative and reproductive growth period of crop, resulting in low yield.

MATERIALS AND METHODS

A field experiment was conducted at the Crop Research Centre of G. B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand (29^0N, latitude and 79.3^0C longitude) during 2005-06 and 2006-07. This experimental station is situated in the *Tarai* belt at the foothills of the Shivalik range of Himalayas at an altitude of 243.89 m above the mean sea level. The experiment was conducted with chickpea (*Cicer aritunum* L.) crop variety- PT-186 sown on 01 Dec. 2005 and 28 Nov., 2006 and harvested on 10 April 2006 and 20 April 2007, respectively. The crops were also grown around the lysimeters to provide a natural and identical environment to the crop grown in the lysimeters. The ET losses was measured with the help of two weighing type lysimeters (Asiatic Equipments, Kolkata) installed at the experimental field. The lysimeter tank having the inside dimension 1.33m × 1.33m × 0.9m made of 3 mm thick steel was used in the study that contained a perforated plate placed 75 cm depth, so as to from a hollow chamber at the bottom to collect percolated water. A tube was inserted through the perforated sheet into bottom of the hollow chamber to facilitate the removal of percolated water. A tap was also filled at the bottom of the tank to drain out the percolated water from the hollow chamber. The daily pan evaporation data were summed up for computing weekly and entire crop seasonal total pan evaporation for all the standard meteorological weeks for both the years. The ratio of measured ET and pan evaporation were computed on weekly basis by dividing weekly total measured ET with weekly total pan evaporation. The ET of chickpea was also estimated separately on weekly basis by the empirical methods of Blaney-Criddle (1950), Jensen-Haise (1963), Stephens-Stewart (1963), Thornthwaite (1948), Turc (1961) and Penman methods (1948). The relationship between measured ET and pan evaporation was studied through regression analysis taking measured ET as dependent variable and pan evaporation as independent variable.

RESULTS AND DISCUSSION

The results obtained from the present investigation are summarized below:

Meteorological conditions during chickpea season:

The chickpea season, in this region, starts from mid November to mid December and continues up to April. The meteorological data indicated that during year 2005-06 weather conditions slightly fluctuated but in year 2006-07, the weather conditions fluctuated considerably. In the month of February and March and there were heavy rainfall and hail storm. In year 2005-06, the mean air temperature was about 17.1^0C. The daily maximum temperature remained nearly 24.5^0C and daily minimmum temperature remained nearly 9.8^0C and increased during late February. The relative humidity was 65 per cent up to February and afterwards it decreased. The average wind speed during the season was 3.5 km hr^{-1} and average bright sunshine about 7.1 hr day^{-1}. The average total solar radiation during this year was about 406.5 ly day^{-1}. The total rainfall during crop period was only 18.2 mm which was very less to support the crop. So some irrigation was needed. There was negligible rainfall in most of weeks during this year. However, in second year (2006-07), the mean air temperature was about 17.5^0C. The daily maximum temperature remained nearly 24.9^0C and daily minimum temperature remained nearly 10.1^0C and slightly increased after February. While both temperature *i.e.* maximum and minimum and relative humidity slightly increased compared to previous year. The wind speed and rainfall were also quite more in year 2006-07 as compared to 2005-06. Wind speed and rainfall were 3.5 km hr^{-1} and 18.2 mm, and 9.8 km hr^{-1} and 275 mm in 2005-06 and 2006-07, respectively. At the time of flowering and pod formation (*i.e.* February and March) there was heavy hailstorm and rainfall in 2006-07, due to this reason, the crop period was increased.

