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Estimation of soil moisture deficit from meteorological factors

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ABSTRACT. Soil moisture deficit has been computed from rainfall, potential evapotranspiration and *F* curve at 30 and 45 cm depths of some representative stations of different climatic zones in India. The *F* curves show the graphical representation of the ratio of actual to potential evapotranspiration. Comparison of the results so computed with the observed soil moisture deficit shows that the method gives estimates with reasonable accuracy. The study is of practical importance for water budgeting and irrigation scheduling.

1. Introduction

The study of soil moisture is of practical importance to agricultural researchers and coordinators. The results could be applied to many sensitive agricultural problems, where moisture is of concern, such as, explaining variations in agricultural production, crop rotations and estimating crop yields on a pre-harvest basis. It is also important for engineering problems associated with water supply for irrigation and other purposes. In areas where moisture is temporarily the limiting growth factor, yields of dry land crops are closely related to the amount and distribution of soil moisture to the plant's root zone during the growth period. Extensive direct measurements of soil moisture, specially in India, is not immediately possible for practical difficulties and may remain so for some years to come. Under this condition large scale studies of crop-water relationships have, therefore, to depend on estimates of soil moisture from available meteorological data, by using suitable budgeting methods.

To examine the amount of soil moisture at any depth, Smith (1970) suggested a technique which required weekly rainfall, potential evapotranspiration and modified *F* curves ($F=AE/PE$) as suggested by Thornthwaite (1955). The same method with some modification has been used in this study.

2. Data

Three stations Kovilpatti, Sholapur and New Delhi have been taken for this study. These stations are different in respect of annual rainfall and its distribution, climatic zone and soil properties. Soil moisture observations are recorded generally once in a fortnight. Weekly observations are also available for a few years. Many observations are missing or have been rejected. Only those years for which considerable soil moisture observations in crops are available have been selected for this investigation. Weekly rainfall and potential evapotranspiration have been used to estimate soil moisture deficit. Potential evapotranspiration has been calculated from Thornthwaite formula (1948). Although dificits have been calculated from September to April, comparison has been done only for periods where soil moisture data in crops were available.

3. Available water

The maximum amount of water which a soil will hold without being water logged is termed "field capacity". This is the water held in the small spaces between soil particles, after excess water has drained from the large pore spaces.

The minimum amount of soil moisture which is available to crops is known as "permanent wilting point". Should soils moisture fall below this amount, the crop will sustain permanent injury from which it cannot recover.

The amount of water contained by the soil between field capacity and wilting point is known as "available water".

Since different crops root to different depths, it is obvious that total amount of soil moisture available to a crop depends both on root depth and the soil type. It is the usual practice to give irrigation when half of the available moisture to the crop has been used up. This is reasonably a good practice, although there is evidence that maximum crop growth is achieved when the soil is kept near field capacity.

4. The concept of soil moisture deficit

The soil moisture deficit is defined as the difference between field capacity and the actual soil moisture. Estimation of moisture deficit is made on the basis of certain fundamental concepts in connection with gain and loss of moisture by soil. We start with a case in which the only source of water is rain and loss is through evaporation from soil and transpiration from crop. It is then simple to calculate week by week changes in the soil moisture content. In terms of the deficit of soil moisture below field capacity, the deficit at the end of the present week equals last week's deficit *plus* this week's evaporation and transpiration *minus* this week's rainfall. In other words, evaporation from soil and transpiration from plants use up water and increase the soil moisture deficit. Rainfall adds water and thus decreases deficit. The soil acts simply as a reservoir for the moisture.

5. Actual evapotranspiration

Several methods have been developed for estimating evapotranspiration by calculation or indirect measurement. Penman (1948) have a more complex equation which considers all meteorological factors. Although the equation gives good estimates of potential evapotranspiration, it is very complicated and requires observations which are not readily available to use. Thornthwaite developed the concept of potential evapotranspiration (*PE*) which in effect postulates the combined daily rate of evaporation and transpiration from a given land, and is independent of the crop and is determined solely by certain meteorological factors, provided that the crop is growing, completely covers the ground from areal view, and has an adequate moisture supply.

Let us designate the ratio AE/PE by F (AE= Actual evapotranspiration and PE=Potential evapotranspiration). The problem before us is to decide the shape of the curve when F is plotted against soil moisture deficit. At a deficit equivalent to wilting point, the value of F may be taken as zero. At field capacity, when deficit is zero $AE=PE$ and value of F is unity. Various writers have proposed different curves between these two limits. Veihmayer and Hendrickson (1955) considered that F is equal to unity almost until wilting point. Denmead and Shaw (1962) held that the shape of the curve depends on the PE rate. At a low value of PE the curve was similar to that proposed by Veihmayer and Hendrickson. Broadly

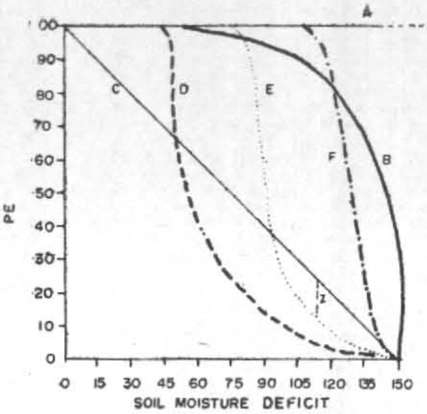

Fig. 1. Available soil moisture (%)

speaking, the curve is concave at low *PE* rate and convex at high rate. Thronthwaite suggested that F was proportional to the deficit giving a straight line relationship. Baier (1969) tried with five curves to find out relationship between soil moisture and AE/PE rate and suggested that a modified curve Fig. 1 based on Thornthwaite's (Thornthwaite and Mathur 1959) proposal of a linear relationship between AE/PE rate and total moisture content, appeared to be the best fit for most soils and crops.

