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A SIMPLE METHOD OF ACCOUNTING THE SOIL WATER BALANCE*

BY

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*This paper is an elaborate form of a farming systems seminar presented in December 1976. This does not constitute a formal publication of ICRISAT.

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ABSTRACT:

A simple but effective method of computing evapotranspiration of the soil moisture is attempted by taking all the factors involved into consideration. It takes into account, the evaporative demand which is the major component in determining the evapotranspiration of the climate of the region, besides the soil type, crop and its various stages of growth and development. Further with the help of the computed values of evapotranspiration accounting of water balance over watersheds has been attempted. To test the efficacy of this method sample computations were made over ICRISAT farm watersheds during the period 1975-76 and the computations found good agreement between the estimated and the observed values of evapotranspiration as well as moisture status of the soil. A good agreement has been observed between the observed transpiration values from hydraulic lysimeter for four different years under four different crops at Samaru and the corresponding estimated values. However, further it is desirable to test these estimated values with the precisely obtained, location specific values obtained from lysimeter based experiments.

1. INTRODUCTION:

In the past, several researchers studied the soil water budgets from rainfall and evaporation, as this is a first step in calculating the expected productivity of an agricultural system under a wide range of climatic conditions and for developing alternate choices and decision strategies for the use of limited available water as a backup resource for increasing and stabilising crop production under rainfed agriculture, it is essential to have more realistic method of computing soil water balance. This is also essential in the development of of agroclimatic models. Estimation of soil water balance requires relationships which correctly predict (a) available soil water storage capacity in the active root zone; (b) the increase in

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in soil water storage resulting from precipitation; (c) surface runoff and deep percolation below active root zone; and (d) evaporation/evapotranspiration from the soil. For the development of agroclimatic models (which is the second stage of agroclimatic classification studies), the soil water balance information can be used in (1) establishing the length of crop growing season (which will help the planning and execution of various alternatives of cropping systems based on the period of soil moisture availability), (2) yield forecasting models, and (3) monitoring supplemental irrigation requirements and studies as the water supply is the principal environmental factor that determines the growing season characteristic in SAT. Examples of soil water balance models which have been used for agroclimatic purposes are those of Marlatt et al. (1961), Kohler and Richards (1962), Fuchs and Stanhill (1963), Holmes and Robertson (1963), Baier and Robertson (1966) and Ayers (1967).

Under a wet soil situation, the simple assumption that the actual evapotranspiration is equal to potential evapotranspiration rate for a complete ground cover can usually be made with confidence eventhough it underestimates evapotranspiration. However, under drier conditions this may not hold true because of restricted availability of soil moisture. Here accounting of actual evapotranspiration is a complex phenomenon. There are several methods in the literature for the estimation of actual evapotranspiration in terms of pan evaporation or potential evapotranspiration. Among these one group of methods takes into account the soil water availability while the other group takes into account the soil water availability as well as evaporative demand of the climatic condition. Some of these methods which are in use are presented in Section 4. However, not all of those earlier methods differentiate between the fallow and the cropped situation nor among the stages of crop growth. The later affects the soil moisture available at different stages of crop for evaporation/transpiration purposes.

In the present paper a method of computing actual evapotranspiration (AE) in terms of pan evaporation (E), which takes into account all the points mentioned above has been attempted. On the basis of this a method of accounting "Soil Water Balance" for (i) developing agroclimatic models and (ii) supplemental irrigation studies has also been suggested.

3. EVAPORATION/EVAPOTRANSPIRATION FROM SOIL:

In determining the "Soil Water Balance", evapotranspiration is one of the complex phenomena to be estimated. The study of evapotranspiration can be divided into two stages: (i) under fallow condition the soil looses water through evaporation. The amount of water lost in turn depends upon soil type (soil factors), the available moisture in the top few cm of the soil profile (i.e. evaporation zone) and evaporative demand (micrometeorological factors), (ii) under cropped condition the soil looses water through both evaporation and transpiration which in turn depend upon soil type, the available moisture in soil profile (i.e. in the evapotranspiration zone), evaporation demand, type of crop cover (crop factors), the crop stages, and crop growth.

