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On the assessment of crop droughts : A case study for Disa (Gujarat)

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ABSTRACT. The comparative nature of meteorological drought studies is pointed out. A monthly rainfall-cum-two-layer soil model to arrive at the ratio of actual water transpired by a ground shading crop to the potential transpiration need is presented. The use of such ratios for characterising the drought situations for a reasonably parameterised crop is explained. A case study for Disa station in Gujarat is presented.

1. Introduction

In dryland agriculture, a "Crop Drought" may be deemed to occur whenever the root zone soil moisture storage, resulting from rainfall becomes insufficient to meet the potential needs of a crop for transpiration and hence of normal growth. The degree of severity of a crop drought is influenced by weather, crop and soil factors. Hence for any given distribution of precipitation, the intensities of crop drought would vary not only from crop to crop and between different varieties of the same crop but also between different dates of sowing/establishment of the same variety. Thus, crop drought asssessments based only on meteorological considerations would be comparative ones, both in time and space. Use of rainfall budgeting techniques based on monthly periods are of value for comparative studies on incidence of crop drought in the rainy season. However, studies using long term averages of monthly precipitation are of little value since they do not give the frequencies of occurrence of different types of situations in a month.

2. Methodology

In light of the above, an empirical method to assess the incidence and intensisty of crop droughts was evolved and applied to Disa (Gujarat). The method essentially consists of assessing the sufficiency of rainfall to meet the crop water needs of a fully established, active crop and using that information to assess rainfall adequacy for crop establishment and maturity. The rationale behind and the details of the method are presented in the following paras.

2.1. *The potential moisture need* — The water lost as evaporation from soil surface and transpiration by plants from a ground shading, short crop when soil moisture is not limiting and large scale advection effects are not present, is termed potential evapotranspiration (PET). During the kharif season, PET is of the order of 4-5 mm over the country (Rao *et al.* 1971 a & b, Venkataraman and Krishnamurthy 1973). In view of the small inter-annual variation, use of a single mean monthly value of PET is justifiable. Since the evaporation component constitutes a small fixed fraction of PET the potential transpiration need (PT) would be smaller than PET. Experimental evidence (Ritchie and Burnett 1971, Venkataraman *et al.* 1976, 1977) shows that PT would be nearly equal to 80 per cent of PET.

2.2. *Potential moisture availability* — Only that fraction of rainfall not lost as evaporation or held in surface zone of evaporative desiccation should be considered as available for transpiration. This amount which may be termed 'Effective Rainfall' (ERR) would have a maximum of limit equal to the root zone moisture storage called the 'Root Constant'. The latter is a function of crop type and is easy of determination. Regarding the ease of availability of root zone moisture, a review of the literature (Fleming 1964, Baier 1967) shows that the extraction of water from plant roots becomes increasingly difficult with an increase in evaporative power of the air and clay content of the soil. A plausible extraction model covering different soils and evaporation regimes is shown in Fig. 1. The maximum amounts per filling of the root zone capacity S which an active ground shading crop can transpire (T) in a month under different conditions of PT, root constants and soil types, could, *a priori*, be formulated as set out in Table 1. The implication of Table 1 is that ERR must exceed the root zone capacity if the transpiration need is to be fully met in the kharif season.

2.3. *The transpiration index* — The moisture provisioning for transpiration during a month of a dry land crop can arise from 3 sources, *viz.*, (*i*) moisture available at the beginning of month as

TABLE 1

Transpiration amounts (mm) per month for one fillings of root zone under various storage capacities, potential transpiration rates and soil conditions