6. Methods

Part of soil moisture deficit equation can be readily evaluated. Rainfall is easily measured and the other part evaporation and transpiration is more difficult to determine. Actual transpiration (*AE*) can be obtained by multiplying the estimated *PE* by a factor depending on the soil moisture. When the soil is at field capacity $PE=AE$, and when soil is dried out to wilting point, the plant can no longer extract moisture. Consequently, *AE* must be either very small or almost zero. Assuming that water losses by drainage or runoff takes place only when soil is above field capacity, it could be possible to obtain intake against removal so as to arrive at a figure for residual moisture in soil. Computation is, of course, started at a time when the soil moisture is known and a convenient way of doing this, is to start from a day when the soil is at field capacity or soil moisture is known.

In this study weekly value of *PE* has been calculated by Thornthwaite method. Calculation was started when soil is at field capacity. Field capacity, wilting point, bulk density, crop cover, soil-depth and available water for different stations are shown in Table 1.

Table 2 gives an example in which estimated deficits were worked out. In this case, F curves (Fig. 1) was drawn as a straight line connecting the moisture deficit of 150 mm, (F=0) to moisture deficit zero (F=1).

TABLE 1

Station	Field capacity	Wilting point	Bulk density	Crop	Soil depth (cm)	Available water (mm)
Kovilpatti	35·5	15·2	1·31	Cotton	30	80
Sholapur	42·5	22·3	1·04	Jowar	30	62
New Delhi	17·5	5·8	1·56	Wheat	45	82

At the beginning of week, the initial deficit, because of earlier heavy rain, is considered to be zero. From the mean air temperature of week 1 *PE* is calculated 25.1 mm, AE=25.1 mm, (as F=1) and rainfall of the week is 36.8 mm. The final deficit at the end of week 1, is equal to earlier deficit *plus* actual evapotranspiration *minus* rainfall of this week, (0+25.1—36.8). Since the result is negative (—11.76) it is considered that the soil is still at field capacity.

In week 2, the *PE* is found to be 27.2 mm, rain 0.2 mm and initial deficit is same as final deficit of 1st week. As deficit is zero, F=1, AE=PE, final deficit at the end of week is (0+27.2 —0.2)=27.0 mm.

In the week 3, *PE* is found to be 24.5 mm, rainfall 16.0 mm and initial deficit 27.0 mm. The F curve is then considered, and it is seen that the value of F corresponding to 27.0 mm is 0·94. The *PE* value when multiplied by this amount, to give AE=23·0. The final deficit is then, taken to be the sum of the AE and initial deficit *minus* rainfall of the week 3 and is entered as (27.0+23.0—16.6) =33·4 mm. This simple process is continued as long as necessary.

7. Results and discussion

In this study soil moisture deficits of three stations, Kovilpatti, Sholapur and New Delhi, each of two periods, have been calculated. Accumulated soil moisture deficit have been estimated upto 30 cm for Kovilpatti and Sholapur and 45 cm for New Delhi. In order to bring out the difference between the estimated and the observed values these have been depicted in Figs. 2-4.

Available water at Kovilpatti has been calculated 80 mm upto 30 cm depth. In year 1959-60 (Fig. 2a) soil moisture deficit derived from present method is lower than observed deficit upto 2nd week except one point and during the last five weeks it is slightly higher. At the 5th week observed deficit is about 22 mm more than the estimated deficit. There were 44 mm rainfall during this week which brought down the estimated deficit.

TABLE 2
(All values in mm)

Week No.	P.E.	Initial	F	$A.E.$	Rain	Final deficit
1	25·1	0	1	25·1	36·8	0
2	27·2	0	1	27·2	0·2	27·0
3	24·5	27·0	·94	23·0	16·6	33·4
4	28·2	33·4	·78	22·0	2·3	53·1

Correlation coefficient between observed and estimated deficit is 0.84. Fig. 2(b) shows the observed and estimated deficit for the year 1961-62. It is clear from the curve that upto 6th week difference between the set of values is very small. Estimated deficit after 6th week is, in general slightly less than observed deficit. Correlation coefficient between two sets of values is 0.91.

Fig. 3(a) gives the soil moisture deficit of Sholapur from 44th week to 7th week for the period 1959-60. There was good rainfall during four weeks (44-47) but rainfall during the rest of the period is almost *nil* which is the normal feature of the station. Curve shows the difference between two set of values is less than 12 mm. Correlation coefficient is 0.91.