In the initial stages of crop growth evaporation is the major source of moisture loss, while at the rapid vegetative growth stage and flowering/reproductive stage transpiration plays the major role. The stage of crop growth is also reflected in size of the root proliferation system. As the crop develops through the various growth stages its roots appear in different locations of the soil at different times. Hence, even if the entire soil profile is at field capacity the available soil moisture for evapotranspiration is different for different stages of crop growth.

A large fraction of the water held in a saturated void in sand can be removed before the thickness of the residual water film becomes very small. In clay by contrast, water has barely begun to leave when the film thickness is the same as that in a sample of sand. The adequacy of soil moisture at different stages of crop growth also depends upon the moisture distribution in the transpirating zone with depth and the drying depth as a function of time after rainfall. The drying with depth also depends upon the nature of the porous material, its thickness and the drying condition.

Precipitation falling on a partly dried soil, but not increasing the content of transpiration zone to the critical value for potential use, is not distributed over the transpiration zone, but remains in top layers of the soil. Therefore, depletion of precipitation falling on the soil has priority irrespective of the moisture content of the soil. This precipitation is used for potential transpiration and when this precipitation is not sufficient for complete potential transpiration, the available content of the transpiration zone is used for the remaining transpiration.

It is an accepted fact that field capacity provides optimum conditions for evapotranspiration, which prevails at the same level up to a certain limit of moisture loss from field capacity and starts declining thereafter up to wilting point. Even at the wilting point the plant continues to absorb negligible amounts of moisture which is of no significance for the normal functions and its very survival. There are many different opinions of the form of water availability function between these two extremes. But, under low evaporative demand conditions it is also seen that transpiration never reaches the zero at wilting point. More water is available to plants from warm soils than from cold soils, because soil retains less water when plants wilt in warm than in cool soils. The amount of water held by a soil at the permanent wilting point ranges from 1 to 8 percent for coarse sandy soils with small specific surface areas to 25 to 30 percent or even higher for clayey soils. When the needs are highest, plant may not be able to get water fast enough to supply the transpiration demand completely. If the PE exceeds 'X' mm d day, the soil, whatever the condition of the water in it, cannot supply water fast enough for crop needs. Under these conditions, the ability of the soil to supply water may exert a controlling influence on transpiration (Denmead and Shaw, 1962).

3. METHOD OF COMPUTING ACTUAL EVAPOTRANSPIRATION:

There are several methods for the estimation of evapotranspiration. These can be arranged into two major groups: (i) theoretical methods and (ii) empirical methods. Under theoretical methods there are three distinctive approaches. They are: (1) Aerodynamic or mass transfer methods, (2) Energy balance methods, (3) Combination (1 and 2) methods. Under empirical methods there are two approaches. They are: (1) Water depletion methods and (2) Methods involving conversion of pan evaporation or potential evapotranspiration through the use of crop coefficient.

Among these, aerodynamic methods are used less often. Although the energy balance methods utilizing the Bowen ratio yield valid estimates of evapotranspiration if the basic assumptions are met, when the Bowen ratio is less than -0.5, the determinants are less reliable. In the combination methods, an energy balance and an aerodynamic equation are combined to produce an equation that can be used to estimate potential evapotranspiration. Here again a soil plant factor must be introduced to obtain actual evapotranspiration estimates.

A number of empirical or semi-empirical equations have been developed for estimating evapotranspiration. Many of these are calibrated for a given crop in a given area and, consequently, the equation constants include the crop and soil factors. In these equations actual evapotranspiration is estimated directly. Jensen and Haise (1963), Jensen (1966), Blaney-Criddle (1960) developed coefficients for growing season for a number of crops at different stages, depending primarily upon amount of leaf cover and a coefficient was calculated for each combination of crop growth period and area. Among the empirical methods, one that is widely used is the conversion of PE or E to AE (An extensive review of pan evaporation as a method of estimating evapotranspiration is given by Pruitt (1967)). The water depletion methods also come under this group.