Evapotranspiration (ET):

Data relating to measured ET have been exemplified in Table 1. The cumulative evapotranspiration of chickpea under Uttarakhand *Tarai* condition was about 416.5 and 475.6 mm in 2005-06 and 2006-07, respectively. This variation may be largely attributed to the variations of crop stages, weather conditions and the variation in duration of crop. The duration of crop during 2005-06 was 131 days while it was 143 days in 2006-07 due to hail storm at time of flowering and pod formation. The average ET was 3.13 mm day^{-1} and 3.24 mm day^{-1} in 2005-06 and 2006-07, respectively. In both years it increased and reached its peak during 9^{th} to 15^{th} standard week. This variation in daily rate of ET may be largely attributed to the variation in crop growth. The plant height, number of leaves, number of branches and development increased as the crop approached maturity and

Table 1 : Daily, weekly and cumulative evapotranspiration of chickpea measured by lysimeter during 2005-2006 and 2006-2007

2005-2006					2006-2007				
Standard week	Weeks	Average ET (mm/day)	Weekly total ET (mm)	Cumulative ET (mm)	Standard week	Weeks	Average ET (mm/day)	Weekly total ET (mm)	Cumulative ET (mm)
49	1-7 Dec.	3.2	22.4	22.4	48	26-2 Dec.	1.1	8.0	8.0
50	8-14 Dec.	2.2	15.4	37.8	49	3-9 Dec.	1.3	8.1	16.1
51	15-21 Dec.	1.9	13.3	51.1	50	10-16 Dec.	1.3	8.0	24.1
52	22-28 Dec.	2.5	17.5	68.6	51	17-23 Dec.	1.1	7.6	31.7
1	29-4 Jan.	1.9	13.4	82.0	52	24-31 Dec.	1.3	8.8	40.5
2	5-11 Jan.	1.5	10.5	92.5	1	1-7 Jan.	1.5	10.5	51.0
3	12-18 Jan.	1.9	13.2	105.7	2	8-14 Jan.	1.2	8.4	59.4
4	19-25 Jan.	2.7	18.9	124.6	3	15-21 Jan.	1.2	8.2	67.6
5	26-1 Feb.	1.9	13.3	137.9	4	22-28 Jan.	1.6	11.4	79.0
6	2-8 Feb.	1.7	11.9	149.8	5	29-4 Feb.	1.6	11.0	90.0
7	9-15 Feb.	1.8	12.6	162.4	6	5-11 Feb.	1.8	5.4	95.4
8	16-22 Feb.	2.5	17.5	179.9	7	12-18 Feb.	4.5	18.0	113.4
9	23-1 Mar.	5.1	35.7	215.6	8	19-25 Feb.	5.7	40.2	153.6
10	2-8 Mar.	3.3	23.1	238.7	9	26-4 Mar.	4.3	30.2	183.8
11	9-15 Mar.	3.1	21.7	260.4	10	5-11 Mar.	4.5	31.5	215.3
12	16-22 Mar.	4.9	34.3	294.7	11	12-18 Mar.	5.4	37.8	253.1
13	23-29 Mar.	5.7	39.9	334.6	12	19-25 Mar.	6.4	44.8	297.9
14	30-5 April	5.6	39.2	373.8	13	26-1 April	6.1	42.5	340.4
15	6-12 April	6.1	42.7	416.5	14	2-8 April	5.3	37.2	377.6
	Mean	3.13			15	9-15 April	5.5	38.5	416.1
					16	16-22 April	8.5	59.5	475.6
	Mean						3.24		

consequently ET of crop also increased. Thus, ET reached to a maximum value in 9th to 15th week after sowing when growth and development also increased to maximum values.

Pan evaporation:

The average cumulative pan evaporation during crop season 2005-06 and 2006-07 were 399.7 and 500.9 mm , respectively (Table 2). The average daily pan evaporation during first year was 2.9 mm day^{-1} which showed much variation. In early stages it was low and decreased upto 7th standard week and later on it increased during maturity phase of crop. The average daily pan evaporation during 2006-07 was 3.4 mm day^{-1}. In early stages, it was low and decreased upto 4th week and after that it was increased upto 8th week then decreased and later on it increased during the maturity phase of crop. This increased and decreased trend in the middle stage was due to heavy rainfall in February and March, due to this, reduction in temperature and duration of bright sunshine (Table 2).

