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A HYDROLOGICAL ASPECT ON CROP

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A B S T R A C T

A mathematical model based on the equation of continuity for soil-moisture variation under different actual precipitation occurrence has been developed using the physical possible relationship between the crop-water requirement and the available soil moisture condition. This hydrological model provides the direct determination of soil moisture as a function of time and corresponding water requirement by a specified crop during a particular phases of the crop via the soil water storage relation. The crop water requirement is a function of crop-phase, type and density, soil-moisture storage at root-depth, soil-nature, radiation energy, vapour-pressure difference and temperatures constrast. A mathematical model has been put forward here for obtaining the soil moisture storage explicitely as a function of the intensity and distribution of the type of rainfall. Special simple cases have been derived for this generalised analysis for showing the correctness of the procedure followed in this investigation.

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INTRODUCTION

The agriculture development in this regims is largely achieved by importing water from other areas for the over all economic growth of the region. The use of arid and semiarid lands is going on increasing day by day with the increasing population for the food production, people settlement and various other economic activities. The inadequate precipitation, groundwater and surface imported water are the sources for the all round agricultural development over these regimes. The full consumptive water requirements of crops in a field for achieving maximum average yield can be obtained only by knowledge of various agrometeorological parameters in the different stages of the specified crop. The available water potential in the different stages of the specified crop. The available water potential in the form of precipitation over any farm in these regimes is highly inadequate for sustaining the crop life and also possessing a very high coefficient of variation with respect to time and space. Therefore, the situation over the regimes can be improve by providing better predictive value of precipitation.

Here we have attempted different case studies for suitable planning of available water resources over farms at Jodhpur and Rajkot by adopting the soil moisture balance equation coupled with water balance equation for determining the decadewise soil moisture variation for the crop Bajra 104 in the field. The input over the field is the precipitation while the output are the various loss factors like DSRO, AET, LI, I, C of the farm area. The percentages of different loss factors have been evaluated on the basis of a few recorded data over the farms for finding the required irrigations over the farms.

Guha (1986) discussed the various aspects on the decision of farm level water-management for the arid and semi-arid crops by utilizing the soil moisture balance equation. Guha and Ballal (1986) obtained a mathematical model for the AET estimation for the crop kharif paddy in relation to various agrometeorological parameters viz. P_E, R_g and T. Guha and Day (1979) obtained a statistical simulation model for the evaluation of direct surface run-off (DSRO) in connection with heavy rainfall. Similar works in this line can be had in Guha and Das (1983), Guha (1984), Guha (1985) Guha (1977,1978), Yao (1969) and Thornthwaite et al(1939) among the others.

METHODOLOGY

It is the well known fact that these regimes possess the special characteristics of highly erratic special and temporal variations of rainfall which is the main source of water resources for different crops. The Table I shows the year to year variation of precipitation during the crop span life. It is to be noted that the precipitation for the crop-life span is only to be considered other than annual rainfall which has, infact, no bearing on the crop-growth.

TABLE NO.I

Decadal rainfall variation yearwise(mm)

Decade/ Yr.	1977	78	79	80	81	82	83	84	Total	Mean/ D
1	42.7	39.7	00.0	-	6.4	50.5	48.8	2.2	190.3	27.2
2	78.5	70.6	215.3	-	43.7	00.0	81.4	12.0	501.5	71.6
3	11.7	00.0	18.8	-	24.3	74.9	117.5	12.5	259.7	37.1
4	31.4	59.2	0.0	-	0.5	7.2	27.2	49.9	175.4	25.1
5*	00.0	50.7	00.0	-	00.0	00.0	56.3	18.5	125.5	17.9
6	43.3	00.0	00.0	-	30.2	0.9	10.8	8.7	93.9	13.4
7	6.9	00.0	5.4	-	94.3	3.0	00.0	37.4	147.6	21.0
8	00.0	00.0	00.0	-	00.0	00.0	00.0	00.0	00.0	00.0
9	00.0	00.0	00.0	-	2.2	00.0	00.0	00.0	2.2	0.31
10				-						
Total	214.5	220.2	239.5	-	239.8	140.5	342.0	154.1	1305.2	186.46
Mean	21.5	22.02	23.9	-	24.0	14.05	34.20	15.41	130.52	22.15

