International Journal of Agricultural Engineering, Vol. 2 No. 2 (October 2009 to March 2010) : 236-242

Research Paper :

Estimation of crop water requirement for irrigation planning in a semi arid region

M.L. CHAVAN, U.M. KHODKE AND N.M. CHANGADE

Accepted : *July, 2009*

ABSTRACT

Historical weather data can be used to develop and modify the management practices to increase the production with the conjunctive use of rain and irrigation water as per the water needs of the crop. Regional scale crop and water resource planning needs determination of reference crop evapotranspiration (eto), probability distribution of rainfall and ETo, and estimates of magnitude and duration of water deficit and surplus which can promote crop production in both irrigated and dryland areas. Daily weather data of 16 years (from 1984 to 2001) for five locations *i.e.*, Aurangabad, Beed, Nanded, Parbhani and Osmanabad of Marathwada region was used to determine reference crop evapotranspiration (ETo). The rainfall and ETo data were analysed to ascertain their fit to various probability distributions. The goodness of fit was determined by χ^2 tests. The developed crop coefficients were used to estimate crop water requirements of 8 major crops of the region. Effective rainfall was used to determine the weeks at which the rainfall exceed or fall deficit of crop water requirement. The study indicated that normal distribution gave the closest fit to the weekly rainfall and ETo data. The seasonal water requirement of cotton, groundnut, sugarcane and banana is higher at Parbhani whereas that of *kharif* sorghum, *rabi* sorghum, wheat and soybean is higher at Osmanabad than other places in the region. the effective rainfall meets the water need of *kharif* sorghum and soybean. The rainfall values during the critical growth stages of *rabi* (sorghum and wheat) and summer crops (groundnut, banana and sugarcane) are deficit than their water requirement in the respective weeks and hence require irrigation during those periods. Among the row crops, wheat and groundnut can only be grown under irrigation. Annual excess rainfall for various crops ranges between 561 - 749 mm for *kharif* sorghum, 124 -195 mm for *rabi* sorghum, 0 - 15 mm for wheat, 624 - 808 mm for soybean, 633 - 786 mm for cotton, 453 - 609 mm for sugarcane and 526 - 703 mm for banana. If the excess rains are effectively harvested, the irrigation potential could be raised in the region.

See end of the article for authors' affiliations

Correspondence to:
M.L. CHAVAN
Department of Irrigation and Drainage Engineering, Dr. Budhajirao Mulik College of Agricultural Engineering and Technology, Mandki – Palvan, Chiplun, RATNAGIRI (M.S.) INDIA.

Key words : Probability distribution, Crop evapotranspiration, Water requirements, Crop coefficient, Excess and Deficit rainfall.

Scarcity and growing competition for fresh water resource will reduce its availability for irrigation and hence efficiency of its economic use will be dominant factor controlling food production. An analysis of benefits from the conjunctive use of rain and irrigation can be accomplished with crop production under rainfall conditions and potential crop production with the application of one or more irrigations (Hargreaves and Samani, 1988). Many times even with favourable climatic conditions, the crop production is very low due to absence of proper water resource planning and scientific management.

The rainfall and its distribution are important for every cultivator, both for deciding the cropping pattern and irrigation needs. The adequacy of rainfall to meet the consumptive needs of crops and other consumptive and non-consumptive water needs is a basic requirement of any region (Sikka and Soni, 1989). Since rainfall is quite erratic in both time and space, probability analysis offers a better scope for predicting the minimum assured rainfall. It is also essential to analyse the short period rainfall like weekly for planning even irrigated agriculture (Mishra *et al.*, 1999) since annual and monthly rainfall data is inadequate to evaluate the deficiencies of soil moisture occuring during different stages of crop growth.

Evapotranspiration (ET) being one of the important components of hydrological cycle requires to be estimated accurately for its reliable application for most of the current hydrologic, water management and crop growth models (Choisnel *et al.*, 1992). In view of wide applicability of potential evapotranspiration data in solving different hydrological problems, the need of computing evapotranspiration rapidly and accurately remains indisputable as direct measurements of evapotranspiration such as lysimetry are time consuming, expensive and needs to be tested on larger areas (Singh and Shukla, 1978). On the contrary, it is rather simple and practical to determine the irrigation requirements from available

climatic data, to workout an excess or deficit of rainfall and also to decide either to store the excess precipitation for further use or to supplement the soil moisture deficit during the dry spell by irrigation.

