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Estimation of crop water requirement of some major crops of Mayurbhanj, Odisha for irrigation planning

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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 20 years (from 1996 to 2015) 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 x^2 tests. The developed crop coefficients were used to estimate crop water requirements of five 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 effective rainfall meets the water need during the growth period of Rice and Maize. The rainfall values during the critical growth stages of Black Gram, Arhar and Mustard are deficit than their water requirement in the respective weeks and hence require irrigation during those periods.*

Keywords*: Probability distribution, Crop evapotranspiration, Water requirements, Crop coefficient, Excess and Deficit rainfall.*

INTRODUCTION

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

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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 work out 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

The study place, Mayurbhanj has an area of 10,418 km² and is located at 22.0087° N latitude and 86.4187° E longitude with an altitude of 559 m above mean sea level. 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 1292 mm . 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 to August. 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 for Mayurbhanj district of Odisha. were collected from India Meteorological Department (IMD) Pune for the years from 1996 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 (Allenet al., 1998) using following equation:

$$ETo = [0.408\ \Delta(Rn-G) - \gamma(900/T+273)\ u_2\ (e_s-e_2)] / \Delta + \gamma(1+0.34\ u_2)$$

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	=	sychrometric constant (K pa $^{o}C^{-1}$).

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 five major crops (Table 1). The crop coefficients of the crops 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 cropevapotranspiration (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. 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. 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 Thus, 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 all the four stages of crop growth of rice (Tillering,

Table 1
Existing cropping pattern and Moisture sensitive period of different crops in Mayurbhanj Region

Sl no	*Crops*	*Season*	*Sowing time (MW)*	*Critical growth stages*	
1	Rice	Kharif	26	Tillering	(32 MW)
				Panicle initiation	(38MW)
				Flowering	(39 MW)
				Milking	(41MW)
2	Maize	Kharif	25	Tasseling	(33MW)
				Silking	(35 MW)
				Cob development	(37 MW)
3	Black Gram	Kharif	28	Flowering	(34 MW)
				Pod filling	(37 MW)
4	Arhar	Kharif	24	Flowering	(37 MW)
				Pod filling	(39 MW)
5	Mustard	Rabi	44	Flowering	(52 MW)
				Siliqua development	(2 MW)

Panicle initiation, Flowering and milking), all the stages of Black gram and Arhar. However, this assured rainfall is not available for rabi crops like mustard as the planting period of the crop normally falls after 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 are higher from 1st MW to 11th MW whereas for remaining weeks there is no significant difference in the values of weekly ETo. During the year the trend of ETo values is similar without any abrupt change. The ETo values increased from 1st to 19th MW 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 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. 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). Based on the average annual relative humidity and wind velocity, the developed Kc values are utilized to determine 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 location under study is 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 are presented in Table 4. Water

Table 2
Growth stage wise crop coefficients of major crops in Mayurbhanj district.

Crop	*Crop growth stage* 1	2	3	4
Rice	0.65 (31-42)	0.75 (26-30)	1.1 (31-36)	0.65 (37-39)
Maize	0.35) (29-31	0.75 (27-31)	1.1 (32-37)	-
Black Gram	0.12 (24-27)	0.55 (42-46)	-	-
Arhar	0.35 (33-34)	0.75 (45-48)	-	-
Mustard	0.45 (24-28)	0.75 (17-21)	-	-

Table 3
Annual/ Seasonal ETo and ETc of different crops at Mayurbhanj

Crops	ETo	ETc	Excess	Deficit
Rice	1235.9	1145.6	9.8	-
Maize	776.6	687.4	6.6	-
Black Gram	651.8	579.8	13.9	-
Arhar	587.9	466.7	28.7	-
Mustard	499.8	412.6	-	-57.9

requirement of Rice crop in the region is1145.6 mm. For Maize, the water requirement is 687.4 mm in the region. The water requirement of Blackgram, Arhar and Mustard is 579.8mm, 466.7mm and 412.6mm respectively.

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 3). Data indicates that the effective rainfall meets the water need at during the growth period of Rice (Table 3). During the growing period of rice rainfall is excess in 7,8 and 11 weeks.). Conversely almost all the weeks of maize, black gram and arhar crop growing period are in excess than the crop water demand. The water requirement of Mustard crop is in deficit during the sensitive crop growth periods at the later stages.

CONCLUSION

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. The rainfall values during the critical growth stages of Black Gram, Arhar and Mustard are deficit than their water requirement in the respective weeks. Therefore, these crops require protective irrigation during those periods.

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