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Effect of soil moisture stress on growth and yield of dryland sorghum

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सार -- बेल्लारी में चार वर्ष (1986-1989) के साप्ताहिक आंकड़ों के आधार पर, सिंचित और असिंचित दोनों स्थितियों में रबी ज्वार के लिए मृदा नमी संतुलन का आकलन किया गया है। नमी के मानों का प्रयोग फसल के बढ़वार के दौरान फसल पर पड़ने वाले जल के प्रतिबल के प्रभाव की अवधि को पहचानने में किया गया है। तत्पश्चात् मृदा जल की यथार्थ मात्रा और कुल उपलब्ध जल का मात्रा से उपज में हुई कमी को मूल्यांकित किया गया है और इस पर चर्चा की गई है। फसल की बढ़वार के दौरान फसल की प्रतिबल अवस्था ज्ञात करने के लिए वाष्पोत्सर्जन और विभव वाष्पोत्सर्जन का अनुपात और फसल द्वारा जल की आवश्यकता ज्ञात की गई है। फसल के जड़ क्षेत्र में आर्द्रता की उपलब्धता के साथ इस अनुपात का सम्बन्ध पाया गया है।

ABSTRACT. Based on weekly data for 4 years (1986-1989) at Bellary, soil moisture balance for rabi sorghum has been worked out for both irrigated and non-irrigated conditions. These soil moisture values have been used to identify periods of water stress which the crop experienced during the growth cycle. The extent of yield reduction due to the stress was then evaluated from the actual soil water content and total available water extent and discussed. The ratio of evapotranspiration to potential evapotranspiration and water requirement of the crop has also been worked out to assess the stress situation of the crop during its growing period. This ratio has been found to be related to moisture availability at the root zone.

Key words—Moisture stress, Evapotranspiration, Crop coefficient, Moisture availability.

1. Introduction

It is now widely recognised that the plant growth is adversely affected as soon as the soil moisture stress increases beyond a certain limit, long before the wilting point is reached. For most of the dryland crops, maximum yields are generally dependent on the soil moisture between the limits of field capacity and some critical range of soil moisture which is higher than wilting point. This critical range depends on the type of crop and its stage of development, on the soil characteristics and on the environmental conditions under which the crop is grown. Certain plants are capable of depleting water from the soil to much drier levels than the wilting point (Slatyer 1958). The moisture absorbed at levels below wilting point is not effective in maintaining vegetative growth and affects the yield and quality of the grain (Kozlowski 1964). Therefore, in considering the amount of water available to dryland crops, the wilting point is of little significance as the lower limit of soil moisture. The lowest limit of moisture availability depends on the species involved and on the prevailing weather conditions.

One of the advantages of the soil moisture balance is that it helps to estimate the extent to which the water need of a crop is met at any stage of its development and growth. Recent soil moisture and evapotranspiration studies have confirmed the usefulness of water balance techniques. Determination of the balance between the amount of moisture entering the system and quantity that leaves it at a given time and location helps to identify periods when it could experience stress.

In the present study, water stress periods have been identified from the water balance technique. The moisture stress thus identified has been used to estimate yield reduction due to stress.

2. Data and analysis

The study pertains to Bellary (15° 09′ N, 76° 51′ E) located at an elevation of 480 metres amsl in Deccan plateau. Sorghum was grown in the experimental field at the station during the rabi season for consecutive four years (1986-1989) mainly as a dryland crop. Weather data from the agrometeorological observatory and the soil characteristics of the station have been utilised to find out moisture balance parameters during the growing period. From the daily observations, weekly totals of various agrometeorological parameters were worked out from the date of sowing to harvest. Around Bellary, soil is mostly clayey, having dark brown colour with a field capacity and wilting point of 45.5 and 27.0% respectively. During all the four crop seasons under study, the same variety SPV-86 was grown in the farm.

