Research Paper:

Measurement of AET in soybean and estimation of PET by various methods and its comparison with AET

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Summary

A field experiment was conducted at experimental farm, Department of Agricultural Meteorology Marathwada Agricultural University, Parbhani. The experiment was conducted with soybean crop cv. MAUS-71 in a field where two weighing types of lysimeter were installed. The experiment was non-replicated and estimation of reference crop evapotranspiration was measured on daily basis. At the same time, the daily weather data were recorded at near by observatory and were tabulated. The PET were estimated and compared with lysimetric observatins. The study ravealed that among the methods tested, modified Penman method was found to be suitable for advocating the irrigation scheduling as it matched well throughout the crop season. The Blaney and Criddle and pan evaporation estimation methods under estimated the values when compared with lysimetric data. As these methods are based on only air temperature, pan evaporation and other parameters such as radiation, relative humidity, bright sunshine hours, wind factor were not included which also played a significant role in affecting ET. The results obtained through these methods are not comparable.

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Soybean (*Glycine max* (L.) Merrill.) is often called as wonder bean due to its high seed protein (38-43%) and edible oil content (18-20%). Maharashtra ranks as second largest growing state contributing nearly 30% area (23.07 lakh ha.) and 34% production (23.99 lakh tones) of the country next to Madhya Pradesh. In respect of productivity Maharashtra stands first in the country with average productivity of 1040 kg/ha^{-1}. (Anonymous 2006).

Soybean is grown as rainfed crop, which is exposed to varying sets of weather conditions in general and rainfall distribution is particular. The acute need of water at critical growth stages, through lysimetric observations and its comparison with different approaches may provide information for decision making in irrigation scheduling the measurement of AET by means of lysimeter and it is essential to establish a relationship between the measured value of AET by lysimeter and the estimated PET by different empirical formulae. Keeping these points in mind, a research project was planned on estimation of crop evapotranspiration in soybean crop through lysimeter and its comparison with the different approaches already published, with the following objectives: to measure daily, weekly and phenophasewise actual evapotranspiration of soybean crop under field conditions, using weighing type lysimeters, to estimate weather based, weekly and phenophase wise potential evapotranspiration in soybean crop, by using the approaches suggested by Blaney criddle, Thronthwaite, modified Penman's and pan evaporation, to asses the ratio of AET : PET in different phenophases and to suggest proper timing for life saving irrigation during crop growing season.

Materials and Methods

A field experiment was conducted at experimental farm, Department of Agricultural Meteorology Marathwada Agricultural University, Parbhani. The experiment was conducted with soybean crop cv. MAUS-71 in a field where two weighing types of lysimeter were installed. The experiment was non-replicated and estimation of reference crop evapotranspiration was measured on daily basis. At the same time, the daily weather data were recorded at near by observatory and were tabulated. The weather parameters were used for estimation of potential evapotranspiration by different methods namely, Blaney and Criddle, Thornthwaite, modified Penman and pan evaporation. These methods were compared with the AET in soybean according to their different phenophesses as well as meteorological week basis.

Potential evapotranspiration by various methods:

The various researches have been developed different empirical formulae of estimation of PET. Using one or more than weather variables combined these are given as below :

Blaney-Criddle method:

$$ET_0 = c\,[\,P\,(0.46\,T + 8)]\ \text{mm/day}$$

Thornthwaite method:

$$e = 1.6\,(10\,t / I)^a$$

Modified penman method:

Based on intensive studies of the climatic and measured gross ET data from various research stations in the world and the available literature on prediction of ET or ET_0. Doorenbos and Pruitt (1977) proposed the modified Penman method, as below for estimation fairly accurately the reference crop ET.

$$ET_0 = c\,[W.\,Rn + (1 - W)\,f\,(u)\,(ea - ed)]$$

Pan evaporation method:

Reference crop evapotranspiration was calculated from pan evaporation using standard pan coefficient of 0.70 for this region (for RHmcan 40 to 70 per cent from Table 18, FAO 24, Doorenbos and Pruitt, 1977) using the following equation:

$$ET_0 = Kp * Epan$$

where, Kp is the pan coefficient and Epan is the pan evaporation (mm d^{-1})

Lysimeters:

Weighing type of lysimeters are the most effective devices for direct measurement of evapotranspiration. Two weighing balance type gravimetric lysimeters, consisting of a weighing platform with 2 tones capacity and a manual data recording arrangement were used to measure the daily evapotranspiration.

