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Assessment of atmospheric drought during monsoon cropping season

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सार — भारत के अर्ध शुष्क पर्यावरण में दक्षिणपश्चिम मानसून के अंतराल की अवधियों में वर्षा-पुष्ट के साथ-साथ सिंचाई-पुष्ट फसलें भी वायुमंडलीय सूखे से प्रभावित होती हैं। वायुमंडलीय सूखा मृदा या कृषि सूखे से भिन्न होता है । फसल की बढ़वार के विभिन्न चरणों में एक या दो सप्ताह के लिए उत्पन्न वायुमंडलीय सूखे की स्थिति मृदा-जल संतुलन में प्रकट नहीं हो पाती, किन्तु इसका प्रभाव फसल की बढ़वार की दरों और उपज पर स्पष्ट दिखाई पड़ता है । वाष्पन पृष्ठों से 4 से 5 कि० मी० प्रति दिन तक अभिवहन द्वारा प्राप्त उर्जा के परिणाम स्वरूप विभव वाष्पोत्सर्जन की दरों में 2 से 3 मि० मी० प्रति दिन तक वृद्धि होने के प्रमाण मौजूद हैं। इस अवस्था को दीर्घ मापक्रम पर अंतराल के दौरान पश्चिमी हवाओं में और स्थानीय पैमाने पर मानसूनोत्तर अवधि में परिवेश की कुछ माता की गर्मी में देखा जा सकता है । ऊपर बताई सीमाओं में मृदा बजट के अलावा अभी तक ऐसी कोई विधि नहीं है जिससे यह बताया जा सके कि फसल की बढ़वार के विभिन्न चरणों के विभिन्न बंटनों में सीजन की कुल वर्षा के वैविध्य के परिणाम स्वरूप उत्पन्न वायुमंडलीय सूखों के वर्षों को अलग अलग पहचान कर वर्गीकृत किया जा सके ।

यह शोधपत्र इस पहलू पर ध्यान केन्द्रित करते हुए, वायुमंडलीय सूखे के अनुमान के लिए शुष्क दिनों की शृंखला के आधार पर विकसित एक अनुभाविक तकनीक की भी व्याख्या करता है ।

ABSTRACT. During break periods in the southwest monsoon season in the semi-arid environment of India, crops under rainfed as well as irrigated conditions are prone to the effect of "atmospheric drought" as distinguished from 'soil' or "agricultural drought". This situation occurring at different stages of crop growth for a week or two is not reflected in the soil water balance, but is revealed in the crop growth rates and yields.

Evidence exists of energy gain through advection by evaporating surfaces of the order of 4 to 5 mm/day resulting in an increase in potential evapotranspiration rates by 2-3 mm/day. This situation can be traced on a macroscale to the westerlies during the 'break periods' and on a local scale to the post monsoon warming of surroundings with a reduced intensity. As yet, apart from the soil budgeting approach with the limitation mentioned above, there appears to be no method by which years with widely varying amounts of total seasonal rainfall but with different distribution patterns in the different growth stages resulting in atmospheric drought could be distinguished from one another or grouped together.

This paper while focussing the attention to this aspect illustrates an empirical technique based on sequential dry days for assessment of atmospheric drought.

1. Introduction

Drought has been defined in several ways and a number of methods have been devised in the past to evaluate it. It is common observation in the subtropics that even with the recommended agronomic practices, crop yields show year to year variation. Generally these variations are attributed to the 'prevailing climatic conditions' or to the 'erratic rainfall distribution'. In this paper some of these aspects are discussed in relation to monsoon rainfall distribution during the kharif cropping season in the Delhi region, and an empirical method for assessment of atmospheric drought is described.

2. Statement of the problem

As to the prevailing climate, 'break monsoon' situations occurring in certain years and persisting for 2 to 3 weeks is an important feature of the southwest monsoon season. Very little rainfall is received during such periods in the semi-arid tracts of the country. Once a dry spell sets in, the temperature, evaporation,

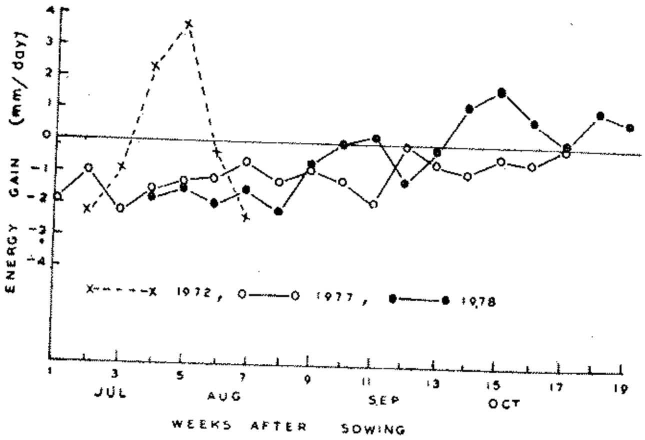

Fig. 1. Energy gain by pan evaporimeter under advective (1972, 1978) and non-advective (1977) conditions