It is to be noted that the initial rainfall is very high and going on decreasing with the crop-life and the shortfall in the rainfall starts from the 5th decade i.e.during the flowering stage. The total rainfall vary from 114 mm to 342 mm with the mean rainfall 221 mm leading to the high value of coefficient of variation.

The table shows yearwise decadal variation of consumptive use of water by the crop BJ 104 for the field Jodhpur during life span of the crop. It is to be mentioned the crop under consideration is having low water requirement.

TABLE No. II

Yearwise decadal variation of evapotranspiration(mm)
Station : Jodhpur

Decade/ Year	1977	78	79	80	81*	82	83	84	Total	Mean/D
1	3.7	3.5	2.8	-	3.1	2.4	1.9	0.8	18.2	2.6
2	3.9	2.3	5.4	-	2.6	2.2	2.0	1.0	19.1	2.7
3	4.1	2.5	5.0	-	3.6	3.3	1.7	1.1	21.3	3.0
4	5.8	5.3	4.6	-	6.8	6.1	2.3	2.6	33.5	4.8
5	7.1	3.5	4.2	-	4.4	9.2	3.9	3.8	36.1	5.1
6	6.4	3.3	5.6	-	2.2	2.3	4.8	5.5	30.1	4.3
7	4.8	3.5	4.0	-	3.3	1.2	5.2	7.3	29.4	4.2
8	1.1	4.1	0.8	-	4.2	0.9	4.7	2.8	18.7	2.7
9	0.7	3.0	0.3	-	3.6	-	1.1	0.5	9.2	1.5
10	-	1.3	-	-	1.3	-	-	0.1	2.7	0.9
Total	37.6	32.4	32.4	-	36.2	27.6	27.6	25.5	218.0	31.14
Mean	3.7	3.2	3.2	-	3.6	2.7	2.7	2.5	22.8	

The AET for the first three decades can be considered as the reference PET for the crop as there is no dearth of SM during this period on the average due to sufficient distribution of rainfall. The average efficiency - factor for conversion rainfall into AET is given by

$$EF = \frac{AET}{P} \times 100\%$$

$$= \frac{218.0}{1385.2} \times 100\% = 16.7\%$$

The depletion of precipitation over the farm is manifested by water balance equation viz.

$$P = DSRO + AET + I + \Delta(SM) \pm L + 9$$

AET. is one of the loss factor of precipitation over the farm during a specified period. All other loss factors are to be computed for proper management of farm water-resources for that period.

The soil moisture variation.

The SM-variation during a specified period is

$$Si = Si - 1 + Pi - (AET)\ i$$

$$\text{i.e. } (\Delta S)i = Pi - (AET)\ i \qquad \ldots. (2)$$

The average decadal SM variation is given at Table III assuming an arbitrary initial SM storage which is not affecting the required time variation of SM in any way. The SM at different rooting zone is given by