Relationship between measured ET and pan evaporation (EP):

The relationship obtained between measured ET and EP is presented in Fig. 1. The average ET/EP ratios were 1.1 and 0.9 during 2005-06 and 2006-27, respectively. These values indicated that pan evaporation was underestimated and overestimated the measured ET. In the early stages (up to 5 weeks) the ET/EP ratio was nearly equal to one but after that it increased. Thus, during the period of rapid plant growth, ET of chickpea was higher than pan evaporation. Later on ET/EP ratio decreased continuously with increased yellowing of

Table 2 : Pan evaporation measured with USWB class A pan evaporimeter of chickpea during 2005-06 and 2006-07

2005-06					2006-07				
Standard weeks	Weeks	Average EP (mm day^{-1})	Weekly total EP (mm)	Cumulative EP (mm)	Standard weeks	Weeks	Average EP (mm/day)	Weekly total EP (mm)	Cumulative EP (mm)
49	1-7 Dec.	2.2	15.6	15.6	48	26-2 Dec.	2.2	16.0	16.0
50	8-14 Dec.	1.9	13.4	29.0	49	3-9 Dec.	1.9	13.0	29.0
51	15-21 Dec.	1.8	13.1	42.1	50	10-16 Dec.	1.6	11.0	40.0
52	22-28 Dec.	2.2	15.5	57.6	51	17-23 Dec.	1.8	12.2	52.2
1	29-4 Jan.	1.4	10.2	67.8	52	24-31 Dec.	1.8	12.3	64.5
2	5-11 Jan.	1.0	6.9	74.7	1	1-7 Jan.	1.9	12.7	77.2
3	12-18 Jan.	1.2	8.3	83.0	2	8-14 Jan.	1.6	12.0	89.2
4	19-25 Jan.	2.1	15.0	98.0	3	15-21 Jan.	1.7	12.1	101.3
5	26-1 Feb.	1.7	12.0	110.0	4	22-28 Jan.	1.5	11.2	112.5
6	2-8 Feb.	1.6	11.5	121.5	5	29-4 Feb.	2.1	14.2	126.7
7	9-15 Feb.	1.7	12.3	133.8	6	5-11 Feb.	4.3	31.2	157.9
8	16-22 Feb.	2.5	17.6	151.4	7	12-18 Feb.	4.7	33.2	191.6
9	23-1 Mar.	5.2	37.0	188.4	8	19-25 Feb.	3.5	25.2	216.8
10	2-8 Mar.	3.2	22.0	211.3	9	26-4 Mar.	3.0	20.4	237.2
11	9-15 Mar.	3.1	21.5	232.8	10	5-11 Mar.	3.1	21.9	259.1
12	16-22 Mar.	4.8	33.5	266.3	11	12-16 Mar.	4.2	29.9	288.5
13	23-29 Mar.	5.8	40.4	306.7	12	19-25 Mar.	5.1	35.6	324.1
14	30-5 Mar.	5.9	41.0	347.7	13	26-1 April	4.6	32.3	356.4
15	6-12 April	7.4	52.0	399.7	14	2-8 April	6.6	46.4	402.8
	Mean	2.9			15	9-15 April	6.9	48.2	451.0
					16	16-22 April	7.1	49.9	500.9
	Mean						3.4		

leaves. This variation in ET/EP ratio might largely be attributed to the high rate of ET during the period of more active plant growth and development. The higher rate of ET than EP was due to high roughness of crop plants as suggested by Rosenberg (1974). The simple correlation and linear regression analysis between ET and EP on weekly basis indicated a reasonable correlation between these parameter in both the years. Pan evaporation underestimated by 7.34 per cent and overestimated 4.93 per cent during 2005-06 and 2006-07, respectively. The value of correlation coefficient (r) was positive in both the years. This, pan evaporation can be used as a criterion for estimating ET of chickpea under Uttarakhand, *Tarai* conditions both on weekly and seasonal basis.