The evapotranspiration observations were obtained from a gravimetric lysimeter. The lysimeter consists of

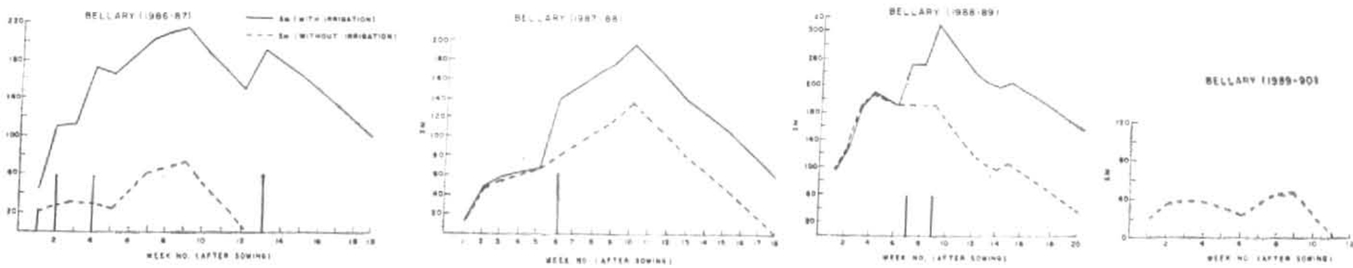

Fig. 1. Weekly variation of soil moisture (vertical lines denote time and amount of irrigation)

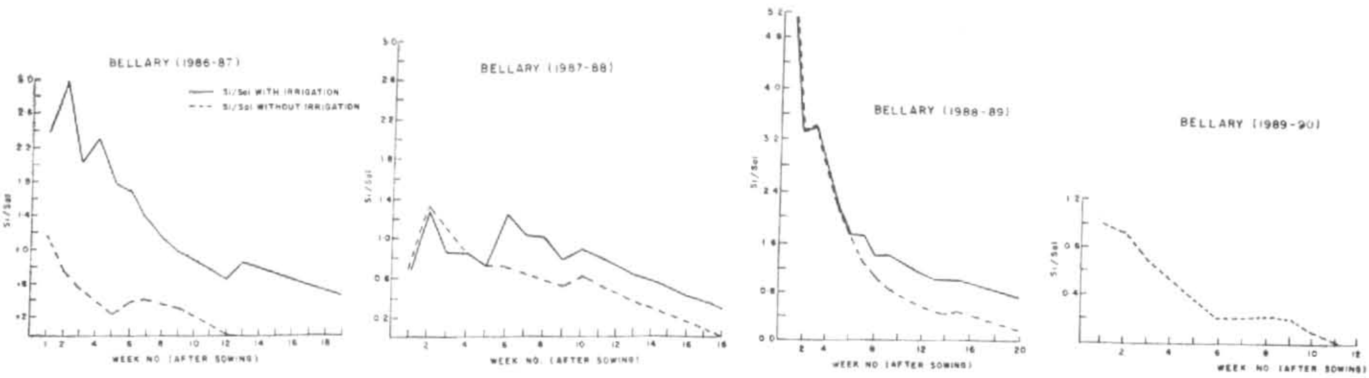

Fig. 2. Weekly march of S_i/Sa_i ratio

sensitive dormant type weighing machine of two tonne capacity, erected in the middle of the crop field on a reinforced concrete structure. A steel tank 1.3×1.3×0.9 m in size in which plants are grown is mounted on the platform of the machine such that its rim is in level with the surrounding soil surface. The steel tank carries a perforated plate at a depth of 75 cm so as to form a hollow chamber at the bottom.

Water balance technique used in the study is similar to that used by Frere and Popov (1979). The following assumptions have been made:

(*i*) Soil water content of the profile up to the rooting depth is at field capacity at the start of the water balance.

(*ii*) The moisture at the end of any week is distributed uniformly over the soil profile.