$$SM\ (D) = (FC - WP) \times D.$$

$$AET = P \times EF \times Kci \qquad \ldots. (3)$$

TABLE NO. III

Decadal Soil Moisture Variation

Crop BJ - 104 — Station : Jodhpur — IRRIGATED

Decade/ yr	77	78	79	80	81*	82	83*	84
1	+ 5.7	+4.7	- 28	-	-24.6	+26	29.8	1.4
2	+45.2	+51.6	+133.3	-	- 6.9	+4.5	91.2	3.4
3	+15.9	+28.6	+102.1	-	-18.6	46.4	+191.7	42.4
4	-10.7	+34.8	56.1	-	-88.1	-6.4	+195.7	34.9
5*	-81.7	+50.5	14.1	-	-132.1	-98.4	223.0	-6.3
6	-102.7	+17.5	-31.9	-	-123.9	-111.4	+113.8	-41.9
7	-143.8	-17.5	-66.5	-	- 62.6	-112.4	+86.8	-69.9
8	-154.8	-59.5	-108.5	-	-104.4	-113.4	75.8	-74.9
9	-161.8	89.5	-138.5	-	-138.4	-	-	-75.9
10	-	-102.5	-151.5	-	-141.9	-	-	
Dates of sowing and harvesting	9.7 to 30.9	14.7 to 17.10	21.7 to 16.10		24.7 to 6.11	24.7 to 9.10	7.7 to 5.10	7.7 to 10.10
Yield /ha	7.84	N.A.	N.A.	N.A.	5.2	3.79	4.875	N.A.

It is to be noted that there is not much yearly variation AET due to the irrigation. The amount of irrigation definitely depends on the deficit of SM. The AET is a function of crop-stage, soil-moisture in the rooting-zone and radiation. The farm is such that it generally suffer from moisture, stress except during the initial three decades when the crop-water requirement is very-less. But during the high crop water requirement the farm is receiving very less precipitation for meeting the required consumptive use. Consequently, the farm needs a permanent irrigation facility from 4th decades. It is to be mentioned that entire irrigation water cannot be utilised by the crop due to the presence of various environmental less-factors like surface-evaporation, runoff, infiltration beyond rooting zone.

Temperature condition

There is practically no significant temperature contrast during the different decades of the crop life-span. The table IV show the temporal temperature variation for the same crop of different years.

TABLE NO. IV

Decadal variation of thermal field

Crop BJ 104 Station : Jodhpur

Decade/ Year	77	78	79	80	81	82	83	84	Total	Mean
1	28.7	27.0	31.9	-	29.6	30.1	430.4	31.1	213.8	30.5
2	30.1	28.5	30.3	-	29.8	30.6	31.4	30.7	211.4	30.2
3.	28.3	30.2	28.4	-	29.7	29.7	29.6	31.2	207.0	29.6
4	28.5	29.4	28.3	-	29.3	29.2	31.3	28.8	204.8	29.3
5	29.5	29.5	29.7	-	30.8	30.7	28.6	28.9	207.7	29.7
6	29.3	27.4	29.8	-	32.0	30.4	28.8	27.8	205.5	29.3
7	28.4	28.7	30.8	-	29.6	30.3	29.1	28.5	205.4	29.3
8	28.9	29.5	29.3	-	28.4	30.1	31.2	27.2	202.6	28.9
9	29.7	29.2	26.7	-	29.1	29.4	31.2	29.6	200.8	28.6
10	-	27.5	-	-	27.8	28.2	-	78.3	-	-

Therefore, under the same thermal regime, the yields of the farm are varying due to management and precipitation i.e. there is no impact of temperature for the crop-yield.

Evaporation Field

Evaporation is a function of temperature gradient and wind on the surface and as the temperature field is practically constant over the farm, it can be presumed that there must not be any significant evaporation difference during the crop life-span. The Table V support the above statement.

TABLE NO. V

Decadal Evaporation Variation

($mm\ d^{-1}$)

Decade/ Year	77	78	79	80	81	82	83	84	Total	Mean
1	5.9	5.8	9.2	-	6.3	7.6	10.9	9.9	55.6	7.9
2	5.9	6.3	5.5	-	6.5	7.0	6.8	9.1	47.1	6.7
3	4.8	8.3	5.0	-	6.2	5.1	5.7	9.2	44.3	6.3
4	6.7	7.2	7.9	-	7.5	6.4	6.9	5.5	48.1	6.9
5	8.3	6.4	8.6	-	8.7	7.6	3.8	5.1	48.5	6.9
6	7.3	7.4	8.2	-	8.9	7.7	4.9	5.1	49.5	7.1
7	7.4	7.2	9.1	-	7.1	8.5	5.3	5.8	50.4	7.2
8	6.8	8.6	8.3	-	6.3	6.9	6.8	5.2	48.9	7.0
9	8.5	7.7	7.1	-	7.4	-	7.1	7.7	45.5	7.6
10	-	8.2	-	-	7.9	-	-	7.5	23.6	7.9
Total	61.6	73.1	68.9	-	75.7	56.8	58.2	70.1	-	-

The result shows that there is no significant change in the evaporation during the crop-life span.