Some of the methods that are developed in the past for computing actual evapotranspiration (AE) in terms of pan evaporation (E) or potential evapotranspiration (PE) as a function of soil moisture are: Veihmeyer and Hendrickson (1955), Pierce (1958), Thornthwaite and Mathur (1959). Marlatt et al. (1961), Holmes and Robertson (1963), Gardner and Ehlig (1963), Shaw (1963), Fitzpatrick et al. (1967), Mustonen and McGuinness (1968) etc. According to Denmead and Shaw (1962) - Veihmeyer and Hendrickson (1955) model is applicable under low evaporative demand conditions; Pierce (1958) (supported later by Mustonen and McGuinness, 1968) model is applicable under moderate evaporative demand conditions and Thornthwaite and Mather (1959) (which was supported later by Gardener and Ehlig, 1963) is applicable under high evaporative demand conditions. And according to Baier (1972) the models of Marlatt et al. (1961), Holmes and Robertson (1963), Gardner and Ehlig (1963), Shaw (1963) and Fitzpatrick et al. (1967) are applicable under medium textured, non-irrigated soils.

From these it can be inferred that most of these models are developed under specific conditions for specific locations or regions and don't take into account the available soil moisture at different stages of crop growth and also soil type condition and the evaporative demand condition etc. Therefore, based on the results that are available in literature mainly Holmes and Robertson (1963) and Denmead and Shaw's (1962) results and some more works viz. Blaney and Criddle (1960), Jensen and Haise (1966), Erie et al. 1965) etc. which deal with the stages of crop, a new and simple method which takes into account all the above mentioned points has been suggested.

The model proposed for the computation of actual evapotranspiration (AE) in terms of pan evaporation (E) under field condition is as follows:

The basic equation can be written as

$$AE = (A_s)\ (ET_m) \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

in which ET_m is the maximum possible evapotranspiration for a given crop in response to the evaporative demand (desiccating power) of the atmosphere and A_s is the soil factor. The maximum evapotranspiration may differ from the potential because the later is defined for a short green crop rather than an actual crop. The maximum evapotranspiration can be related to the evaporative demand of the atmosphere by the equation:

$$ET_m = (A_c) f(E') \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

in which $f(E')$ is the function used as a measure of the evaporative demand of the atmosphere, in which E' represents the evaporation from a free water surface and A_c is a crop factor/or proportionality factor. By combining equations 1 and 2 we get:

$$AE = f\ (E')\ (A_s)\ (A_c) \quad \ldots\ldots\ldots\ldots\ (3)$$

As the crop factor (A_c) and soil factor (A_s) cannot act individually[+] a modified form as developed in this study is given as follows:

$$(AE/E) = (a+B)\ e^{-f} \quad \ldots\ldots\ldots\ldots\ (4)$$

Where AE = Actual evapotranspiration, mm/day;

E = Pan evaporation, mm/day

(can be used either estimated from the formula of Reddy and Rao, 1973 or observed)

$$B = \frac{(5-E')t}{0.4K\sqrt{E'}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

(= evaporative demand coefficient; E' - represents the mean pan evaporation at a station for a standard week/day, vary accordingly as the data is weekly or daily (mm/day)]

$$f = (-2+t)/b_i K \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)^*$$

(If $f \leq 0$ then $f = o$ only)

[+]The loss of water from the soil is a combined function of the atmospheric energy causing evaporation from the soil and surfaces of plants and of the availability of water in the soil to provide this atmospheric requirements (Denmead and Shaw, 1962; Holmes and Robertson, 1963).

[*]In the case of supplemental irrigation (i.e. instantaneous water addition to the soil) $f = (-1+t)/b_i K$.

a = Crop coefficient (for fallow condition and (Rainfed crops: $a = 1$ (for irrigated crops (like sugarcane, paddy etc: $a >$

K = Maximum available soil moisture storage capacity of the soil, mm 1)

$t = 1, 2, 3 \ldots\ldots x$, number of dry days after zeroth day
(1 represents the zeroth day i.e., rainy day),
(On those days when the water is standing on the soil,
$t = 1$ for those days).

b_i = Crop growth stage coefficient, represented by fig. 1
(b_i is a function of $\frac{(L)}{(100)} t'$, i is varying from
1 to 100% respectively from sowing to harvest); fig. 1
can be used in water balance analysis (under individual
crop situation it varies).