The water excess or deficit and hence irrigation or drainage requirement of crops depends on the soil, crop and meteorological conditions of the area which can be determined for planning suitable cropping pattern using the weather data of the region (Mishra, 1998). Estimates of the magnitude and duration of water deficit and surplus are of vital importance for planning crop and water management practices to promote crop production in both irrigated and dryland areas (Sikka and Soni, 1989). Such studies on estimating crop water requirements and irrigation planning based on excess and deficit of rainfall are meagre and not reported for semi arid region. Hence, the present investigation was planned with a view to work out the weeks in which precipitation exceeds the crop demand and the weeks of deficit by using the concept of reference crop evapotranspiration (ETo) and effective rainfall.

METHODOLOGY

Study area and location:

Marathwada region comprises of eight districts with total area of 64818 sq km. The region that comes under scarcity and assured to high rainfall zone is situated in between 18° to 20°N latitude and 75° to 78°E longitude. Meteorological data is being recorded at five stations *viz*., Aurangabad, Beed, Nanded, Osmanabad and Parbhani in the region. There are three distinct seasons in the region *viz*. the summer from March to June, rainy season from June to middle of October and winter season from mid October to end of February. The average annual rainfall of the region is about 792 mm (Epitome of Agriculture, 2002). The month of May is generally hottest as the mean maximum temperature increases to 44°C. The maximum rainfall is received in the month of July. During rainy season, the humidity is as high as 70 to 84 per cent, whereas in winter afternoon, it comes down to about 50 per cent. The wind speed is generally highest in the month of June.

Data collection and analysis:

Daily and weekly values of rainfall, temperature, relative humidity, wind speed and cloudiness, maximum and actual sunshine hours recorded at five different locations of a semi arid region of Marathwada were collected from India Meteorological Department (IMD) Pune for the years from 1984 to 2001. These data were used for estimation of reference crop evapotranspiration (ETo) and analyzed for probability distributions. The daily ETo at the respective meteorological station was estimated using FAO Penman-Monteith method (Allen *et al.*, 1998) using following equation:

$$ETo = \frac{0.408\ \Delta\ (R_n - G) + \gamma \frac{900}{T + 273} u_2\ (e_s - e_a)}{\Delta + \gamma\ (1 + 0.34\ u_2)}$$

where, ETo = Reference crop evapotranspiration (mm Day^{-1}), T= Mean daily air temperature at 2-m Height (°C), R_n = Net radiation at the crop surface (MJ $m^{-2}day^{-1}$), G = Soil heat flux density (MJ $m^{-2}\,day^{-1}$), u_2 = Wind speed at 2-m height (m s^{-1}), e_s = Saturation vapour pressure (Kpa), e_a = Actual vapour pressure (Kpa), (e_s-e_a) = Vapour pressure deficit (Kpa), δ = Slope of vapour pressure curve (Kpa $°C^{-1}$) and γ =Psychrometric constant (K pa $°C^{-1}$).

The effective rainfall was computed as a ratio of ETo to total rainfall for a certain group of days during the growing season (Dastane, 1974). The probability analysis of weekly ETo and rainfall was carried out by using three distributions *viz*., Normal, Lognormal and Gamma distribution with Chi-square test for goodness of fit since hydrological variables like rainfall over certain period was involved (Varshney, 1989). The best-fit distribution was then used for prediction of ETo and rainfall at 50, 70 and 90 per cent probability. The common cropping pattern mostly followed in the region was identified which consists of eight major crops (Table 1).