Relationships

The relationships among the various agro-meteorological parameters are furnished in the figs. 1,2 and 3. It can be visualised that there is a lag between rainfall maxima and AET. It is not necessary that PE be maximum when AET is maximum. The relationship between AET and P_E is

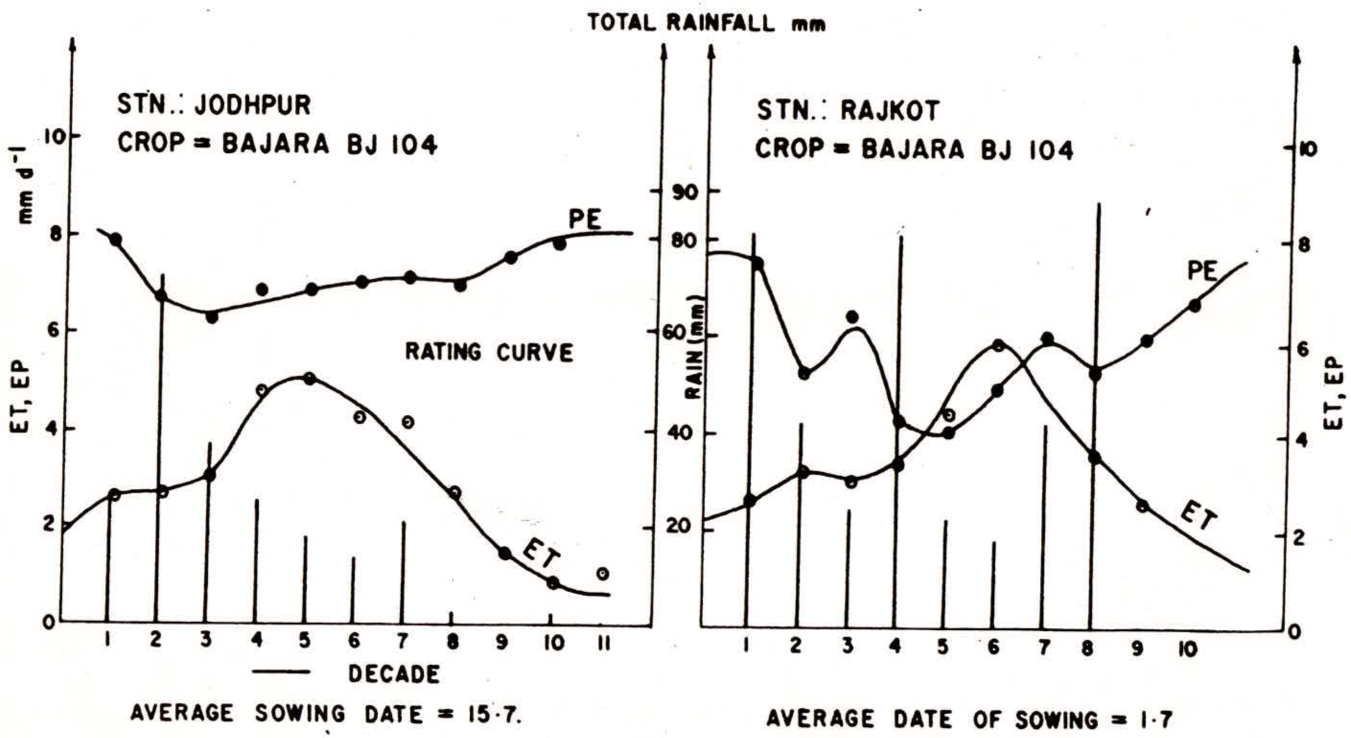
TOTAL RAINFALL mm
STN.: JODHPUR
CROP = BAJARA BJ 104
mm d⁻¹
ET, EP
PE
ET
RATING CURVE
DECADE
AVERAGE SOWING DATE = 15·7.
STN.: RAJKOT
CROP = BAJARA BJ 104
RAIN (mm)
PE
ET
ET, EP
AVERAGE DATE OF SOWING = 1·7