Potential transpiration (mm/day)	Soil type	Storage capacity (mm) 100	150	200	250	300	Remarks
2	Fine & heavy	60 (1·0)	60 (1·0)	60 (1·0)	60 (1·0)	60 (1·0)	Transpiration (T) at potential rate in available range in fine soils. T at potential rate upto 75% in available range and at 50% the potential thereafter in heavy soils.
3	Fine	90 (1·0)	90 (1·0)	90 (1·0)	90 (1·0)	90 (1·0)	
	Heavy	83 (0·9)	90 (1·0)	90 (1·0)	90 (1·0)	90 (1·0)	
4	Fine	98 (0·8)	115 (0·96)	120 (1·0)	120 (1·0)	120 (1·0)	T at potential rate upto 75% in available range and at 50% the potential thereafter in fine soils.
	Heavy	85 (0·7)	98 (0·8)	110 (0·9)	120 (1·0)	120 (1·0)	
5	Fine	100 (0·66)	132 (0·9)	150 (1·0)	150 (1·0)	150 (1·0)	T at potential rate upto 50% in the available range and at 50% the potential afterwards in heavy soils.
	Heavy	100 (0·66)	113 (0·75)	125 (0·8)	137 (0·9)	150 (1·0)	
6	Fine & heavy	100 (0·6)	128 (0·7)	140 (0·8)	152 (0·9)	165 (0·97)	T at potential rate upto 50% in the available range and at 50% the potential rate thereafter in both fine and heavy soils.
7	Fine & heavy	100 (0·5)	142 (0·68)	154 (0·73)	167 (0·8)	181 (0·86)	
8	Fine & heavy	100 (0·4)	150 (0·63)	170 (0·7)	183 (0·76)	194 (0·8)	

NOTE — Figures in brackets indicate the fraction of potential transpiration need that is met.

carry over of rainfall from previous month, (*ii*) recharge of root zone moisture from current month's rainfall and (*iii*) augmentation of transpiration loss from root zone storage by rainfall of current month. The ratio of actual amount of water transpired (AT) to PT may be termed as the 'Transpiration Index'. The transpiration index would be a rational measure of crop water stress.

3. Assessment of transpiration index

In light of the previous paragraphs, the assessment of the transpiration index, for a ground shading, rainfed crop growing under a PET of x mm per day and having a moisture capacity of y mm for evapotranspiration (ET), was done by budgeting the monthly rainfall for evaporative depletion, transpiratory consumption, soil moisture storage and carry over as detailed below:

3.1. *Evaporative depletion of rainfall* — Out of the total of y mm available for ET, the amount held in the surface layer of evaporative desiccation is not available for crop use. This irrespective of soil type is held to be conservative and about 18 mm per one wetting of the evaporative soil zone to field capacity (Staple and Lehane 1944, 1952). In practice the evaporative zone would be wetted more than once. However, the potential evaporation at the soil surface (PS) of a ground covering crop would be as pointed out earlier, 1/5 of PET. Therefore, in a month evaporative depletion would be $6x$ mm. As PET in the rainy season is of the order of 5 mm, out of the total monthly rainfall (P), the amount available for soil moisture recharge was taken as $P - 6x$ and designated as R.

3.2. *Transpiration need* — As evaporation accounts for 20% of PET the monthly potential transpiration (PT) was taken as $24x$ mm per month.

3.3. *Transpiratory consumption* — The moisture capacity for transpiration S was taken as equal to $y - 20$ mm. Corresponding to a PE of $4/5x$ mm per day and moisture capacity of $y - 20$ mm, the transpiration amount was found from Table 1 and was designated as T. When R is less than S, the amount of transpiratory consumption from current month's rainfall was taken as the lesser of the quantities R and T and was designated as A.

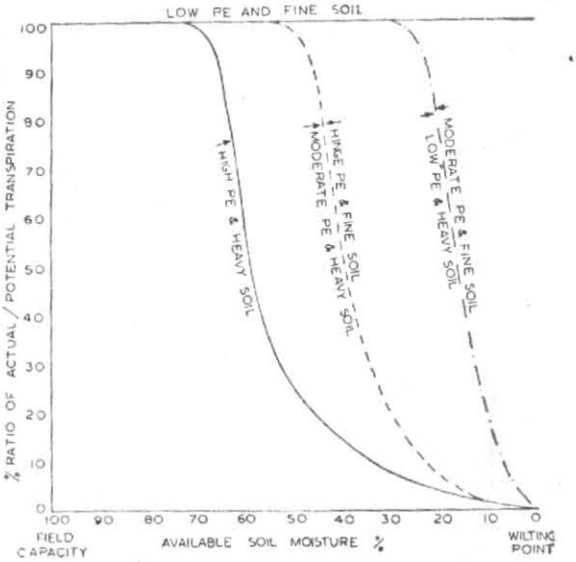

Fig. 1

3.3.1. *Moisture replenishment* — When R is greater than S, there will be additional quantity equal to $R-S$ available for transpiration. This was designated as B and transpiratory consumption was taken as $A+B$ or $24x$ whichever is lower.

