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DROUGHT ANALYSIS USING SOIL MOISTURE STATUS

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ABSTRACT

The drought situation can be described by a selected set of variables depending upon the particular water user or interest. For agricultural drought particularly the soil moisture status in the root zone can be the best indicator of the drought conditions. A number of drought definitions have been given, however, an operational definition of drought (particularly agricultural drought) could best be the one that compares daily rainfall values to evapotransipiration rates to determine rate of soil moisture depletion to give upto date status of available soil moisture. An attempt has been made in the present paper to analyse the drought severity levels based on soil moisture status in the root zone and sensitivity of crop growth stages to soil moisture stress. Utility of soil moisture models for carrying out such analysis has been indicated. Soil moisture data as recorded for Bajra (Pearl millet) crop has been used to indicate utility of soil moisture approach for drought analysis.

1.0 INTRODUCTION

The variability of meteorological, hydrological and agro-climatological conditions over space and time have created a situation that nearly one third of the geographical area and 29% population of the country are affected by drought. The occurrence of drought leads to depletion of soil moisture, reduction in stream flow and consequent reservoir and tank levels and depletion of groundwater. It also affects the water quality adversely.

Drought starts slowly, has long duration, is of the creeping and pervasive nature covering vast areas. Drought is generally viewed as a sustained regionally extensive occurrence of below normal water availability. There are different types of drought i.e. meteorological, agricultural and hydrological, and all are caused due to lack of water availability. Hydrological drought which means lack of water resources, and agricultural drought, which may be defined as a time when crop growth is restricted due to lack of soil moisture do not necessarily coincide with periods of meteorological drought.

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Soil is the store house of water from where plants extracts moisture for their evapotranspirational needs. It is an established fact that the soil moisture deficit beyond a certain limit adversely affects the plant growth and causes wilting of plants. This results in declined agricultural production which can be taken as a physical measure of drought. The severity of drought can be studied by defining different levels of soil moisture deficits. Therefore, availability of soil moisture to the plants can be considered as an indicator for agricultural drought analysis.

2.0 SOIL MOISTURE AND DROUGHT CONCEPT

The soil moisture is one of the important elements of land phase of hydrologic cycle as most of the hydrological activities take place in unsaturated zone. The soil acts simply as a reservoir for the moisture from where plants extract moisture to satisfy their evapotranspirational needs. Deficiency in soil moisture adversely affects plant growth, and governs infiltration and storm runoff. The soil moisture deficit is defined as the difference between field capacity and actual soil moisture (i.e. current soil moisture). It has been well established that soil moisture deficit beyond a certain limit adversely affects plant growth and causes wilting of plants. This results in declined agricultural production which is normally taken as a measure of agricultural drought. When soil moisture falls below 'permanent wilting point', the crop will normally sustain permanent injury from which it cannot recover and their may lead to situation of severe or disastrous drought. The severity of drought can be studied by defining different levels of soil moisture deficits (Smart, 1983).

Van Bavel (1953) suggested the definition of drought on the basis of soil moisture conditions and resultant plant behaviour, rather than on some direct interpretation of the rainfall record. A drought day was defined as a 24-hour period (starting at the time of the day at which the precipitation of the previous day was recorded) in which the soil moisture stress (moisture tension plus osmotic pressure) exceed a limit which, on the basis of experimental evidence, may be taken as a point at which the productive processes of the crop are appreciably decreased. Whilhite and Glantz (1985) quoted the studies done by Kulik in 1960 which represented drought intensity as the difference between plant water demand and available soil water. It was reported that the upper 0.2 m of soil was critical to plant growth because of nutrient supplies, root activity and activities of micro-organisms. Therefore, drying of this soil layer was taken as an early indicator for loss of production, i.e. a measure of drought intensity. However, the total amount of soil moisture available to a crop depends both on the soil type and the crop as different soils have different soil moisture characteristics and different crops root to different depths.

3.0 DROUGHT ANALYSIS APPROACH

A number of soil moisture accounting models have been developed by research workers. However, these have not been used for analysing drought situations for working out management strategies. Soil moisture available for plant growth in the system at any time can be determined using the soil water balance equation as below:

$$W(t+1) = W(t) + P - R - S - AE \quad \ldots (1)$$

where,

$W(t)$ = soil moisture at the beginning of t^{th} day in mm,

$W(t+1)$ = soil moisture at the end of t^{th} day in mm,

P = precipitation during t^{th} day in mm,

R = Surface runoff during t^{th} day in mm ,

S = deep percolation below root zone in mm, and

AE = actual evapotranspiration during t^{th} day in mm

Various models use different methodologies for determining the variables used in equation (1). Once the soil moisture levels are generated using these models, these can be verified using actual field data. The depth of soil profile should be predetermined based on which drought analysis is carried out. The depth will depend upon the type of soil, crop type etc. Based on the number of days during which the soil moisture level goes below a threshold value of soil moisture the occurrence of drought days is determined. Regarding fixing up threshold value of soil moisture a number of experiments have been done for various crops. Lohani & Rahman (1985) have quoted some researchers who have found that for soybean crop the soil moisture depletion should not exceed 40% during early flowering and pod filling stages. The IAR I Monograph No.4 on 'Water Requirement & Irrigation Management of crops in India' has listed optimum soil water depletion (% of available waterholding capacity) levels for various crops in different soil types and regions. For example, for wheat crop the optimum depletion level is indicated as 40-50% in sandy loam soil (60 cm depth) at Delhi. Generally it has been observed that 50% depletion level is the optimum soil water depletion level in irrigated areas to maintain good crop yields. However, in dry lands or rainfed agriculture this criteria may not hold good to define threshold limits.