Actual crop evapotranspiration:

The daily actual crop (ETc) for each phenophase was obtained using lysimeter data with respect to soybean crop grown in and outside the lysimeter. The AET values were derived from the difference of weight of the lysimeter in 24 hours, which was recorded daily at 8.30 am.

Crop coefficient:

The measured crop coefficients (Kc) for all the methods for soybean crop under study was calculated using the relation:

$$K_C = ET_C / ET_0$$

ETc is the actual crop evapotranspiration mm day^{-1} measured from lysimeter and PET estimated by the Blaney and Criddle, Thronthwaite, E Pan and modified Penman method.

RESULTS AND DISCUSSION

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads:

Blaney and criddle approach:

The recorded data on AET was compared with estimated PET using Blaney and Criddle approach. The data measured through lysimeters in different phenophases are presented in Table 1 and 2 and Fig. (1 and 2) which range from 11.74mm to 70.56mm, while the PET values estimated through this method ranged between 10.3mm to 62.2mm. The comparison between AET measured in lysimeters and estimated PET through this approach showed that the estimated PET was underestimated (Table 1). This is not true in practical ; The under estimation of PET over AET may be attributed to only air temperature which has been considered as an limiting factor, whereas, the other important parameters such as aerodynamic characteristics were ignored.

The results on meteorological week basis also showed similar trend in respect of this approach, however, during later stage of crop *i.e.* MW 27, 37, 39 and 40 had shown comparably higher values of PET over measured lysimeteric data. But during this period there were continuous showers, which should have equal AET values and PET values. These results were closely in confirmity with the results of Kadam *et al.* (1978) for Marathwada region.

Table 1: Measured actual evapotranspiration (AET) and etimated potential evapotranspiration (PET) values according to different phenophases of the soybean crop by various methods

Phenophases	Actual evapotranspiration (AET in mm)	Potential evapotranspiration (PET in mm)			
		Blaney and criddle	Modified Penman	Thornthwaite	Pan evaporation
Sowing to emergence (P_1)	11.74	15	34.88	25.08	11.06
Emergence to seedling (P_2)	70.56	62.2	184.79	107.23	69.65
Seedling to branching (P_3)	28.79	25.6	49.92	39.84	23.24
Branching to flowering (P_4)	15.57	10.3	28.08	19.46	13.51
Flowering to pod formation (P_5)	22.15	19.1	46.42	28.66	18.83
Pod formation to grain formation (P_6)	21.44	17.9	22.13	28.68	17.57
Grain formation to pod development (P_7)	42.09	35.8	80.44	53.76	36.26
Pod development to grain development in full size (P_8)	55.9	50.5	87.97	69.74	47.46
Dough stage (P_9)	54.13	50.7	99.06	73.98	43.96
Maturity (P_{10})	10.42	23.14	32.78	25.64	17.99

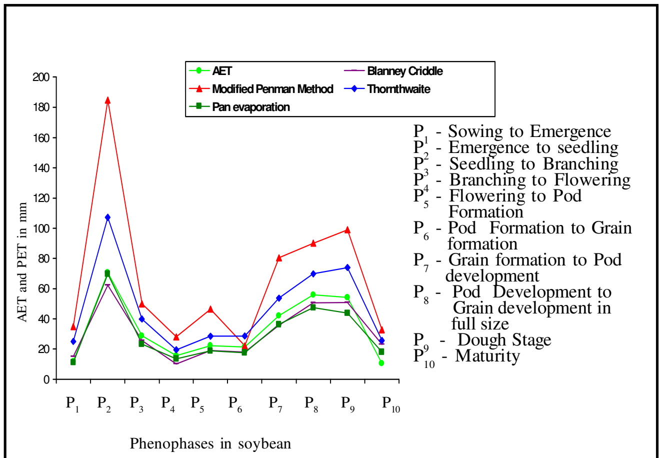

Fig. 1: Phenophases, AET and PET by the different methods during soybean crop growing season

Thornthwaite approach:

The recorded data on AET were compared with estimated PET using Thornthwaite approach. The data revealed that the AET values measured through lysimeters in different phenophases as well as meteorological week wise presented in Table (1 and 2) and Fig. (1 and 2) which ranged from 10.42mm to 70.56mm. While the PET values estimated through this method ranged between 19.46mm to 107.23mm. The comparison between AET measured in lysimeters and estimated PET through this approach showed that the estimated PET were higher than measured AET of the crop in various phenophases. However, when there were rains in a week spread over more rainy days, the evapotranspirative demand of the atmosphere should have met and the AET values should have been equal to PET, but this was not observed. The reason of higher PET values, is also attributed to the fact that in this approach only air temperature is considered to be limiting factor. However the other parameters such as radiation, atmospheric humidity, wind speed, and vapour pressure was not taken care of, However, this method seems to be useful where data on these parameters are not available and hence being used widely for estimation of crop water requirements.