3.3.2. *Moisture carry over* — Additional water can be transpired by the crop if there is a carry over of moisture C from the preceding month. Carry over can occur if $A+C$ or $A+B+C$ exceeds PT, *viz.*, 24 x and will be equal to the difference D or S whichever is lower. For the first month in which $R > 24\ x$, C was taken as 0. For subsequent months C was taken as equal to D of the preceding month as computed above.

3.4. *The transpiration index* — In the above computation the quantity K, equal to $(A+C)/24x$ or $(A+B+C)/24\ x$, as the case may be, gives subject to a maximum value of 1.0, a measure of the crop moisture stress for a fully established crop.

3.4.1. A sample computation relating to the derivation of K from basic data of P, PT and moisture storage is shown in Appendix.

4. Severity of moisture stress

4.1. *For ground shading vegetative crop phase* — A reference to Table 1 at this stage shows that when the value of K is less than 0.66 the moisture is likely to be below permanent wilting point. On this basis the following criteria was stipulated regarding the degree of moisture stress:

$K=$ 0·95 or above	No stress
$K=$ 0·85 to 0·94	Slight stress
$K=$ 0·75 to 0·84	Moderate stress
$K=$ 0·65 to 0·74	Severe stress
$K=$ 0·5 to 0·64	Very severe stress
$K=$ Less than 0·5	Death

4.2. *During maturity* — The quantum of soil moisture storage from rainfall in this period will not be significantly different from that of an established, active crop. Dry land crops can mature in a month. Most of the crops tend to dry up during maturity and would be consuming about 1/5 of the PT loss at the end of the maturity period. Therefore, the average consumption during the period of maturity will be equal to 0.6 times PT. Therefore, K values ranging from 0.5 to 0.6 are required for maturing a crop without moisture stress in a month.

4.3. *During establishment*—The transpiration needs of a crop from the period between germination and the stage when it could transpire at the potential rate would be opposite to that of the maturity phase. Hence the potential transpiration would be 0.6 times PT for the period under consideration. However, during this period, which is of the order of a month, the amount of effective rainfall will be smaller compared to that for a full grown crop because of additional evaporative depletion. Assuming that the evaporative descication layer only needs to be filled once a week in this period before storage occurs in the lower layers, the extra evaporative depletion will be equal to 40 mm or $8x$ mm.

The average transpiration need in this period is 0.4 x mm/day and total will be 12 x mm. Thus the total need of effective rainfall for optimum transpiration is $8\ x + 12\ x = 20\ x$. Since the effective rainfall for optimum transpiration of a full grown crop is 24 x, a value of $K = 0.8$ should be suitable for maintaining optimum growth in the intermediary period.

If one allows for transpiration loss that can maintain the moisture reserve above the wilting point at 1/2 the potential need the requirement will be $8\ x + 6\ x = 14\ x$. As $K = 24\ x$, K values of less than 0.6 are not suitable for ensuring survival at this stage of the crop.

4.4. *Allowance for sowing requirement* — With a PE of 5 mm which normally prevails at the sowing time an amount of 25 mm of soil moisture in the layers immediately below the zone of evaporative dessication would be required to ensure tillage. This is equivalent to an increase in the K value by 0.2.