FIG. I

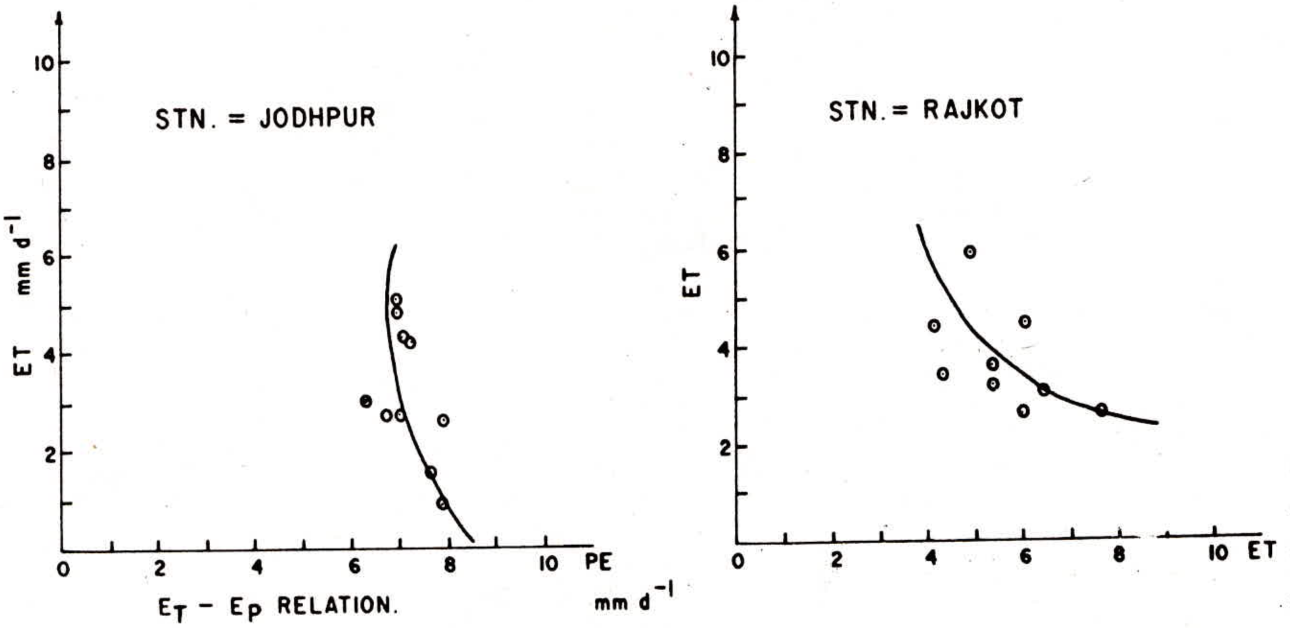
STN. = JODHPUR
ET mm d-1
PE
mm d-1
ET - Ep RELATION.
STN. = RAJKOT
ET
ET