The already developed stage-wise crop coefficients of the cotton and sorghum were used (Khodke and Gundekar, 2006) whereas for other crops they were estimated using standard procedure (Doorenbos and Pruitt, 1977; Allen *et al.*, 1998). The week-wise crop evapotranspiration (ETc) for each crop was estimated using ETo and Kc. The weekly rainfall and crop-evapotranspiration (ETc) values at 50, 70 and 90 per cent probability levels and effective rainfall were used to determine the weeks at which the rainfall exceed or fall deficit of crop water requirement.

RESULTS AND DISCUSSION

The results obtained from the present investigation are discussed below :

Rainfall analysis:

Analysis of rainfall data indicated that the rainfall in the region mostly starts from 22nd MW with total duration of 21 weeks till 43rd MW whereas 31st MW onwards rainfall shows a slight decline till 43rd MW. There after rainfall amount was meagre for rest of the meteorological weeks. In general, rainfall pattern of Beed and Parbhani

Table 1 : Existing cropping patterns followed in Marathwada region

Cropping Pattern	Seasons					
	Kharif		*Rabi*		Summer	
	Crop	Sowing Time, MW	Crop	Sowing Time, MW	Crop	Sowing Time, MW
1.	Sorghum	23	Wheat	44	-	-
2.	Soybean	24	Sorghum	39	-	-
3.	Green gram	23	Sorghum	39	-	-
4.	Cotton	21	Cotton	-	Groundnut	4
5.	Sugarcane	-	Sugarcane	1	Sugarcane	-
6.	Banana	31	Banana	-	Banana	-

was nearly same wherein the rainfall begins from 23rd MW and ends to 43rd MW consisting again of total 21 weeks. Conversely, at Osmanabad, there were total 22 weeks of rainfall with noticeable amount and rainfall starts early as compared to other stations from 21st MW and continue up to 42nd MW. The average annual rainfall of Osmanabad was less compared to Parbhani, Nanded and Aurangabad and nearly same as in Beed.

The statistical analysis of rainfall indicates large-scale variability during different years (coefficient of variation) and rainfall did not always follow particular distribution from year to year (coefficient of skewness). Probability analysis of weekly rainfall with the Chi-square test for goodness of fit at 5 % significance level (Chow, 1964; Hann, 1977) showed that the estimated chi-square values were less than the corresponding tabulated values under normal distribution for almost all the weeks, lognormal distribution for some weeks and gamma distribution for very few weeks indicating their significance for those weeks.

Probability distribution of rainfall:

As the weekly rainfall has high variability and the data are much skewed rainfall data was analyzed by Weibull's method (Tambile, 1991; Ray *et al.*, 1980) and the amount of rainfall at 50, 70 and 90 per cent probability levels were worked out.

It was observed that at 90 per cent probability level or at equivalent to 10 per cent risk, significant amount of rainfall is available from 23rd to 41stMW at all the locations. Although at 50 per cent chance of occurrence, rainfall started from 21st MW at all five locations its disappearance at these locations was different such as 43rd MW at Aurangabad, Nanded and Parbhani; 44th MW at Beed; and 42nd MW at Osmanabad. The total rainfall period varies accordingly from 22nd to 25th weeks.

At 70 per cent probability with 30 per cent risk level, appreciable amount of rainfall started from 21st MW and disappear at 42nd MW comprising total 22 weeks of rainfall period at Aurangabad and Osmanabad whereas at Beed, Nanded and Parbhani the significant amount of rainfall was started from 21st and lasted till 42nd MW consisting of 22 weeks.

Thus, in general, it can be concluded that appreciable amount of rainfall is available mostly during 21st MW to 42nd MW at 30 per cent risk level which coincides with the first three stages of crop growth of cotton (initial, crop development and mid season), first stage of banana and third stage of sugarcane (mid season). However, this assured rainfall is not available for *rabi* crops like wheat and sorghum and all the summer crops such as summer groundnut as the planting period of these crops normally falls after rainfall periods. The other critical growth stages of banana and sugarcane also do not fall in the rainfall periods. The 70 per cent probability values of rainfall are used for estimating effective rainfall, which is equivalent to 30 per cent risk. This is normally used for planning of irrigation and cropping system (Darbal and Rao, 1997), to reduce the risk in planning of excess rainfall.