In view of this, it is proposed that following criteria may be adopted for taking various levels of soil water deficit (SWD) for taking various severity levels of drought:

if	SWD/AWC	=	0.7 to	0.8	Moderate drought
	SWD/AWC	=	0.8 to	0.9	Severe drought
	SWD/AWC	0	0.9		Disastrous drought

Based on daily observation of soil moisture in the root zone the number of drought days can be determined using above criteria. However, based on type of crop and soil type the criterion may need to be revised.

4.0 SOIL MOISTURE DEFICIT & INCIDENCE OF DROUGHT

Under the drought studies programme of the National Institute of Hydrology, attempts have been made to obtain soil moisture monitoring data for analysing drought conditions. In this connection, the analysis of soil moisture data for Bajra (Pearl millet) crop for Jodhpur has been carried out. Bajra being a drought hardly crop can tolerate the moisture stress upto 75% depletion of available soil moisture. The severity levels for defining drought conditions have been used as described in earlier section.

Field capacity and permanent wilting point of the loamy sand soils of Jodhpur are taken 135 mm & 45 mm respectively. Therefore,

Available water holding capacity (AWC) = 135 - 45 = 90 mm

Soil water deficit (SWD) = 90 x 0.7= 63 mm

SWD of 63 mm corresponds to 72 mm (say 70 mm) soil moisture content. So, 70 mm is taken as threshold value and similarly 60 mm as the level of severe drought.

The weekly variation of average soil moisture (from 4 depths) for four growing seasons i.e. 1983-86 is plotted in figure 1.0. The series is truncated at 60 mm soil moisture level to separate the time series in drought & non drought periods. The periods when soil moisture continuously runs below this truncation level, it indicates the period of drought (i.e. duration or run length). The magnitude of drought is given by the average deviation and severity by cumulative deviations. In order to quantify effect of drought, the moisture stress during vegetative and reproductive stages of crop growth has been considered and given equal weightage with some consideration to that of seedling stage. The analysis of run lengths indicates that during 1985 & 1986 there was a period of SWD of 16 & 20 days during vegetative and reproductive growth stages of crop with an average deficit of 8 & 10 mm respectively. For a small period of time (5-7 days) soil moisture remained even below severe deficit level during reproductive stage in both the years causing serious crop damages. It indicates that 1985 & 1986 were severe drought years, from the view point of soil moisture shortage is the root zone. While year 1983 was not a drought year as for almost all the time during vegetative & reproductive stage soil moisture remained above 60 mm. There was a mild drought in 1984 in which soil moisture remained below 60 mm in early vegetative and late reproductive stages for