Estimation of chickpea ET by empirical methods:

Blaney and Criddle method (1950):

The total cumulative ET estimated by this method (400.3 mm) was slightly lower than the measured cumulative ET (416.5 m) in 2005-06 while the total cumulative ET estimated by this method (492.4 mm) was slightly more than measured cumulative ET (475.6 mm) in 2006-07. The average daily rate of ET estimated by this method (3.01 mm day^{-1}) was slightly less in comparison to measured rate of ET (3.13 mm day^{-1}) in 2005-06 while in second year estimated ET (3.35 mm day^{-1}) was more than the measured ET (3.24 mm day^{-1}). The daily estimates of ET on weekly basis showed positive correlation with measured ET. This method gave slightly poor correlation between measured ET and estimated ET. Thus, this method can be considered as a slightly suitable method for estimating ET in this region (Table 3 and 4).

Jensen and Haise method (1963):

This method provided a good estimation of ET in both years. The estimated cumulative ET (417.6 mm) was close to measured cumulative ET (416.5 mm) and

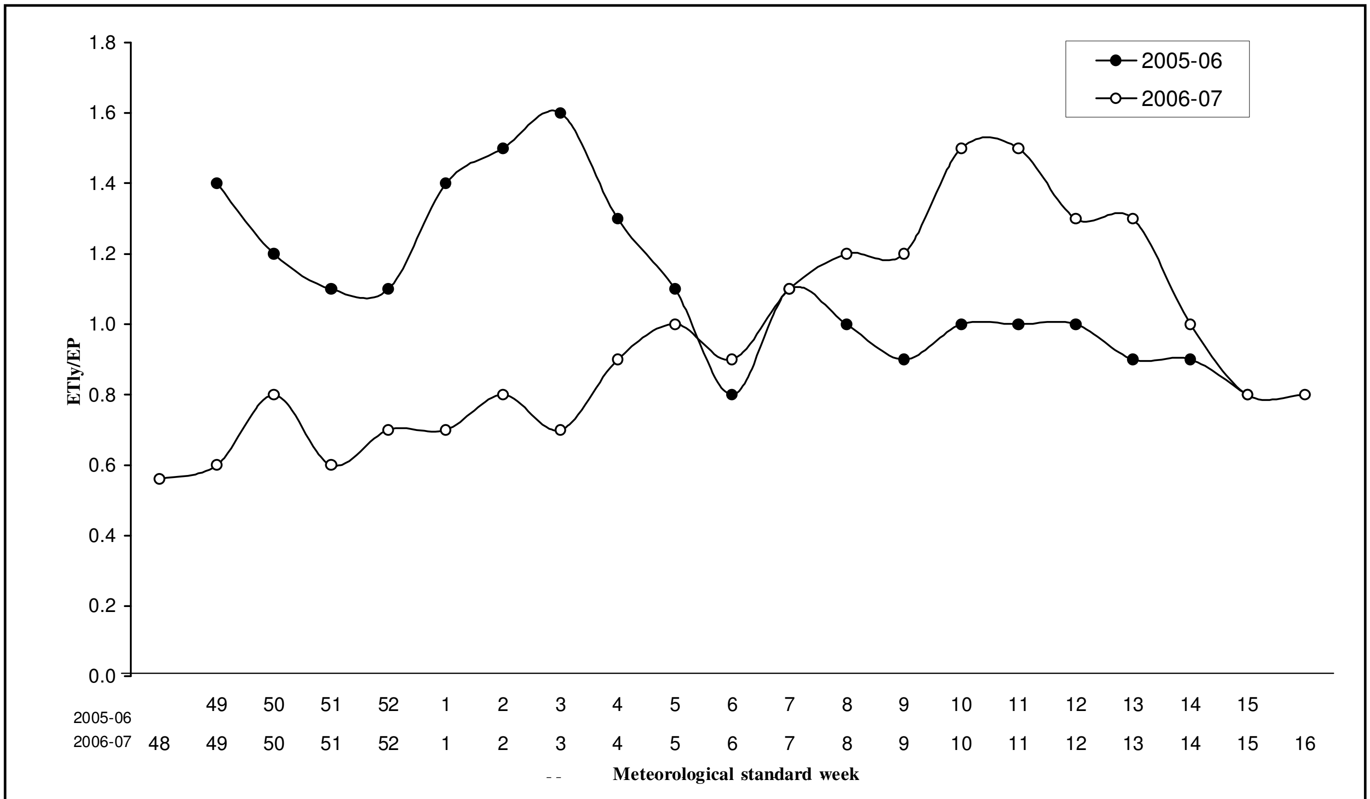

Fig. 1: Line diagram of ratio of measured ET by lysimeter and measured EP by USWB class A pan evaporation

estimated cumulative ET (423.31 mm) was low as compared to measured cumulative ET (475.6 mm). The average daily rate of ET estimated by this method (3.14 mm day^{-1}) was almost equal to measured ET (3.13 mm day^{-1}) in first year while second year, ET estimated by this method was 2.88 mm day^{-1} was low in comparison to measured ET 3.24 mm day^{-1}. The daily estimated of ET done on weekly basis showed good correlation with measured ET for chickpea. This method is somewhat suitable for chickpea. Similar results for chickpea at Pantnagar have also been reported by Singh (1974) (Table 3 and 4).