Analysis of ETo:

Analysis of data revealed that the ETo values at Osmanabad are higher than those at other stations from 1st MW to 11th MW whereas for remaining weeks there is no significant difference in the values of weekly ETo. During the year at all five locations, the trend of ETo values is similar without any abrupt change. The ETo values at all stations increased from 1st to 19th MW in general thereafter, ETo values decreased and remained constant between 36th to 52nd MW. Statistical properties such as mean, standard deviation, coefficient of variation and skewness were computed for weekly ETo. The coefficient of variation values less than 1 for almost all the weeks indicate low variability in weekly ETo values amongst the years whereas the skewness coefficient ranges between of -1 to +1 for most of the weeks

indicating less skewness in weekly ETo values.

Probability analysis of ETo:

Although the weekly ETo values are not much skewed with less variability, in order to keep the uniformity, all the three distributions such as Normal, Lognormal and Gamma were fitted to ETo. The data showed that the calculated Chi-square values are less than the tabulated values for most of the weeks in case of Normal and Lognormal distributions. Therefore, the hypothesis that data are from specified distribution is accepted. In case of Gamma distribution, the calculated values of Chi-square are greater than tabulated values for all the five locations except at some weeks. Therefore in general it is concluded that Gamma distribution does not fit well for the weekly ETo values whereas Normal and Lognormal distribution describe the weekly ETo for 100 per cent data at all five locations. Therefore, the data of ETo at different probability level can be used for irrigation planning (Jadhav and Kshirsagar, 1992; Sritharam and Clyma, 1984) rather than taking the average ETo, which may otherwise overestimate the water requirements. The ETo values at 70 per cent probability for Normal and Lognormal distributions are nearly close. This may be due to low skewness coefficient for which logarithmic transformation of original data does not yield significant difference.

Crop coefficient and moisture sensitive period:

The week wise values were read from the developed curves (Table 2).

Since the average annual relative humidity and wind velocity for five locations is nearly equal, the developed Kc values can be utilized for all the location for determining the crop water requirement. The moisture sensitive periods of major crops considered for the study were identified and the crop evapotranspiration (ETc) for different crops at the locations under study are presented in Table 3.

Crop water requirement:

The crop water requirements were worked out (ETc) using reference crop evapotranspiration (ETo) at 70% probability for the respective location and the crop coefficients. The data regarding ETo and ETc for various crops at each location are presented in Table 4.

At Parbhani, the seasonal water requirement of cotton, groundnut, sugarcane and banana is higher than those at Aurangabad, Beed, Nanded and Osmanabad. At Osmanabad the seasonal water requirement of *kharif* sorghum, *rabi* sorghum, wheat and soybean is higher than other locations because of high reference crop evapotranspiration.

Water requirement of *kharif* sorghum in the region ranges from 391.5 to 414.3 mm whereas *rabi* sorghum the range is from 257 to 299.2 mm. For wheat, the water requirement is between 309 to 363 mm in the region having maximum at Osmanabad and minimum at Beed. The maximum water requirement of soybean is 435.9 mm at Osmanabad and minimum of 359.9 mm at Beed. In case of cotton, the water requirement ranges from 575 to 684 mm. The seasonal water requirement of summer groundnut of this region ranges from 563 to 682 mm with minimum at Beed and maximum at Parbhani. There is significant difference between the water requirements of sugarcane at various locations with maximum at Parbhani (1728 mm) and minimum at Beed (1440 mm). Similarly, banana was found to have highest annual water requirement ranging from 1502 to 1805 mm.

Excess and deficit of rainfall:

The effective rainfall is calculated at 70 per cent probability by taking the ratio of ETo and rainfall both at 70 per cent probability. The week wise effective rainfall at 70 per cent chance of occurrence was estimated. These values of effective rainfall were further used for estimating the weeks of deficit and excess (Table 5).