Fig. 3(b) shows that the estimated deficit is less than observed deficit upto 50th week but during the next six weeks estimated deficit is more than observed. The estimated values are, in general, in good agreement with the observed values. Correlation coefficient is 0.82.

Fig.4(a) depicts the soil moisture of New Delhi for the year 1957-58 at 45 cm depth. At 48th week estimated deficit is about 15 mm more than observed deficit. Due to good rainfall at 49th week this difference has come down to 1 mm at 50th week. Difference between two set of values during the rest of the period is less than 3 mm except 5th and 13th week. Correlation coefficient is 0.94.

In the year 1963-64 estimated deficit is more than observed deficit upto 52nd week and it is less from 1st week to 7th week (Fig. 4b). Although the difference between the two set of values is more than 11 mm at least two points, good agreement is observed in the two curves. Correlation coefficient is 0.78.

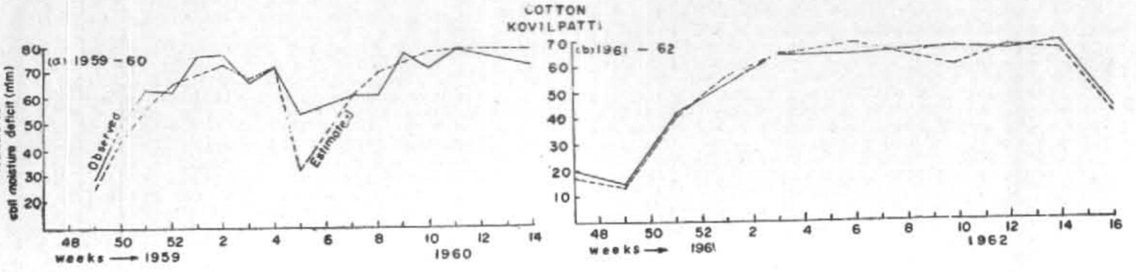

Fig. 2

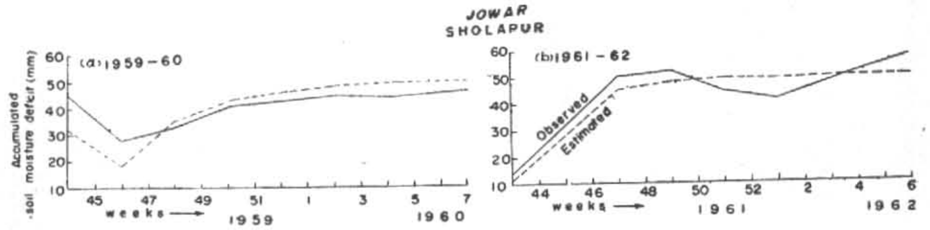

Fig. 3

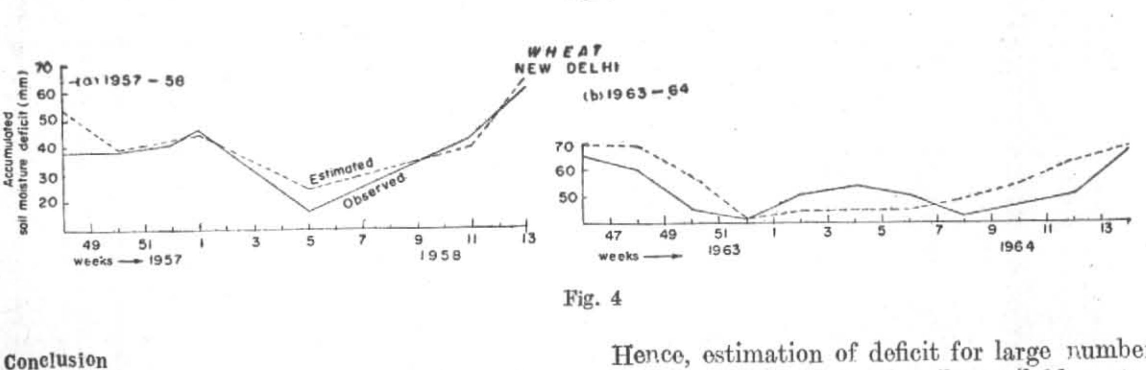

Fig. 4

8. Conclusion

In practice it is rarely necessary to know the deficit to an accuracy of order 2 or 3 mm. Probably 10 to 15 mm accuracy would be good enough in most cases (Smith 1970). In the present study it is assumed that all the rainfall is available at the end of the week. This is obviously not so. Deficit may be slightly different, if rainfall is taken at the beginning or middle of the period.

Under the particular assumption it is found that soil moisture deficit with plant cover could be estimated with fairly good degree of accuracy. Such estimates are obviously important in scheduling irrigation of well established actively growing crops. As mentioned earlier collection of actual soil moisture data which would be representative for a large crop region would be a stupendous task. Hence, estimation of deficit for large number of stations with the help of easily available meteorological parameters is very important and gives an idea about the water available to crops under constant evaporation demand. This ultimately helps water budgeting, land use planning and cropping pattern.

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