5. Postulation of a moisture stress model

In the light of the above discussion, the K value requirements for normal growth and survival of a dryland crop at Disa, in which the SW monsoon season is the rainy period, were taken as follows:

	Sowing-cum-intermediate growth period	Potential transpiation stage		Maturity period
	(Jun-Jul)	Aug	Sep	(October)
Normal growth	1·0	1·0	1·0	0·6
Survival	0·6	0·5	0·5	0·4

6. A case study for Disa (Gujarat)

6.1. *Analysis* – Using the approach outlined above it was decided to study the occurrence of different

TABLE 2

Intra-seasonal distribution of K values and the class of crop drought experienced at Disa (Gujarat)

Year	Jun	Jul	Aug	Sep	Oct	Class of drought
1901	0	0·2	0·8	0	0	S
1902	0	0	0·7	1·0	0·10	MS
1903	0	1·0	1·0	0·8		M
1904	0	0·63	0	0	0	VS
1905	0	1·0	0·83	0·11	0	MS
1906	0·1	0·8	0·9	0·9	0·3	VL
1907	0	0·83	1·0	0·83	0	L
1908	0	1·0	1·0	0·83	0	L
1909	0	1·0	1·0	1·0	0·63	O
1910	1·0	1·0	1·0	0·7	0	L
1911	0·3	0	0	0	0	VS
1912	0·15	1·0	1·0	1·0	0·25	VL
1913	1·0	1·0	1·0	1·0	0	L
1914	0·36	1·0	1·0	1·0	0·2	VL
1915	0	0·4	0	0	0·18	VS
1916	0·25	0	1·0	1·0	0·63	M
1917	0·3	1·0	1·0	1·0	1·0	O
1918	0·2	0	1·0	1·0	0·83	M
1919	0·1	1·0	1·0	0·92	0	L
1920	0·9	0·84	0·23	0	0	MS
1921	0	1·0	1·0	1·0	0·83	O
1922	0	0·9	1·0	1·0	0·83	O
1923	0	0·57	0·25	0	0	S
1924	0	1·0	1·0	1·0	0·83	O
1925	0	0·76	0·10	0	0	S
1926	0	1·0	1·0	1·0	0·83	O
1927	0	1·0	1·0	0·9	0	L
1928	0	1·0	1·0	0·1	0	MS
1929	0·2	1·0	1·0	0·1	0	MS
1930	0·1	0·9	0·2	0	0	S
1931	0	0·15	1·0	0·85	0	MS
1932	0	1·0	1·0	0·5	0	M
1933	0	1·0	1·0	1·0	0·25	VL
1934	0·8	1·0	1·0	0·83	0	VL
1935	0	1·0	0·96	0	0	MS
1936	0·1	0·4	0	1·0	0	S
1937	0·7	1·0	0·83	1·0	0·8	O
1938	0·3	1·0	1·0	0·8	0	L
1939	0	0·1	1·0	0·3	0	VS
1940	0·65	0·7	0·83	0	0	MS
1941	0	1·0	1·0	0·83	0	L
1942	0·5	0·94	1·0	0	0	MS
1943	0·5	1·0	1·0	0·25	0	M
1944	0·15	1·0	1·0	0·83	0	L
1945 to 1947	No data					
1948	0	1·0	0·15	0	0	S
1949	0	0·73	1·0	0·4	0	MS
1950	0	1·0	1·0	1·0	0·5	O
1951	0	0·9	0·7	0	0	MS
1952	0·15	1·0	1·0	0·54	0	M
1953	0·5	0·5	1·0	0·83	0	L
1954	0·2	1·0	1·0	1·0	0·83	O
1955	0	0	1·0	1·0	0·75	M
1956	0·7	1·0	1·0	0·8	0·1	VL
1957	0·6	0·5	1·0	0·1	0	MS
1958	0	0·9	0·14	0·7	0·3	MS
1959	0	1·0	1·0	1·0	0·83	O
1960	0	1·0	0·53	0	0	S
1961	0·37	1·0	0·9	1·0	0·83	O
1962	0	0·4	0·7	0·25	0	S
1963	0	0·64	1·0	1·0	0·6	L
1964	0	1·0	1·0	0·65	0	M
1965	0	1·0	1·0	0·2	0	S
1966	0	0·82	0	1·0	0·83	M
1967	0·3	1·0	1·0	1·0	0·30	O
1968	0	1·0	1·0	0·13	0	MS
1969	0	1·0	0·4	0	0	S
1970	0·3	0·5	1·0	1·0	0·3	L