The basic equation is :

$$S_i = S_{i-1} + P_i - WR_i \quad (1)$$

where, S_i —Water retained in the soil at the end of the *i*th week,

S_{i-1} —Water observed in the soil at the beginning of the *i*th week,

P_i —Precipitation and/or irrigation during the week,

WR_i —Water requirement (maximum evapotranspiration) of the crop during the *i*th week (estimated from the equation given below):

$$WR_i = Kcr_i \times PET_i \quad (2)$$

here, PET —Potential evapotranspiration during the *i*th week, and, Kcr_i — Crop coefficient during the *i*th week.

Sorghum, as we know, is more drought resistant than many other cereals. This is due to its extensive root system which grows rapidly beyond 100 cm, keeping water uptake adequate to maintain the plant. In the present water balance technique, a root depth of a maximum of 120 cm has been chosen.

One of the main features of this method is the recognition of the part soil plays in water resource management in day to day operations and crop estimation. The PET values were computed from Penman's (1963) formula. Maximum and minimum temperature, relative humidity, surface wind and hours of sunshine are the climatic factors needed in computing PET by this method. The data have been obtained from the records of Division of Agricultural Meteorology, Pune. Kcr_i values (Table 1) were based on those given by Doorenbos and Kassam (1979).

TABLE 1

Weekly Kcr_i values for dry land sorghum

Week	Kcr	Week	Kcr	Week	Kcr
1	0.3	7	1.0	13	0.55
2	0.3	8	1.0	14	0.50
3	0.4	9	1.1	15	0.50
4	0.5	10	0.8	16	0.50
5	0.7	11	0.75	17	0.50
6	0.75	12	0.75	18	0.50