Modified Penman method:

The recorded data on AET were compared with estimated PET using modified Penman approach. The data revealed that the AET values measuered through lysimetres in different phenophase as well as meteorological week wise are presented in Table (1 and 2) and Fig. (1 and 2). The measured AET ranged from 10.42 (P_{10}) MW to 70.56mm(P_2), where as the PET values estimated through this method ranged between 28.08 (P_4).to 184.79mm (P_2) . The comparison between AET measured in lysimeters and estimated PET through this approach showed that the estimated PET values where higher than AET measured in phenophases of the crop. Similar trend was also noticed when it was treated under meteorological week bans. This attributed to aerodynamic and radiation terms which has been considered. The turbulant eddies that are mainly responsible for the transport of water vapour. The complete earth surface maintains wet conditions due to south west monsoon rains and the vapour pressure gradients will be directed into the atmosphere, hence the eddies transport more vapour through turbulence and

Table 2: Measured actual evapotranspiration (AET) and estimated potential evapotranspiration (PET) values according to meteorological week (MW) of the soybean crop by various methods

Meteorological weeks	Actual evapotranspiration (AET in mm)	Potential evapotranspiration (PET in mm)			
		Blaney and criddle	Modified Penman	Thornthwaite	Pan evaporation
26	22.93	19.1	38.62	35.64	17.71
27	19.6	22	70.43	35.48	23.66
28	23.64	19.2	58.83	35.5	23.31
29	24.85	22.5	58.56	36.2	22.54
30	25.32	21.7	46.82	35.08	20.3
31	26.1	19.6	45.51	34.32	21.63
32	26.43	21.6	53.89	33.45	21.91
33	24.45	22.1	49.94	33.72	22.91
34	28.06	23.9	53.24	34.2	24.08
35	25.95	20.8	37.98	33.58	20.02
36	24.56	21.9	43.1	31.69	22.26
37	26.06	28.4	47.26	32.76	21.49
38	21.68	17.2	35.51	32.02	17.43
39	23.74	25.9	48.39	32.54	19.11
40	10.22	26.63	42.42	28.91	26.95

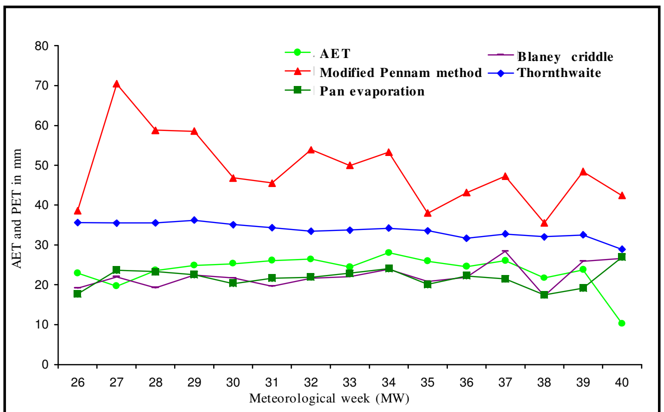

Fig. 2: Meteorological week, AET and PET by the different methods during soybean crop growing season

contributed to high values of PET as compared with AET values. At the same time the resistance offered by plant body under field conditions, the AET values were relatively lower than PET. The highest PET values as well as measured AET values were recorded in P_2 (Emergence to Seedling). It is evident that the duration for these phenophases was of longer duration coupled with higher air temperature and relatively lower relative humidity of both the timings (morning and noon).

The actual evapotranspiration (AET) for soybean was lower than the estimated potential evapotranspiration (PET) by modified Penman approach. The measured AET values and estimated PET values by this approach during pod formation to grain formation stage, where AET values matched with PET, since rainfall was more or less uniformly distributed resulting in the soil water availability. This showed higher crop water requirements during pod formation to grain formation stage. Due to these reason AET remained higher even after pod formation to grain formation stage. Due to availability of soil water resulting from rainfall events and high evaporative demand of atmosphere. It was also observed that the high rainfall restricted crop roots to uptake soil water resulting in lower values of AET. Result thus indicated that the PET was affected mostly due to availability of soil water, evaporative demand of atmosphere and the stage of soybean crop. These results are closely related with Kadam *et al.* (1978) for Marathwada region.