FIG. 2

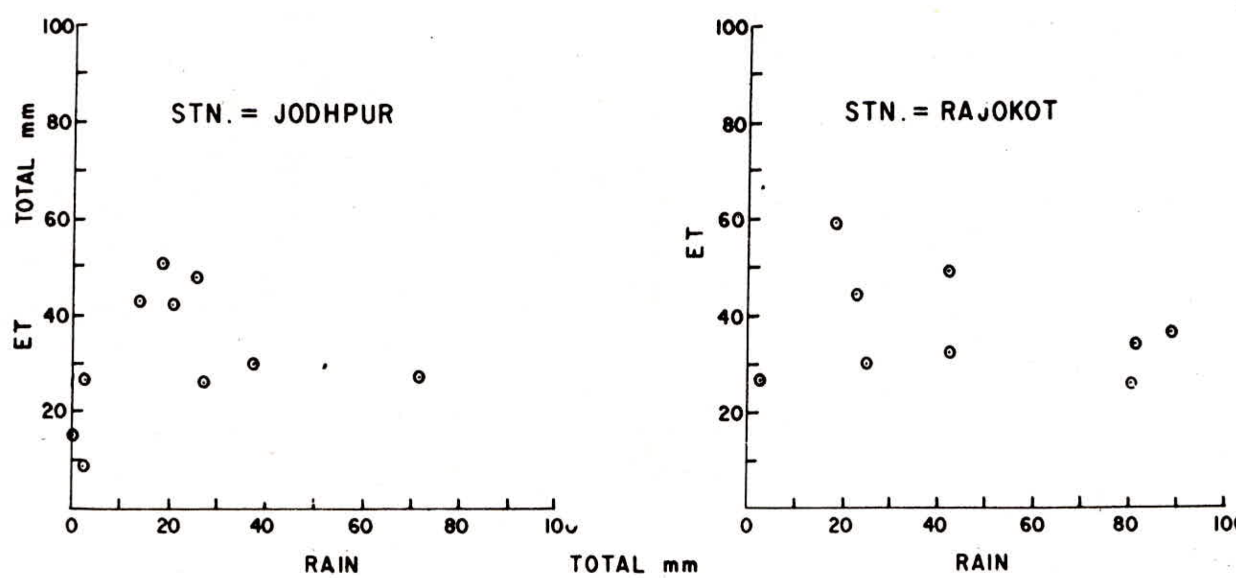
STN. = JODHPUR
ET TOTAL mm
RAIN
TOTAL mm
STN. = RAJOKOT
ET
RAIN

FIG. 3

non-linear and not linear as used by many authors. It can be seen that low value of AET is at high value of P_E, therefore the expected relation will be of the type,

$$AET \times P_E = Const \qquad \ldots\ldots (4)$$

The relationship between AET and precipitation is of exponential type and, in fact, high AET has been observed for the low rainfall values.

REFERENCES

Guha, M.K. 1986. A Decision of Farm Management. Second Indian Agro.Met. Congress, Mar 10-12.

Guha, M.K. and Ballal, A.S. 1986. A Model of E_T-estimation for kharif paddy. J.Agril & Forest Met (In Press).

Guha, M.K. and Day, J.S. 1979. A Statistical study of Storm Flow from Rainfall Proc. Nat. Symp. Hydrol. Wat. Res. Eng. Proc. Vol. III, April.

Guha, M.K. and Das, H.P. 1983. On some Farm Water Management in Arid Zone, Proc. Sem. Irrig. CBIP. Vol.II pp C-1 to C-9.

Guha, M.K. 1984. Deterministic Time variation of Drought. Mausam, Vol.**35** No.3, pp-344.

Guha, M.K. 1985. A conceptual model for Sub-Humid Zone. Nat. Symp. Const. Crops. Visha Bharati University.

Guha, M.K. 1978. A Deterministic Model of Rainfall Run-off Relation. Proc. Symp. Hydrol. Vol.II, April.

Guha, M.K. 1977. A Deterministic Non-Linear Model for Rainfall Run-off Relation. I.J.Met. Hydrol-Geoph. Vol.28 No.2 pp-243-246.

Yao, A.Y.M. 1969. The R-Index For Plant Water Requirements. J.Agril. Met. Vol.6 No.4 pp 259-273.

Thornthwaite, C.W. 1939. The Determination of Evaporation from Land and Water Surface. Mon.Wea. Rev. Vol.67 pp 4-11.