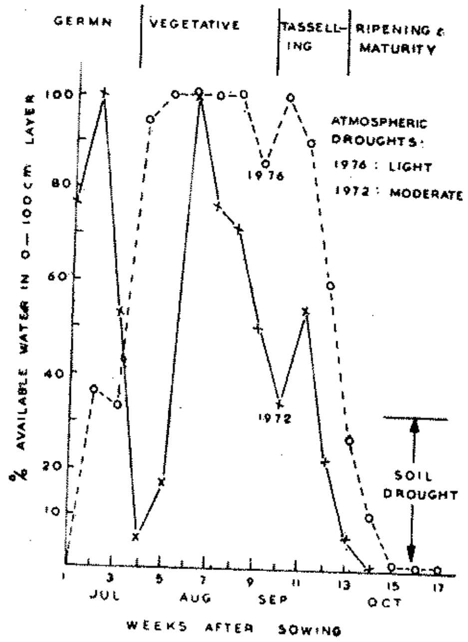

Fig. 2. Atmospheric drought and available water in soil

duration of bright sunshine increase. It can be said that temperatures, transpirational and respiratory losses from the crops are mainly controlled by the degree of activity of the monsoon. This is directly reflected in the amount and frequency of rainfall received during this season or by the absence of it. Thus analysis of rainfall distribution in relation to transpirational losses is an important factor in assessment of drought during this season.

During the 'break monsoon' conditions, it has been observed that the evaporating surfaces come under the influence of advective conditions (Sastry 1979). Energy gain by an evaporating surface during three monsoons representing (a) advective conditions (macroscale) during the mid-monsoon season (1972) governed by upper air circulation creating break monsoon features, (b) advective conditions of local origin under the influence of post monsoon warming due to early withdrawal of monsoon (1978) and (c) a normal season (1977) are shown in Fig. 1. During the break monsoon periods the evapotranspiration rates increase above the normal value by 4 to 5 mm/day and under post monsoon advective conditions by 1-2 mm/day. These conditions occur at different stages of crop growth in different years and in any analysis of atmospheric drought it is necessary to give weightage to this factor even if the crop is irrigated.

Determination of how erratic or how favourable a rainfall distribution is, in a certain year, is a formidable task. Firstly, rainfall distribution even if it could be quantified by any means, favourable to one crop or variety may not be favourable to the other; even for the same crop in any particular year, it is closely linked with the date of sowing. Hence, any analysis for determining the rainfall distribution type must necessarily be related to the duration of crop phenological events and cannot be generalised for all crops. Secondly, in many parts of the country the coefficient of variability of weekly rainfall is known to lie between 80 & 180 per cent (Sastry 1979) rendering any generalizations on probabilistic models or other statistical analysis of limited practical use, as these often fail to represent situations obtaining in most of the individual years.

It is often quoted that determination of soil water balance is a solution to find out how erratic or how favourable a rainfall distribution is with respect to a particular crop. Though this partly meets the requirement where soil water balance is derived from elaborate field experiments, this by itself seems insufficient to assess the temporal variability observed in yields even under irrigated conditions. Environmental stress on crop growth and development due to consecutive rainless days such as those encountered during the break monsoon periods does not always appear to be reflected in soil water balance values. To account for this, it is necessary to supplement information on soil water balance with an assessment of atmospheric drought in relation to crop developmental phases. Apart from the soil water budgeting approach with the limitation mentioned above, as yet no method appears to have been evolved by which favourable or unfavourable rainfall distributions could be 'typed' and grouped together in relation to atmospheric stress on crop developmental stages.

3. Materials and methods

Daily rainfall data collected at the farm observatory of the Indian Agricultural Research Institute, New Delhi (Lat. 28° 35′ N, Long. 77° 12′ E) for the period 1940 to 1980 have been used in the present study.

3.8. *Dry days and dry weeks*

To determine atmospheric drought, a 'dry day' has been defined. In the Delhi region the average potential evapotranspiration as well as the mesh covered pan evaporation rates during the kharif season are about 5 mm/day. Previous studies (Sastry 1979) showed that in relatively dry years, soil moisture in the 0-60 cm layer gets depleted at 6 mm/day during this season. Considering these factors, a day with rainfall less than 6 mm/24 hours has been defined as a 'dry day'.