Pan evaporation method:

The measured data on AET in different phenophases as well as meteorological week wise were compared with estimated PET data estimated through Pan Evaporation method and were compared and presented in Table 1 and Fig. 1. The comparison of the data showed that the PET estimated through this method was almost matching with the AET measured in different phenophases. This may be due to lustrous canopy development in its grand growth period which seems to have increased AET as compared to PET estimated through this method.

Table 3 : Estimated crop coefficient values (K_c) according to different phenophases of the soybean crop by various methods

Phenophases	Blaney and criddle	Modified penman	Thornthwaite	Pan evaporation
Sowing to emergence (P_1)	0.79	0.34	0.47	1.07
Emergence to seedling (P_2)	1.14	0.39	0.66	1.02
Seedling to branching (P_3)	1.13	0.58	0.73	1.24
Branching to flowering (P_4)	1.52	0.56	0.81	1.16
Flowering to pod formation (P_5)	1.16	0.48	0.78	1.18
Pod formation to grain formation (P_6)	1.2	0.97	0.75	1.23
Grain formation to pod development (P_7)	1.18	0.53	0.79	1.17
Pod development to grain development in full size (P_8)	1.11	0.63	0.81	1.18
Dough stage (P_9)	1.07	0.55	0.74	1.24
Maturity (P_{10})	0.46	0.32	0.41	0.58

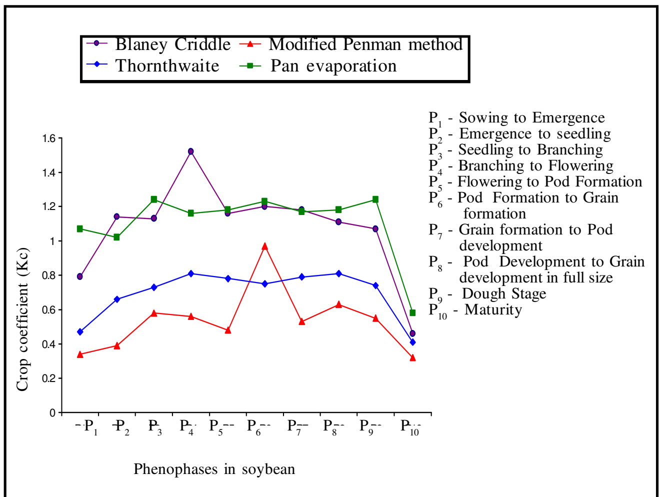

Fig. 3: Phenophases and crop coefficient (Kc) by the different methods during soybean crop growing season

However, the AET values showed higher trend during P_8 (pod development stage) and P_9 (dough stage) than PET estimated through this approach.

The data on AET measured through lysimetres and PET estimated through Pan evaporation method on meteorological week basis are presented in Table 2 and Fig. 2. The data revealed that the AET measured showed higher values in MW 26, onwards till MW 39 except MW 27. The higher PET values seems to be due to lustours canopy development in MW 40 the leaf resistence should have reduced AET, when compared with PET measured thourogh this approach. These results are in agreement with Kadam *et al.* (1978) for Marathwada region.

The crop coefficient (K_C) is the ratio of AET to PET. It clearly means that crop coefficient is the value which represents the canopy development and radiation trapping, in the course of crop development. The estimated (K_C) values were obtained using different approaches. Data in this study on phenophase basis as well as meteorological week basis are presented in Table 3 and 4 graphically in Fig. 3 and 4, respectively.

The data indicated that the K_C values obtained through Blaney and Criddle and Pan evaporation approach was higher than one throughout the crop life cycle as well as meteorological week basis. The comparison of different approaches revealed that the K_C values obtained through Thornthwaite method were next to Blaney and Criddle and Pan evaporation. The K_C values through modified Penman approach showed lower K_C values throughout the different phenophases as well as through meteorological week wise. The higher K_C values were due to lower PET values estimated through Blanny and Criddle, Pan evaporation and Thornthwaite approaches. The K_C values in different phenophases obtained to various approaches ranged between 0.46 to 1.52, 0.58 to 1.24, 0.41 to 0.81 and 0.32 to 0.58 for Blaney and Criddle, pan evaporation, Thornthwaite and modified Penman approach, respectively. While these values when estimated on meteorological week basis ranged between 0.39 to 1.34, 0.38 to 1.29, 0.36 to 0.83 and 0.25 to 0.69

Table 4 : Estimated crop coefficient (K_c) values according to different meteorological weeks of the soybean crop by various methods