Data indicates that the effective rainfall meets the water need at all the stations during the growth period of

Table 2 : Growth stage-wise crop coefficients of major crops in Marathwada (Annual)

Crop	Crop growth stage					
	1	2	3	4	5	6
K Sorghum	0.35 (23-25)*	0.75 (26-30)	1.1 (31-36)	0.65 (37-39)	-	-
S. Bean	0.35 (24-26)	0.75 (27-31)	1.1 (32-37)	0.6 (38-42)	-	-
Cotton	0.45 (23-26)	0.75 (27-33)	1.15 (34-42)	0.75 (43-49)	-	-
Rabi Sorghum	0.12 (39-41)	0.55 (42-46)	1.0 (47-52)	0.5 (51-4)	-	-
Wheat	0.35 (43-44)	0.75 (45-48)	1.15 (49-3)	0.45 (4-7)	-	-
Summer groundnut	0.45 (4-6)	0.75 (7-11)	1.01 (12-18)	0.77 (19-22)	-	-
Sugarcane	0.6 (1-9)	0.85 (10-17)	1.0 (18-26)	1.15 (27-39)	1.25 (41-48)	0.85 (49-52)
Banana	0.65 (31-47)	0.9 (48-4)	1.2 (5-29)	1.05 (30)	-	-

Table 3 : Moisture sensitive period of different crops in Marathwada Region

Crop	Critical growth stage	Period (MW)	Crop	Critical growth stage	Period (MW)
Kharif Sorghum	Booting	29-30	Rabi Sorghum	Booting	43-45
	Blooming	32-34		Blooming	47-48
	Milk dough	37-38		Milk dough	52-1
Soybean	Blooming	34-35	Wheat	Crown root initiation	46-47
	Seed formation	40-41		Tillering	49
Cotton	Flowering & boll formation	29-38		Jointing	51
	Boll development	38-41		Flowering	1-2
Groundnut	Flowering	10-12		Milking	5
	Pegging	12-14		Daugh stage	6-7
	Pod development	14-17			
Sugarcane	Formative	27-40	Banana	Fruit development	17-29

Table 4. Annual/ Seasonal ETo and ETc of different crops at various locations in Marathwada Region

Location	ETo/ETc	Aurangabad	Beed	Nanded	Osmanabad	Parbhani
Khairf Sorghum	ETo	518.9	444.9	545.3	538.8	553.3
	ETc	391.5	338.9	413.7	414.3	412.7
Rabi Sorghum	ETo	462.8	414.1	454.9	479.9	457.2
	ETc	285.0	256.8	275.6	299.2	273.9
Wheat	ETo	446.7	396.3	425.8	465.4	425.8
	ETc	344.2	309.1	328.5	363.0	326.6
Soybean	ETo	554.3	481.9	588.3	579.9	589.9
	ETc	410.4	359.9	434.6	435.9	432.9
Cotton	ETo	804.1	697.6	827.6	828.4	839.2
	ETc	655.4	574.9	677.6	682.3	683.8
Groundnut	ETo	776.0	681.5	728.5	799.0	824.9
	ETc	657.4	563.4	603.9	655.7	682.1
Sugarcane	ETo	1722.7	1492.3	1673.9	1760.5	1779.3
	ETc	1661.7	1439.7	1627.8	1698.7	1728.0
Banana	ETo	1722.7	1492.3	1673.9	1760.5	1779.0
	ETc	1742.5	1502.3	1678.4	1771.2	1805.1

kharif sorghum (Table 5). In most of the weeks, the available water is in excess for *kharif* sorghum except for some weeks at Beed, Nanded and Osmanabad showing deficit water demands for *kharif* sorghum. During the growing period of *kharif* sorghum rainfall is excess in 13 weeks at Aurangabad and Beed where as at Nanded, Osmanabad and Parbhani the weeks of excess rainfall are 15, 12 and 14, respectively.

For *rabi* sorghum during the initial growth period (39 to 42 MW) the rainfall is in excess than the water requirement of the crop whereas during its mid growth stage four weeks (1st to 4th MW) at Aurangabad, Beed, Osmanabad and Parbhani and three weeks (2nd to 4th) at Nanded are rainfall deficit weeks as per the water requirements. During the crop growth period of wheat, the rainfall amount was deficit although indicating that wheat can be grown at all stations only under irrigation. Conversely almost all the weeks of soybean crop growing period are in excess than the crop water demand, except 30, 33, 36 and 37th MW at Aurangabad, 27, 31, 33 and 34th MW at Beed and Osmanabad, 37 and 38th MW at Nanded, and 29, 33, 37 and 39th MW at Parbhani.