It is well recognized that continuous periods of atmospheric stress are more detrimental to crop growth rather than intermittent dry periods (van Bavel 1953). For the Delhi region, frequencies of dry spells using 4 and 7 continuous dry days in a week as criteria revealed that 4-day dry spells are more frequent (Sastry 1976). A 4-day spell is to be considered as a normal feature of the region and is not suitable to evaluate weekly drought patterns. Therefore for evaluating the frequency of dry weeks in each crop phase, a week with 7 sequential dry days is proposed as a characteristic of a 'dry week' for this region.

The kharif season in the Delhi region starts from 1st week of July and the rains normally cease by the 3rd week of September. The present analysis covers 17 weeks starting from 1 July, the 17th week ending on 27 October corresponding with the normal cropping season of corn. The various crop phases and their duration starting from 1 July are broadly divided as follows :

Phase No.	*Description of phase*	*Duration*	*Criterion for defining drought in terms of dry weeks*
I	Sowing and germination	2 weeks (1 & 2)	****
II	Vegetative	7 weeks (3 - 9)	⩾ 4 weeks dry
III	Tasselling	3 weeks (10 - 12)	⩾ 2 weeks
IV	Grain filling and maturity	5 weeks (13 - 17)	⩾ 4 weeks
V@	Sowing to harvest	17 weeks (1 - 17)	⩾ 10 weeks

****This phase has not been considered for analysis since sowing is done after the first few showers are actually received and the top layers of the soil get moist.

@ For convenience of analysis this is named as phase V and represents the overall effect of meteorological conditions on crop growth during the whole cropping season.

Following the criteria shown above the total number of phases affected by atmospheric drought in each year have been worked out.

3.2. *Severity of atmospheric drought*

Drought severity has been classified (phases ii-v only) as follows :

Four phases — Disastrous	One phase — light
Three phases — Severe	
Two phases — Moderate	None of the phases — unaffected

The years are grouped under different degrees of drought severity and then ranked within each group in order of increasing magnitude of seasonal rainfall received from July to October in the different years to give weightage to the seasonal rainfall in the assessment of atmospheric drought within each category.

TABLE 1

Classification of atmospheric drought (based on rainfall data for the period 1940-1980)

Dominance of dry period in phase	Year	July-October rainfall (mm)	Drought class
Four phases	1941	142.1	Disastrous
	1951	214.3	
Three phases	1943	358.0	
	1940	526.9	
	1968	530.5	Severe
	1944	579.7	
	1954	657.0	
Two phases	1979	262.2	
	1946	321.4	
	1952	359.7	
	1953	410.8	
	1965	472.4	Moderate
	1974	486.1	
	1970	584.5	
	1972	639.1	
	1980	714.4	
	1978	911.2	
One phase	1966	421.6	
	1973	462.5	
	1942	522.4	
	1959	527.2	
	1948	527.8	
	1949	548.9	
	1957	570.1	
	1963	592.3	
	1945	613.6	
	1956	640.4	Light
	1950	641.1	
	1962	663.2	
	1956	695.9	
	1969	705.3	
	1960	717.1	
	1976	869.4	
	1971	929.7	
	1967	983.5	
	1977	1101.5	
	1964	1126.5	
None of the phases	1947	511.5	
	1958	900.5	Unaffected
	1961	924.6	
	1975	1068.4	

TABLE 2

Frequency of drought intensity in the Delhi region (based on data for the period 1940-1980)

	Frequency in 41 years			
	Disastrous	Severe	Moderate	Light/no drought
Atmospheric drought	2	5	9	25
Soil drought	6	5	10	20
Range of total seasonal rainfall (mm)	142-214	358-657	262-911	422-1126

(Normal seasonal rainfall : 597 mm)

TABLE 3

Drought frequency during crop phases of corn (based on data for the period 1940-1980)

	Frequency in 41 years	
	Tasselling phase	Seasonal value
Atmospheric drought	21 (51%)	8 (20%)
Soil drought	15 (37%)	14 (34%)
Soil and atmospheric droughts in the same year	12 (29%)	6 (15%)

3.3. *Soil drought*

Weekly soil water balance for the period 1940 to 1980 has been worked out following Slatyer's step-function approach (Mc Alpine 1970) and per cent available water in the root zone in each week has been computed. If in any week the estimated available water remained below 33 per cent and if this has prevailed for more than half the duration of the crop phase, that particular phase is considered to have been affected by soil drought. Based on this, frequencies of occurrence of soil drought in each of the crop phases have been worked out for determining soil drought severity and classified, as in the case of atmospheric drought.