= 0.02, under fallow condition.

L = Crop duration in days, (viz. 75, 110 and 150 days
respectively for short, medium and long period crops etc.)

$t' = 1$ to L, respectively from sowing to harvest, in days.

Therefore, the final equation can be written as:

$$AE = E\left[1.0 + \left\{\frac{(5-E')\,t}{0.4K\sqrt{E'}}\right\}\right] e^{-(-2+t)/b_i K}$$

The value of K takes into account the different crops by assuming the available soil moisture according to the maximum root proliferation of each crop. The soil moisture reservoir is equal to the quantum of available moisture holding capacity of the soil in the rooting depth of the crop. For example, heavy soils (clay # 25 or 30%) have been assumed to have soil moisture storage capacity of 200 mm/meter depth; medium soils (clay # 15%) to have a storage capacity of about 125 - 150 mm/meter depth; and light sandy soils to have a storage capacity of 75 - 100 mm/meter depth. Active root zone depths vary widely in different soils, and different species within a range.

Initially the following were adopted as generalised figures (Virmani, 1976);

Crop	Depth in meters
Groundnut forages	0.5
Grain crops	1.0
Castor, pigeonpea	1.5

If a groundnut crop is grown in a light sandy soil having an available water storage capacity of 100 mm/meter depth - the soil moisture reservoir available for crop utilisation will be : K = 100 X .5 = 50 mm; similarly for castor or pigeonpea : K = 100 X 1.5 = 150 mm etc.

Similarly, the available moisture reservoir will vary with stages of the crop i.e., according to the root proliferation in the soil at different stages of crop. However, this will be taken into account by the term b_i.

Using this model the variation of AE/E under different situations is discussed. In all these cases the soil is saturated initially and dried out without adding any supplemental water at later stages. The variation of AE/E in terms of t as well as % available soil moisture is presented.

Case i :- Under fallow condition (b_i = 0.02).

Three conditions are necessary to sustain evaporation from a porous body - heat must be supplied to meet the latent heat requirement of evaporation; the vapour must be transported away from the zone of evaporation by diffusion or convection or both; there must be a continuous supply of water from the interio. of the body to the evaporation site. Accordingly, the evaporation rate of soil is limited either by external evaporativity or by the soil's own ability to deliver water, whichever is the lesser at any time. The process by which soil moisture evaporates and the soil surface dries has been studied by numerous investigators during the last two decades (e.g. Hide, 1954; Lemon, 1956; Gardner, 1959; Weigand and Taylor, 1961; Gardner and Hillel, 1962; Black et al., 1969; Hillel, 1971; Gardner, 1973). Numerical models of soil moisture evaporation have been published by Hanks and Gardner (1965), Ripple et al, (1972), Van Keulen and Hillel (1974) and Hillel (1975,1976).

Under constant evaporativity, the evaporation process has been divided into three stages. (Philip 1957, 1967; Feodoroff and Rafi, 1962) - a constant-rate stage, controlled by external evaporativity; a falling rate stage, controlled by the soil profiles transmission of water to the evaporation zone, and a vapour diffusion stage, during which evaporation continues at a very slow and relatively constant rate controlled by the vapour diffusivity of the dried surface zone. In actual nature, evaporativity is obviously not constant but intermittent, as it fluctuates diurnally (Jackson, 1973; Jackson et al. 1973) and varies from day to day, so it may become difficult or even impossible to discern or distinguish between the stages described above (Hillel, 1977) and also the third stage possible only when the soil moisture reaches a certain critical value at the beginning of the first stage (the critical level can be taken as > 50% of the soil moisture level). This stage has not been taken into account in the development of the present model as this is a constant factor. In the computation of AE/E, this can be accounted by choosing a constant value for AE/E which is less than or equal to 0.1. This constant factor varies depending upon the type of soil and evaporative demand condition. Under high evaporative demand condition and shallow soil situation this can be taken as 0.05 and under low evaporative demand condition and deep soil situation this can be taken as 0.1 i.e. when AE/E reaches 0.05/0.1 then AE/E will be continued at 0.05 /0.1. By this assumption the error involved in the computations is negligible. (This can also be followed even under cropped situation). However, in the following theoretical case studies this has not been accounted.