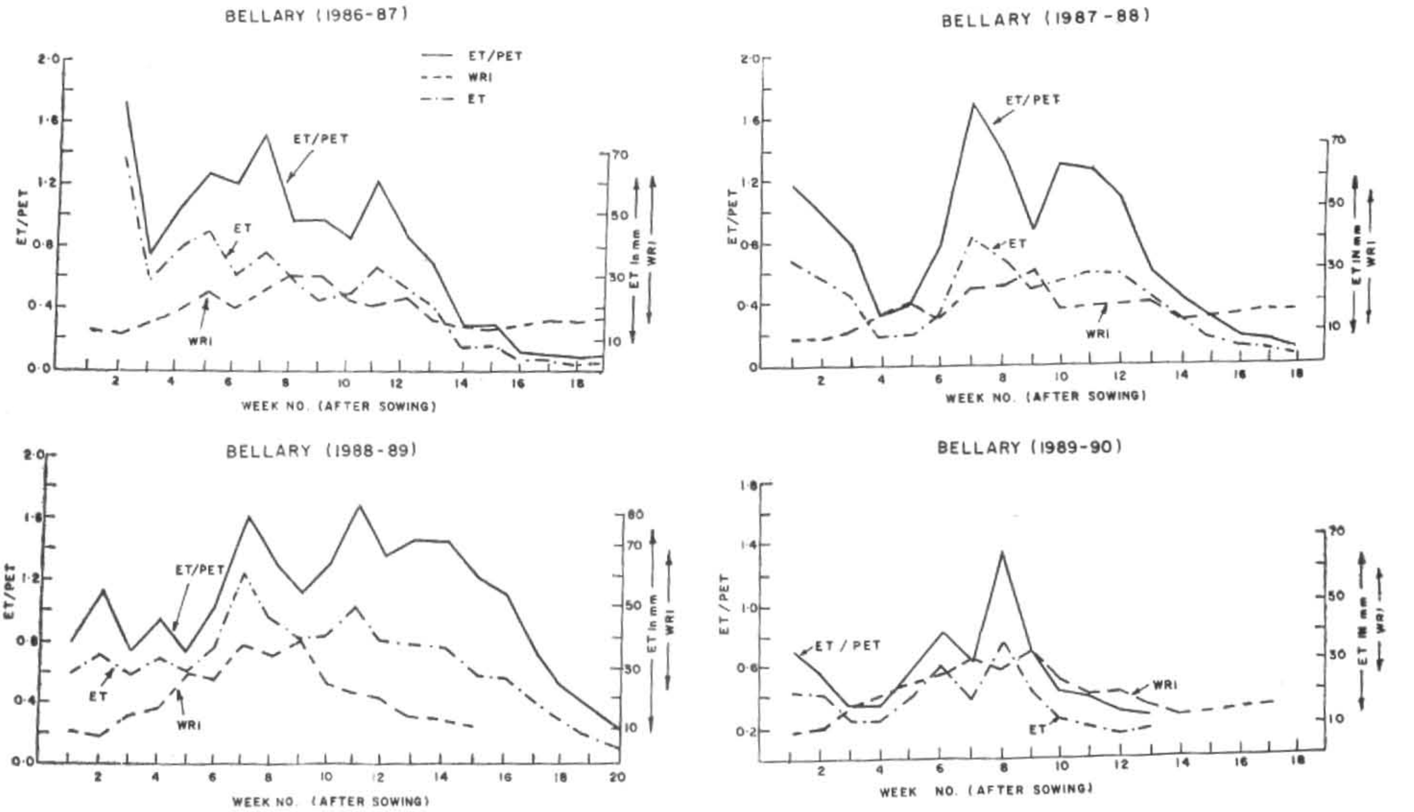

Fig. 3. Weekly march of WR, ET and ET/PET ratio

3. Results and discussion

3.1. *Weekly variation of soil moisture and yield*

If the soil water content falls below a certain level, the actual crop evapotranspiration (ETA) is smaller than the potential crop evapotranspiration. This implies that the crop development is in some way affected. The crop development is generally delayed if water stress occurs during the vegetative period, but the yield itself is affected when stress occurs during some critical periods of the crop growth. In general, stress occurs when 50% of the total available water is depleted. This value, however, varies from crop to crop. The potential evapotranspiration also influences the amount to which the available soil water can be depleted while maintaining the actual rate of evapotranspiration equal to the potential crop evapotranspiration (Doorenbos and Kassam 1979).

Under the rainfed culture, naturally the crop yield is significantly lower than when it is irrigated. A comparative study of the yields in the data used for the present study is given in Table 2. The yield is found to get drastically reduced when no irrigation is provided.

Assuming the yield in 1989-1990 as standard yield under rainfed culture, subtraction of this amount from yield in irrigated years give us how much yield increase takes place due to irrigation. This amount is seen to vary from nearly 500 kg/hec in 1988-1989 to 110 kg/hec in 1986-1987.

Fig. 1 shows weekly soil moisture variations at the field site, for 1986-1987, 1987-1988 and 1988-1989 when the fields were intermittently irrigated and 1989-1990 when there was no irrigation. Because of the application of irrigation, the soil moisture remained above 80 mm in most weeks in 1986-1987 and 1987-1988 although moisture availability was rather low for first few weeks in 1987-1988. The pattern of the march of soil moisture was more or less same for both the years. The year 1988-1989, however, offered ideal moisture regime to the crop. This picture changes drastically when irrigation was not provided to the crop in 1989-1990. It is seen that at no stage of the crop development the available soil moisture exceeded 50 mm, in fact, for most weeks it remained around 40 mm.

3.2. *Water balance and stress computation*

In the present study, the period of the crop stress has been quantified and compared to the yield. For this purpose stress has been considered only between the reproduction stage and 3 weeks prior to harvest. This, as is well known, is the most critical period and any stress during this interval adversely affects the crop. For the ith week the total available soil moisture (Sa_i, in mm) is defined as :

$$Sa_i = 0.1\,(S_f - S_w) \times D \qquad (3)$$

where,

S_f — Soil moisture at field capacity (%),

S_w — Soil moisture at wilting point (%)

and D (cm) is the rooting depth during ith week. Assigning different values to D consistent with the crop growth-Sa_i for different weeks can be calculated from Eqn. (3). Ratio of actual to the available soil moisture, S_i/Sa_i is depicted for each of the crop season in Fig. 2. For any week S_i/Sa_i provide an indication of water availability to crop at its rooting zone. In the study weekly $S_i/Sa_i \leq 1$ was considered as a stress week (*cf.* Olderman and Frere 1982).