The water requirement of cotton crop at various locations is in deficit during the sensitive crop growth periods after 42nd MW barring few exceptions whereas the initial crop-growing periods are in excess amount of rainfall at all the locations.

During the crop growth period of summer groundnut all the weeks are of deficit rainfall weeks indicating that provision of irrigation is must for growing summer groundnut crop at all locations.

During the growth of sugarcane and banana although

Table 5 : Annual/ Seasonal excess and deficit of rainfall for different crops at various locations

Sr. No.	Crop		Locations				
			A' bad	Beed	Nanded	Osmanabad	Parbhani
1.	*Kharif* Sorghum	ETc	391.5	338.9	413.7	414.3	412.7
		Deficit	-6.8	-31.7	-15.3	-65.8	-19.9
		Excess	146.5	212.6	246.3	153.4	230
2.	Soybean	ETc	410.4	359.9	434.6	435.9	432.9
		Deficit	-17.9	-30.2	-41.2	-56.9	-24.2
		Excess	149.3	202.5	293.2	167.0	266.8
3.	Cotton	ETc	655.4	574.9	677.6	682.3	683.8
		Deficit	-193.7	-182.4	-237.1	-231.2	-191.9
		Excess	148.1	186.9	276.9	127.9	234.9
4.	*Rabi* Sorghum	ETc	285.0	256.8	275.6	299.2	273.9
		Deficit	-229.4	-217.6	-228.0	-271.9	-207.9
		Excess	55.6	63.5	75.1	90.1	56.8
5.	Wheat	ETc	344.2	309.1	328.5	363.0	326.61
		Deficit	-312.5	-286.1	-285.9	-356.4	-284.66
		Excess	0	0	0	0	0
6.	Groundnut	ETc	657.4	563.4	603.9	655.7	682.1
		Deficit	-624.5	-538.5	-575.1	-612.2	-655.7
		Excess	0	0	0	0	0
7.	Sugarcane	ETc	1661	1439	1627	1698	1728
		Deficit	-1056	-929	-1029	-1136	-1077
		Excess	41	98	175	63	109
8.	Banana	ETc	1742	1502	1678	1771	1805
		Deficit	-1227	-1071	-1163	-1302	-1262
		Excess	131	177	258	157	218

from 23 to 42nd MW the rainfall is in excess most of the remaining weeks where the crop is in critical growth stages the rainfall is in deficit. Similar was the trend for banana at all locations of the region (Table 5).

Conclusions:

– The study reveals that the rainfall pattern of Beed and Parbhani is nearly same as far as the onset and end of monsoon whereas although rainfall is less at Osmanabad the total rainfall weeks are more as compared to other four locations.

– Weekly rainfall data can be described by Normal distribution whereas Lognormal and Gamma distribution cannot be fitted. Similarly weekly reference crop evapotranspiration (ETo) was not much skewed and has very less variability from year to year and Normal and Lognormal distribution describe the data of weekly ETo at all five locations of Marathwada.

– The rainfall values during the critical growth stages of *rabi* (sorghum and wheat) and summer crops (groundnut, banana and sugarcane) are deficit than their water requirement in the respective weeks. Therefore, these crops require protective irrigation during those periods. Annual excess rainfall for various crops ranges between 561 - 749 mm for *kharif* sorghum, 124 -195 mm for *rabi* sorghum, 0 - 15 mm for wheat, 624 - 808 mm for soybean, 633 - 786 mm for cotton, 453 - 609 mm for sugarcane and 526 - 703 mm for banana. As regards summer groundnut the rainfall is slightly in excess by 12.86 mm only at Aurangabad whereas at all other locations showed deficit rainfall values during the crop growth period of groundnut.