Stephens-Stewart method (1963):

This method was highly underestimated ET in this region for chickpea. The estimated cumulative ET (324.5 mm) was very low as compared to measured cumulative ET (416.5 mm) in 2005-06. The estimated cumulative

Table 3 : Relation between measured and estimated ET by different mathematical method for chickpea crop (2005-06)

	Thornthwaite	Turc	Stephens-Stewart	Blaney-Criddle	Jensen-Haise	Modified Penman
No. of pairs	19	19	19	19	19	19
Mean measured ET (mm/day)	3.13	3.13	3.13	3.13	3.13	3.13
Mean estimated ET (mm/day)	2.84	2.95	2.44	3.01	3.14	3.07
Over (+) under (-) estimation (%)	-9.2	-5.7	-22.0	-3.83	-0.30	-1.9
Correlation Coefficient	0.801**	0.641**	0.848**	0.706**	0.837**	0.864**
Regression equation	$ET = 0.007ET_{TW} + 0.943$	$ET = 0.0248ET_{T} + 0.589$	$ET = 0.023 ET_{ss} + 0.424$	$ET = 0.042ET_{U} + 0.524$	$ET = -0.0179ET_j + 1.356$	$ET = -0.0007ET_p + 0.976$

Table 4: Relation between measured and Estimated ET by different mathematical method for Chickpea crop (2006-07)

	Thornthwaite	Turc	Stephens-Stewart	Blanney-Criddle	Jensen-Haise	Modified Penman
No. of pairs	21	21	21	21	21	21
Mean measured ET (mm/day)	3.24	3.24	3.24	3.24	3.24	3.24
Mean estimated ET (mm/day)	2.92	2.74	2.66	3.35	2.88	3.21
Over (+) under (-) estimation (%)	-9.8	-15.4	-17.9	+3.39	11.1	-0.9
Correlation Coefficient	0.867**	0.873**	0.849**	0.493*	0.939**	0.888**
Regression equation	$ET = 0.038ET_{TV} + 0.594$	$ET = 0.016ET_T + 0.975$	ET= 0.065 ETss+0.424	$ET = 0.042ET_U + 0.394$	ET = 0.030ETj + 0.700	ET = 0.006ETp + 0.877

* and ** indicate significance of values at P= 0.05 and P=0.01.