Fig. 2a represents the variation of AE/E under fallow condition with time (t) for K = 50 and 300 mm under different evaporative demand conditions, E' = 2, 5 and 10 mm/day. Fig. 2b represents the same in terms of % available soil moisture. It is seen from this figure that under high evaporative demand condition high % of water is extracted from the soil compared to low evaporative demand condition; similarly under low K values the atmosphere receives high % of water from the soil. Table 1 presents the available soil moisture in mm for evaporation under high and low K values and under different E' values.

The evaporation from wet bare soil is usually about the same as that from a free water surface. The evaporation from bare soil decreases very rapidly to near zero within a few days (fig. 2a). The primary reasons for the sudden evaporation decrease is that the rates of evaporation exceed the rate at which the soil is able to transmit water to the surface into the soil (thus lengthening the vapour diffusion pathway) and increases the resistance to vapour flow to the surface. As a result the vapour pressure at the soil surface is less than the saturated value i.e., the relative vapour pressure (actual/saturated) is slightly less than one (Slatyer, 1967). Soil surface evaporation is highly dependent on soil wetting frequency because the soil usually only contained about a few mm of stored water which could evaporate substantially at the maximum rate.

Table 1: Available soil moisture for evaporation from the fallow soil (in mm) when the field is under field capacity initially for different values of K and E'

E' mm/day	K = Available soil moisture, mm	
	50	300
2	6	18
5	12	37
10	22	70

Case ii :- Under maximum transpiration condition (b_i = 0.24)

This case is similar to the models discussed in page 5 para 2. Fig. 3a represents the variation of AE/E with time (t) for K = 50 and 300 mm under different evaporative demand conditions, E' = 2 and 10 mm/day. Fig. 3b represents the same in terms of % available soil moisture. Fig. 3b and 2b show opposite variation with E' i.e., in fig. 3b the curve for high evaporative demand condition is to the left of low evaporative demand condition curve while it is opposite in fig. 2b. This figure also shows significant change with E' for the same K.

The range over which moisture is readily available (in this case) depends on the moisture release characteristics of the soil (Holmes and Robertson, 1963). The relative transpiration rate declines in a clay soil at a higher available soil moisture content than in a sandy soil where the actual transpiration rate is close to the potential over a much wider range of soil moisture content (Gardner, 1960; Gardner and Ehlig, 1963; Marlatt et al., 1961; Denmead and Shaw, 1962). The results in fig. 3b are in confirmation with the above views.

Case iii:- Under crop condition (b_i varies from 0.02 to 0.34):

Fig. 4a represents the variation of AE/E with time (t) from zeroth day for K = 50 and 300 mm under different evaporative demand conditions, E' = 2 and 10 mm/day. Fig. 4b represents the same in terms of % available soil moisture. Here also, the soil is considered at field capacity on sowing day and no supplemental water is added. The length of the crop is considered as L = 100 days. It can be seen from fig. 4b that in the beginning the curves of high evaporative demand are towards left of low evaporative demand curves (follows the fallow situation - case i). While it is opposite at later stage (follows the maximum transpiration - case ii). The effect of K is significantly seen at the later stage of the curves. Under the crop situation the soil moisture depletion curves vary significantly with K and E'. Under this situation the water depletion is more under high evaporative demand condition than under low evaporative demand condition irrespective of K.

For some time after seedling emergence, the water use of annual crops may be dominated by the E from bare soil. As the plant continues to grow, transpiration becomes more significant relative to soil evaporation and for a period of time the evapotranspiration is related to the degree of crop cover (up to middle of elongation phase). Two principal factors associated with degree of crop cover can be expected to influence evapotranspiration. The first is related to reflection. Based on reflection alone, evapotranspiration would normally be expected to increase as per cent of cover increases. The second factor is related to the evaporation of water from a bare soil as compared to the transpiration from a crop. Evaporation from moist bare soil decreases rapidly 1 or 2 days after an irrigation or a rain. Under the same conditions transpiration may not be limited until 2 weeks later. Almost without exception, past studies have shown that evapotranspiration increases as the per cent of cover increases up to 50 percent cover. Complete cover is not always necessary for maximum transpiration (Gates and Hanks, 1967).