– If the excess rains are effectively harvested, the irrigation potential could be raised in the region

Authors' affiliations:
U.M. KOHDKE, Department of Soil and Water Conservation Engineering, College of Agricultural Engineering and Technology, Marathwada Agricultural University, PARBHANI (M.S.) INDIA
N.M. CHANGADE, Department of Irrigation and Drainage Engineering, Dr. Budhajirao Mulik College of Agricultural Engineering and Technology, Mandki – Palvan, Chiplun, RATNAGIRI (M.S.) INDIA.

REFERENCES

Allen, R., Percira, L.A., Raes, D. and Smith, M., (1998). Crop Evapotranspiration. FAO Irrigation and Drainage, paper no. 56. Food and Agricultural organization of the United Nations, Rome, Italy: 293.

Choisnel, R. S., de Villele, O. and Lacroze, F. (1992). Une Approache Uniformisee du calcul del Evapotranspiration Potentielle Pour L'enesemble des pays de la communaute. Europeenne Commission des Communities Europeenne, Luxembourg, EUR 14223: 178.

Chow, V. T. (1964). *Handbook of Applied Hydrology*, Mc-Graw Hill Book Company, New York: 81-91.

Darbal, P. P. and Rao, K. A. (1997). Estimation of crop coefficient and irrigation requirement under various irrigation levels for Tea during dry period. *Indian J. Soil Cons.*, **25**(3): 233-235.

Dastane, N. G. (1974). Effective Rainfall in Irrigated Agriculture, FAO Irrig. Drain. Paper No. 25 FAO, UN Rome.

Doorenbos and Pruitt (1997). Guidelines for predicting crop water requirement. FAO Irrig. Drain. Paper No. 24. FAO, Rome, Italy: 156 – 179.

Epitome of Agriculture (2002). Commissionerate of Agriculture (M. S.) Pune: 1-28.

Hann, C. T. (1977). *Statistical Methods in Hydrology* IOWA University Press/A mes.

Hargreaves, G.H. and Samani, Z.A. (1988). Reference crop evapotranspiration from ambient air temperature. *Trans, ASAE.*, **25** (17): 11.

Jadhav, V. D. and A. G. Kshirsagar (1992). Probability analysis of reference crop ET. B. Tech. Thesis, MPKV, Rahuri: 1-41

Khodke, U.M. and Gundekar, H.G. (2006). Evaluation of some crop coefficients for some crops in semi arid region of Marathwada In Souvenir 40th Ann. Convention of ISAE, AEC & RI TNAU Coimbatore SWC-2006-MI-03: 4.45

Mishra, S.K. (1998). Probability analysis of rainfall for crop planning. *J. agric. Engg.*, **16**: 27-34.

Mishra, A.K., Sarkar, J.K. and Bhattacharya, A.K. (1999). Stochastic rainfall forecasting for weekly water resources assessment in lower Assam. *Indian J. Soil Conservation*, **27**(2): 99-111.

Ray, G. R., Senapati, P.C. and Lal, R. (1980). Rainfall analysis for crop planning at Gopalpur (Orissa). *J. agric. Engg.*, **17** (3-4) : 1-8.

Sikka, A.K. and Soni, B. (1989). Estimation of rainfall deficit and surplus probabilities for water management and crop planning. IE (I) *Journal-Ag*, **70**: 10-13.

Singh, R.V. and Shukla, K.H. (1978). Installation of Non-weighing lysimeters for measurements of Evapotranspiration. *J. agric. Engg, ISAE XV,* (2): 74-85.

Sritharam, S. and Clyma, W. (1984). Probability based design *ET. J. ASAE*, 84-18.

Tambile, R.H., Deshmukh, U.G. , Acharya, A.R. Mantri and B. P. Sawant (1991). Probability analysis of annual rainfall at Parbhani (M.S.) for crop planning. *J. Indian Water Resources Soc.*, **11**(2): 23-28.

Varshney, K.G. (1989). Frequency analysis of weekly rainfall using analytical techniques. Proc. XXV Annul Conv. of ISAE Udaipur Jan 5-7, 2989 Paper No. 89-20: 140-147.

***