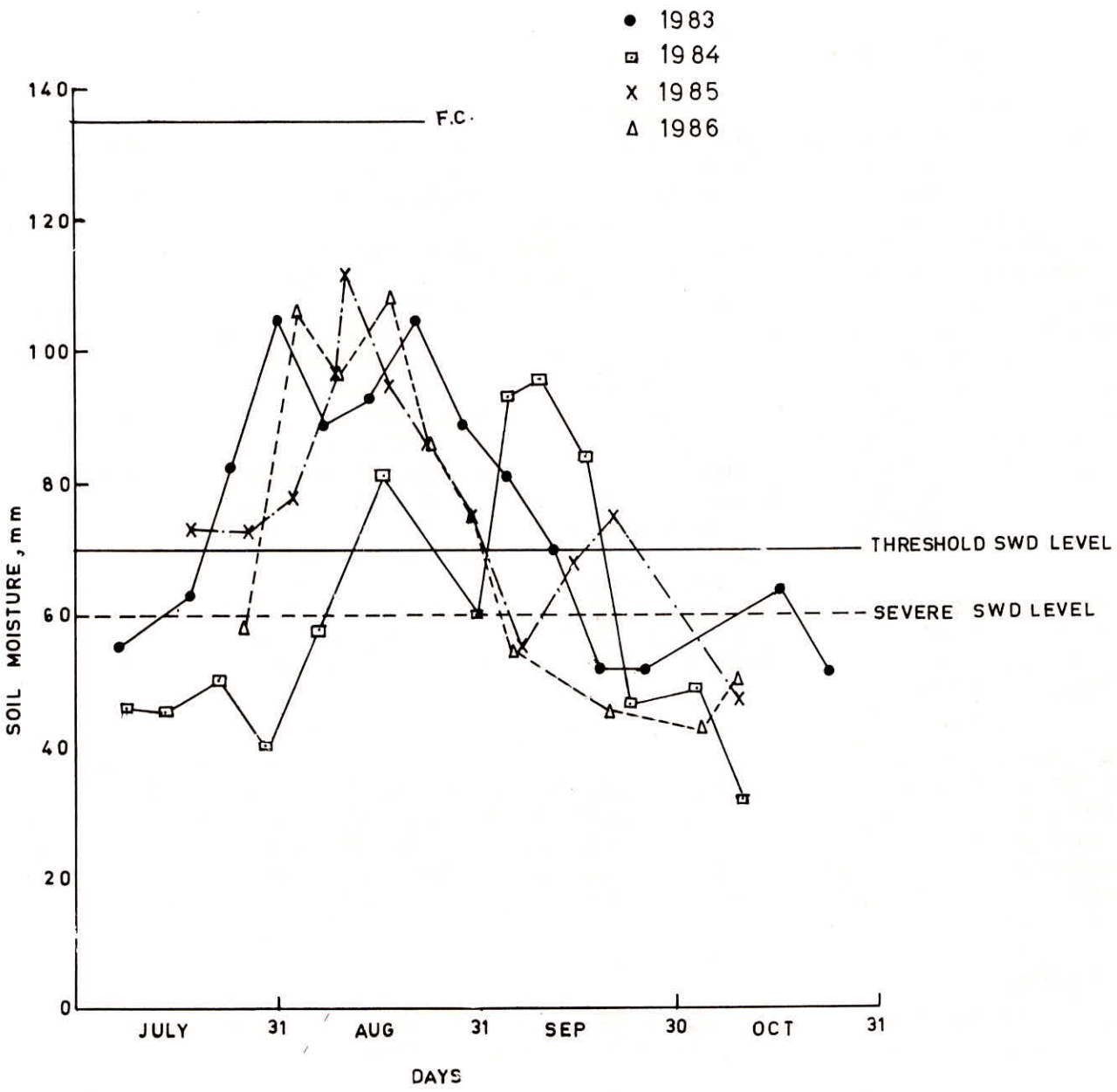

FIG. 1 – WEEKLY SOIL MOISTURE VARIATION FOR DROUGHT STUDIES

a brief period of about one week. The crop production data collected for these years also substantiate these results and confirms that 1985 & 1986 were severe drought years as the crop yield was 5.7 & 6.8 Q/ha for years 1985 and 1986, respectively as against 25 & 12.7 Q/ha reported for 1983 and 1984 respectively.

5.0 CONCLUSION

Soil water deficit which is an indicator of water availability to crop, affects agricultural production, and this can be taken as an index of drought. Using soil moisture simulation models the soil moisture levels can be predicted using inputs of rainfall and potential evapotranspiration. Based on the threshold values of soil moisture as selected for various types of crops the incidence, duration, frequency and severity of drought conditions can be evaluated. The success of this approach, however, will depend upon prediction of soil moisture levels and fixing up of threshold soil moisture values. Such values of soil moisture which will determine sensivity of various growth stages can be established after carrying out lot of experiments as these depend upon type of soil, physiographic conditions, type of crop etc. For proper calibration of soil moisture models more experimental data would be needed. Based on the simulated soil moisture levels, a series of soil moisture levels below preset drought situation level can be made and frequency distribution analysis of such series would give drought severity at various probability levels. Also the past historical data of soil moisture availability over the growing season for various soil types to determine the safe growing season, critical moisture deficit periods which will assist in planning suitable cropping pattern in drought prone areas.

An attempt has been made in the paper to indicate suitability of using the soil moisture status as one of the important indications of drought situations. The various threshold values of soil moisture availability for defining severity levels of drought have been taken based on experimental results reported by researchers. However, more detailed and comprehensive studies would be required for establishing soil moisture index as one of the prominent indices for drought prediction and management.

REFERENCES

1. IARI Monograph No.4, Water Requirement & Irrigation Management of Crops in India, IARI, WTC, New Delhi, 1977.

2. Lohani, V.K. & A. Rahman, (1985), 'A Computer Program for Irrigation Scheduling of Soyabean', Seminar on Irrigation Water Management, Jan. 12-13, 1985, Roorkee.

3. Sikka, A.K. & G.C. Mishra (1985), 'Drought Analysis Using Soil Moisture Simulation Approaches', Technical Note (TN-13), NIH, Roorkee

4. Smart, G.M. (1983), 'Drought Analysis and Soil Moisture Predictions', J. Irrig. Drainage, ASCE, 109(2), pp. 251-261.

5. Van Bavel, C.H.M. (1953), 'A Drought Criterion and its Application in Evaluating Drought Incidence and Hazard', Agronomy Jr., 45, pp. 167-172.

6. Wilhite, D.A. & M.S. Glantz (1985), 'Understanding the Drought Phenomenon; The Role of Definitions', Water International, 10, pp. 111-120.