Meteorological weeks	Blaney and criddle	Modified penman	Thornthwaite	Pan evaporation
26	1.21	0.6	0.65	1.29
27	0.89	0.28	0.56	0.83
28	1.24	0.41	0.67	1.02
29	1.11	0.43	0.69	1.11
30	1.17	0.55	0.73	1.25
31	1.34	0.58	0.77	1.21
32	1.23	0.5	0.8	1.21
33	1.11	0.49	0.73	1.07
34	1.18	0.53	0.83	1.17
35	1.25	0.69	0.78	1.3
36	1.13	0.57	0.78	1.11
37	0.92	0.56	0.8	1.22
38	1.27	0.62	0.68	1.25
39	0.92	0.5	0.73	1.25
40	0.39	0.25	0.36	0.38

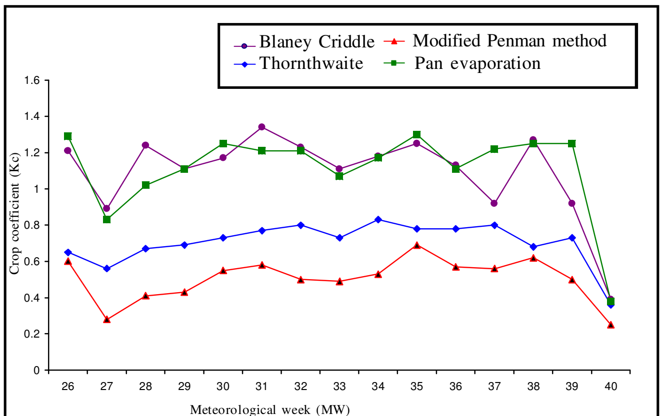

Fig. 4: Meteorological week and crop coefficient (K_C) by the different methods during soybean crop growing season

for Blaney and Criddle, Pan evaporation, Thornthwaite and modified Penman approach, respectively. The trend indicated that the K_C values increased uniformly and gradually through P_1 (sowing to emergence) to P_9 (dough stage). The comparison between different approaches showed a similar trend in all the methods studied. The crop coefficient (K_C) graph reflects seedling stage with low values and then rising limb during increased growth and peak at the crop attaining maximum cover and growth followed by the decreasing limb when leaves started shedding at the end of the growth cycle (Li *et al.,*2003).

The modified Penman mehtod was correct estimation of K_C as suggested by FAO56 Allen *et al.* (1998) according to various phenophases of soybean. The K_C values for soybean increased in modified Penman method in pod formation to grain formation stage, due to the need of protective irrigation at this stage. These results are closely related with the Shih and Gaseho (1997).

Temporal variation of crop coefficients (K_C) for soybean:

Temporal variation of Kc for soybean indicates a cyclic variation of K_C throughout the crop growth period. The variation in K_C may be occurrence of rainfall events resulting in increased values of K_C whereas when the soil is dry. The less availability of soil water reduces Kc values. The K_C values of soybean increased during pod formation to grain formation stage due to high evaporative demand. The PET values were affected due to the availability of soil water, method of estimation of PET due to variation in Kc occurred.

Also it demonstrated that the measured crop coefficient for soybean was higher than the empirical K_C by Blaney and Criddle and the pan evaporation approaches. On the other hand in the later crop growth stages namely, seedling, flowering, pod formation, grain formation and pod development stages. The measured in Kc values were higher than those suggested by in FAO 56 Allen (1994) Crop coefficients were found to vary with the percentage of the ground covered by crops, rate of crop development, time to achieve full ground cover and frequency of precipitation (Jagtap and Jones 1989). The higher measured K_C values in the various crop stages by Blaney and Criddle and Pan evaporation in indicated that the error in prediction of PET and crop canopy cover was the least and hence showed higher K_C than empirical one. On the contrary, the lower measured K_C P_1 (sowing to emergence) and P_{10} (maturity) growth stages may be attributed to the fact that the lower rainfall observed due to which limited availability of water for crop at these growth stages.

Conclusion:

The following conclusions could be drawn from the result of the study;

– The Blaney Criddle, Thronthwaite and Pan evaporation methods did not give correct prediction of PET, due to the estimated Kc values did not give correct estimation at various phenophases.

– For estimation of potential evapotranspiration (PET) under Marathwada region at Parbhani conditions, the modified Penman method is the most suitable having sound theoretical formulations and more accuracy in estimation as compared with the Blaney Criddle, Thornthwaite and Pan evaporation methods.

– The total seasonal actual evapotranspiration (AET) for soybean was found to be 353.59 mm at Parbhani to be less than the seasonal water requirement of this crop for Marathwada region.

This again necessiates the application of protective irrigation to soybean especially during pod formation to grain formation stage by the modified penman method.

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