classes of drought that would have been experienced under a PET of 5 mm/day during the crop season at Disa (Gujarat) by a 4 month crop sown in late June/early July and maturing in October end. For this the monthly totals of rainfall for the months June-October for all available years in the period 1901-1970 were taken. In computing the K values maximum soil moisture storage was allowed for at 10 cm and maximum transpiration for one filling of root zone was taken as 85 mm by reference to Table 1. It needs to be mentioned here that temporal variations in rainfall in the above months might necessitate shifts in the crop phases but the rainfall influence as determined by calendar months will substantially remain the same. This is because of the near identical K requirements in the first 3 months.

6.2. *Results and discussion* — The monthly K values in the period June-October for the years 1901 to 1970 thus computed are presented yearwise in Table 2. From the intra-seasonal march of K values, an assessment of the severity of crop drought was made and the year placed in one of the 7 categories, *viz.*, no drought (O), very light drought (VL), light drought (L), moderate drought (M), moderately severe drought (MS), severe drought (S) and very severe drought (VS). The years and frequency of occurrence of the above classes of drought are presented in Table 3. The greater occurrence of light to nil droughts in comparison to the frequency of severe drought is quite reassuring. The greater occurrence of moderately severe droughts than the moderate ones call for use of shorter duration varieties, possessing resistance to atmospheric drought, especially in years of late starting of the crop season. It is also seen that incidence of either severe or very severe drought is likely once in about 12 years. However, the years in between would not be necessarily free of severe droughts.

TABLE 3

Occurrence of crop drought of various classes at Disa (Gujarat) in the period 1901-1970

	No drought	Light	Very light	Moderate	Moderately severe	Severe	Very severe
	1909	1907	1906	1903	1902	1901	1904
	1917	1908	1912	1916	1905	1936	1911
	1921	1910	1914	1918	1920	1948	1915
	1922	1913	1933	1932	1928	1960	1923
	1924	1919	1934	1943	1929	1962	1925
	1926	1927	1956	1952	1931	1965	1930
	1937	1938		1955	1935	1969	1939
	1950	1941		1964	1940		
	1954	1944		1966	1942		
	1959	1953			1949		
	1961	1963			1951		
	1967	1970			1957		
					1858		
					1968		
Total No. of years	12	12	6	9	14	7	7
Percentage	18	18	9	13	21	10.5	10.5

TABLE 4

Yearwise yield of grain jowar in Banaskantha district in Gujarat (1949-63)

Year	Yield (lb/acre)	Yield as percentage of mean for the period	Yield as percentage of normal year yield taken as 250 lb/acre	Drought classification
1949	162	73	65	MS
1950	231	104	92	O
1951	238	108	95	MS
1952	243	110	97	M
1953	248	112	100	L
1954	240	109	96	O
1955	153	69	61	M
1956	314	142	120	VL
1957	147	67	60	MS
1958	201	91	80	MS
1959	142	64	73	O
1960	123	56	50	S
1961	254	115	100	O
1962	418	189	160	S
1963	206	93	82	L

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APPENDIX

Computation of transpiration index K

Crop state = Ground shading, vegetative. PET = 5 mm/day, Root constant value = 100 mm, Max. transpiration per filling of root zone = 85 mm *vide* Table 1, PT = 120 mm

	Jun	Jul	Aug	Sep	Oct	Nov	Jun	Jul	Aug	Sep	Oct	Nov
	Year 1902						Year 1909					
P (mm)	17	24	126	174	0	0	26	210	328	141	1	0
R (mm)	0	0	96	144	0	0	0	180	298	111	0	0
A (mm)	0	0.	85	85	0	0	0	85	85	85	0	0
B (mm)	0	0	0	44	0	0	0	80	198	11	0	0
C (mm)	0	0	0	0	9	0	0	0	45	100	76	0
D (mm)	0	0	0	9	0	0	0	45	100	76	0	0
K	0	0	0·7	1·0	0·10	0	0	1·0	1·0	1·0	0·63	0·0

$$K = (A+B+C)/120 \leq 1 \cdot 0$$