4. METHOD OF ACCOUNTING THE SOIL WATER BALANCE:

The term soil water balance refers to the balance between the moisture added through precipitation and moisture lost through evapotranspiration resulting in change of soil moisture and runoff. The soil water balance is influenced by a number of processes such as infiltration, evapotranspiration and drainage etc. The process of evapotranspiration is driven by atmospheric water demand and limited by soil and plant characteristics and soil moisture content.

The daily/weekly soil balance equation can be written as:

$\Delta S_n = P_n - AE_n - RO_n - D_n$ ....(1)

Where ΔS_n = Soil moisture change:

($\Delta S_n = SM_n - SM_{n-1}$ where SM_n and SM_{n-1} respectively stands for soil moisture on $_n$th and $_{n-1}$th day/week;

P_n = Precipitation on $_n$th day/week;

AE_n = Actual evapotranspiration on $_n$th day/week;

RO_n = Surface runoff on $_n$th day/week;

D_n = Drainage on $_n$th day/week (as the amount of water passing beyond the root zone, or for experimental purposes, as the amount passing below the lowest point of measurement).

A simplification is frequently sought by making measurements during periods of rainless weather where it is assumed P_n, RO_n and D_n equal to zero and in which equation (1) becomes $AE_n = \Delta S_n$. However, the assumption that D_n can be neglected during periods of rainless weather may introduce errors under shallow water table condition, as water may move upwards into the root zone along water potential gradients (Van Bavel et al.,1968), otherwise the above equation holds well under reasonable limits for all practical purposes.

In the next few pages a method of computing the soil water balance using daily or weekly data is presented. In this model instead of water depletion technique, time, t factor has been used. Using this anology, computations have been made using the data of ICRISAT farm.

PROCEDURE FOR THE COMPUTATION OF SOIL WATER BALANCE USING THE NEW MODEL*

The procedure followed in the estimation of 'soil water balance' based on the model developed in this study is explained as follows:

(i) Separate the fallow and cropped situation and assign the length of the crop (L, in days or weeks);

(ii) Assign the value of b_i under cropped situation from fig. 1 and $b_i = 0.02$ for fallow situation;

(iii) Assign the value of K, the maximum available soil moisture storage capacity of the soil in rooting zone based on soil and root penetration under that crop situation.

(iv) Assigning the value of t for a day in a week is done as follows:

(a) If the precipitation $P_n > 20$√ mm then t takes the values as 1,2, ... X, in days until a fresh precipitation occurs;

(b) If the precipitation $P_n \leq 20$ mm then for $Y (= P_n/E$, E = mm/day) intiger days t = 1,2,.....Y for Y days and from (Y+1) the day onwards t takes the values as X+1, X+2, ...(X being t value of the last day in the last week/or day preceeding to this rainy week or the value of t on the day when AE= 0 in the preceeding rainy week/or day, whichever is small is taken) in days until fresh precipitation occurs and later again follows either (a) or (b) according to P_n.

(v) Runoff $(RO_n + D_n) = SM_{n-1} + P_n - K$; and

(vi) Soil moisture at the end of the week or day $SM_n = (SM_{n-1} + P_n - AE_n - RO_n - D_n)$.

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*Under shallow water table situation i.e. the water table in the rooting zone itself, this method (for a matter of fact even any other method) underestimates the evapotranspiration, as the moisture is continuously supplied by the under ground storage to meet the atmospheric requirement. However, this can be avoided bu considering the case as low evaporative demand situation and wit out budgeting the soil moisture or it can be assumed at potential rate. As the distance between the water table and the rooting zone increases the accuracy of the estimates by the present method will also increase considerably.