ET (391.0 mm) was also very low as compared to measured cumulative ET (475.6 mm) in 2006-07. The average daily rate of ET estimated by this method 2.44 and 2.66 mm day^{-1} was low in comparison to measured rate of 3.13 and 3.24 mm day^{-1} in 2005-06 and 2006-07, respectively. The underestimation of ET by this method is mainly attributed to the fact that short term mean temperature is not a suitable measurement of incoming radiation as suggested by Ayoade (1976). This method gave slightly positive correlation. The estimated values of ET were much lower than the measured values (Table 3 and 4).

Turc method (1961):

In 2005-06, estimated cumulative ET (392.3 mm) was low as compared to measured ET (416.5 mm) while in 2006-07, estimated cumulative ET (402.7 mm) was also less than measured cumulative ET (475.6 mm). This method underestimated the daily rate of ET by 5.7 and 15.1 per cent in both years. There was positive correlation between estimated, by this method, and measured ET. Metochis (1977) also reported a poor correlation between measured ET of lucerne and the ET estimated by this method (Table 3 and 4).

Thornthwaite method (1948):

The cumulative ET estimated by this method was 372.4 mm in 2005-06 which was less than the measured cumulative ET 416.5 mm. While in 2006-07, cumulative estimated ET was 429.2 mm which was also less than cumulative measured ET 475.6 mm. The estimated daily ET rate were 2.84 and 2.92 mm day^{-1} in 2005-06and 2006-07, respectively. The measured ET rates were 3.13 and 3.24 mm day^{-1} in first and second year, respectively. Thus, this method underestimated measured ET by 9.2 and 9.8 per cent in both years. As this method is based on mean air temperature, the over estimation or underestimation might be attributed to low temperature during crop season. The over estimation of ET by this formula during summers has also been reported by Ward (1963). On weekly basis the estimated ET had good correlation with measured ET (r= 0.801 and 0.867) in both the years. But it was underestimated with measured ET. The weekly estimated value of ET was almost same during the chickpea season while measured ET varied largely due to weather condition and differences in crop growth (Table 3 and 4).

Modified Penman method (1948):

This method gave a very suitable result which was very close to measured ET. The cumulative estimated ET by this method was 420.93 mm which was closer to measured cumulative ET 416.5 mm in first year and similarly, estimated was 451.2 mm which also closer to measured cumulative ET (475.6 mm) in second year. The daily estimate of ET (3.07 mm day^{-1}) in first year by this method was closer to measured daily ET (3.13 mm day^{-1}), while in second year, daily estimated ET was 3.21 mm day^{-1} was also close to measured daily ET (3.24 mm day^{-1}). This method showed good positive correlation between estimated ET and measured ET in both years. Doorenbos and Pruitt (1975) suggested that as the modified Penman method took into consideration the more number of meteorological parameters, gives better results. Thus, this method is the most suitable method for estimating evapotranspiration in the *Tarai* region of Uttarakhand. (Table 3 and 4)

Conclusion:

The total evapotranspiration in the experimental region was 416.5 mm during 2005-06 while for year 2006-07, it was 475.6 mm. In both the years during early and maturity phase the ET rate was high. The total pan evaporation during 2005-06 was 399.7 mm while for year 2006-07 it was 500.9 mm. The average pan evaporation was 2.9 and 3.4 mm day^{-1} during 2005-06 and 2006-07, respectively. On weekly basis, pan evaporation showed a positive correlation with ET during both the years. During vegetative phase of chickpea, the temperature and ET were low while during reproductive phase, temperature and ET were high and relative humidity was low in both years. It may be concluded that low temperature and low ET during vegetative phase and high temperature, more ET and low relative humidity were favourable for reproductive phase of chickpea. Further, it was experienced that rainfall and hailstorm at flowering and pod development stages were very injurious. Among the different empirical methods modified Penman method was found more appropriate than others.

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