4. Results and discussion

4.1. *Atmospheric drought*

A tentative classification of drought severity with the years of their occurrence based on the method described above is shown in Table 1. The results reveal that disastrous drought conditions prevailed in the years 1941 and 1951 both due to meagre rainfall received during the season and also due to its uneven distribution. The results also bring about the significance of consideration of rainfall distribution in relation to crop phases. For example, the years 1954 and 1962 with 65.7 cm and 66.3 cm of seasonal rainfall are classified as being affected by 'severe' and 'light' drought respectively. Soil moisture distribution for these years also confirmed this classification.

4.2. *Frequency of atmospheric and soil drought intensities*

Frequency of intensity of soil and atmospheric droughts along with the range of seasonal rainfall in each class are shown in Table 2. Severe to moderate atmospheric and soil drought conditions are observed on equal number of occasions. Light/no drought conditions together account for 50 to 60 per cent of the time. However, the range of rainfall within which the different classes of drought occur is of significance. Recent irrigation experiments gave 42 cm as the consumptive use of water by corn crop for the Delhi region (Dastane *et al.* 1970). The minimum rainfall for light or no drought conditions as obtained in this analysis is 42 cm and this amount well-distributed over the cropping season appears to ensure optimum atmospheric and soil moisture conditions for corn crop in the region.

4.3. *Atmospheric and soil drought in crop phases*

Tasselling phase is considered to be moisture sensitive for corn crop. For comparing soil and atmospheric droughts independently as well as their simultaneous occurrence in the tasselling phase with that of the whole cropping season, their frequencies of occurrence are shown in Table 3. During the tasselling period, atmospheric drought is more frequent (51%) than the occurrence of soil drought. This shows that in general, the soil gets sufficiently recharged by the time the crop reaches tasselling stage in spite of frequent atmospheric drought. Rainfall distribution is more erratic than soil moisture distribution at this time as this phase coincides with the withdrawal of southwest monsoon rains in certain years. However, when the whole season is considered as a single unit (phase V) soil drought appears to be more predominant than atmospheric drought. This is attributable to inactive monsoon conditions during the vegetative and post tasselling phases in a number of years revealing the effect of temporal variability of rainfall on soil drought, though atmospheric drought is less severe.

4.4. *Atmospheric drought and available soil water*

Typical available water distribution patterns during the kharif cropping season illustrative of rapid moisture depletion due to advective conditions during the monsoon break periods in the vegetative phase (1972) and in a normal year (1976) are shown in Fig. 2. Both the years received above-normal seasonal rainfall but during 1972, atmospheric drought prevailed for 8 out of 12 weeks upto tasselling stage, whereas in 1976, it was absent. In such a year as 1972 an early withdrawal of monsoon would have lead to a disastrous drought.

5. Conclusion

The results presented above point out to the desirability of evaluation of atmospheric drought in the different phases of crop growth. The inputs used for this analysis are rainfall and potential evapotranspiration and information on crop phenology. The procedure outlined above for assessment of atmospheric drought is not claimed to be exhaustive or without limitations, but may be considered as a preliminary approach in utilizing simple criteria in relation to crop phenology to obtain specific information affecting crop growth and development in the different phases. By choosing suitable threshold values for rainfall and its duration as used here in defining a dry day, this procedure can be extended to obtain frequencies of consecutive water logging days, periods of consecutive high evaporation rates, run of etc, in relation to crop developmental phases and crop tolerance limits. Further efforts need also to be directed towards development of "rainfall equivalents" based on integrated experimental determinations on soil moisture depletion patterns, rainfall intensity, consecutive dry and wet spells, cumulative rainfall in relation to crop phases and crop water requirements and soil characteristics to enable a quicker assessment of the effect of rainfall distribution on crop growth.

References

Dastane, N.G., Singh, Mahendra, Hukkeri, S.B. and Vamadevan, V.K., 1970, *Review of work done on water requirement of crops in India,* Navbharat Prakashan, Poona.

McAlpine, J.R., 1970, Estimating pasture growth periods and droughts from simple water balance models, Proc. XI Intl. Grasslands Congress, Australia, 1970.

Sastry, P.S.N., 1976, Climate and crop planning with particular reference to rainfall. In : *Climate and Rice,* Intl., Rice Res. Instt. Philippines, 1974, pp. 51-63.

Sastry, P.S. N. and Chakravarty, N. V. K., 1976, Effects of advective conditions on evaporation rates in the Delhi region, *Hydrology Review,* **2** (4), 40-42.

Sastry, P. S. N., 1979, Evaporation and water balance in a semi-arid monsoonal climate under advective conditions. In : *Improving Crop and Animal Productivity.* Proc. Intl. Symp. Oxford & I. B. H. Publ., Co., New Delhi, pp. 316-321.

van Bavel, C. H. M., 1953, A drought criterion and its appplication in evaluating drought incidence and hazard, *Agron. J.*, **45**, 167-172.