The number of weeks of the crop stress is given in Table 2.

TABLE 2

Details of crop information as influenced by moisture stress

Year	Irrigated/ non-irrigated	Date of Sowing	Date of Harvest	Stress period (week)	Yield (kg/hec)
1986-87	Irrigated	25 Sep' 86	3 Feb' 87	8	1041
1987-88	Irrigated	10 Oct' 87	9 Feb' 88	7	1403
1988-89	Irrigated	7 Sep' 88	21 Jan' 89	3	1431
1989-90	Non-irrigated	29 Sep' 89	22 Jan' 90	14	931

It is obvious from above that the yield is inversely proportional to the stress period, the larger the stress duration, the lower is the yield.

The water balance method was also worked out ignoring the amount of irrigation as mentioned above. Ratio of S_i and Sa_i for each week of the crop season is also depicted in Fig. 2. The ratio S_i/Sa_i is found to be less than 1.0 for nearly all weeks except the first one or two weeks in 1986-1987 and 1987-1988. In 1988-1989 also, it appears that crops would have experienced stress after 8th week. This means during all these years the crop would have suffered extensively but for irrigation.

3.3. *Evapotranspiratory loss and climatic demand*

A lysimeter tank is in operation at the experimental farm at Bellary. The weekly march of actual evapotranspiration (ET) obtained from the lysimeter observations for all the 4 years is depicted in Fig. 3. Water requirement (WR), of crop given as a product of crop coefficient and potential evapotranspiration is also given in the figure. It is seen that peak loss occurs between 6 & 8 weeks of sowing (Sarker *et al.* 1976). Subsequently the loss is reduced generally. However, in some cases another peak in water loss around 10-11 weeks from sowing is also observed. The high values observed at the start of the crop season reflects the irrigation provided to the crop at the time of sowing.

A value of this ratio ET/PET less than 0.5 is generally taken as a stress situation, because in such situations even half of the atmospheric demand for moisture is not met and crop may suffer. Supplemental irrigation depending on stress situation should be provided in such cases for the crop survival and development. It may be seen that during 1986-1987 after 13th week crop experienced stress. The stress in 1987-1988 were experienced in two spells, namely, once in three weeks spell in initial growth stage and another on after 14th week.

The peaks in ET/PET in the years 1986-1987, 1988-1989 were observed initially at the 7th and later on the 11th week. No such pattern was seen in 1989-1990. The water requirement did not reveal large year to year variations. The water requirement appears quite large during 8-9th weeks compared to other weeks. This period generally coincides with the start of flowering phases.

3.4. *Relationship between actual and maximum crop evapotranspiration and soil moisture availability*

The ratio of ET to maximum crop evapotranspiration WR gives an indication of how much the crop-water demand is met. This term is, no doubt related to the ratio of actual soil moisture and maximum soil-water content as the root zone.

An attempt was made to find out the relationship between ET/WR and S_i/Sa_i.

Based on 76 data points, the following linear regression equation has been obtained:

$$ET/WR = 2.76 \times S_i/Sa_i - 1.39 \quad (4)$$

The equation shows a correlation coefficient of 0.59, which is significant at 5% level. From above, it is evident that the ratio of evapotranspiration to maximum crop evapotranspiration is dependent on the availability of moisture at the root zone.

4 Conclusions

(*i*) Without irrigation, the actual soil moisture is less than the available soil moisture in a large number of weeks resulting in moisture stress.

(*ii*) The ratio of actual to potential evapotranspiration during the growth season can be used to determine time and quantity of irrigation.

(*iii*) The extent to which crop water requirements are met is closely related to the proportion of actual soil moisture out of the total available soil moisture in the root zone.

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