√If the data is daily (or for any other specified period including weekly data), then instead of 20 mm, the total amount that has been evaporated/ evapotranspired since the last rain (where t = 1) has to be taken. If two rainy spells are separated by zero soil moisture status or AE = 0, then it follows 'a' in accounting for t irrespective of rainfall amount either in the case of daily data/or weekly data/ or any other specified period.

If K is defined accurately the other terms like SM and (RO,D) can be estimated quite accurately in this model.

Using this procedure AE and soil moisture values have been computed and compared with observed data. These are presented in next few pages.

Case studies:

(i) Comparison between observed and estimated AE values:

Using the gravimetric lysimeter of dimensions 124 X 124 X 70 cm^3, regular evapotranspiration observations have been made in BW3A watershed. In the lysimeter chickpea has been sown on 8th October and the soil was saturated on 4th October. Period totals of AE, E and P are presented in Table 2.

The computation of $(AE/E)_0$ is done as follows:

The maximum root penetration with available soil moisture 250 mm/meter depth (estimated by gravimetric method) has been taken as 60 cms. Therefore, in this case K = 250 X 0.6 = 150 mm, and the length of the crop is L = 84 days (or 12 weeks).

AE values have been computed using the procedure as explained in the previous pages from daily data. And these results are presented in Table 2. Also Table 2 presents the cumulative period totals of AE.

The cumulative values indicated negligible difference between observed and computed values of AE. Generally on the whole the observed and computed values of AE are in good agreement.

(ii) Comparison between estimated and observed soil water balance over BW3 A watershed:

The soil moisture balance in 1975-'76 (i.e. 1st week in 1975 to 8th week in 1976) has been computed over BW3A watershed using the weekly pan evaporation, rainfall (Met. Observ.) and runoff (BW3A - 0.4% graded ridge and furrow system - deep black soil). In the period under consideration two crops have been grown. For the kharif and Rabi crops the lengths, L, have been taken as 100 and 130 days respectively. And the value of K = 200 mm. (as suggested by

See Appendix I for some more case studies

Table 2: Observed and estimated values of AE (Gravimetric lysimeter - BW3 A).

Period: 4th October to 31st December 1976. K = 150 mm

Period	E mm/'n' days	P mm	(AE)/E O	AE, mm/'n' O	AE, mm/'n' O	Cumulative AE O	Cumulative AE O	Remarks
4/10 - 9/10	35.0	NX	.74	26.1	22.5	26.1	22.5	SOWING
9/10 - 25/10	99.6	25.9	.61	62.2	66.8	88.3	89.3	
25/10 - 5/11	60.6	70.8	.84	50.5	60.2	138.8	149.5	
5/11 - 12/11	36.3	22.9	.94	34.1	22.4	172.9	171.9	L=84 days
12/11 - 19/11	30.8	4.2	.78	21.8	28.8	194.7	200.7	
19/11 - 26/11	21.3	5.1	.86	17.1	19.0	211.8	219.7	
26/11 - 3/12	35.2	0.0	.53	17.6	18.9	229.3	238.6	
3/12 - 10/12	32.1	83.2	.94	29.7	30.4	259.0	269.0	
10/12 - 17/12	33.8	0.0	.74	25.3	17.8	284.3	286.8	Chickpea w… infested b… disease.
17/12 - 24/12	31.7	0.0	.54	17.1	9.7	301.4	296.5	
24/12 - 31/12	41.4	0.0	.21	7.7	5.9	309.1	302.4	HARVEST

SOWING = 8/10/1976 C = Computed

HARVEST = 31/12/1976 O = Observed*

NX = Saturated soil

AE = Actual Evapotranspiration, mm/period

E = Pan evaporation, mm/period

P = Precipitation/or supplemental water, mm

* Observations were taken by Mr. S. Ramakrishna and Mr. Thomas

Dr. M.B. Russell to Dr. J.G. Ryan*) has been taken for the computation of AE. The procedure followed in the estimation of AE is same as that explained above. Table 3 presents the estimated AE values along with precipitation, evaporation, soil moisture at the end of each week, drainage and runoff.

In this case the soil moisture balance is obtained as follows:

If $SM_{n-1}+P_n - RO_n > K$ then $D_n = P_n - RO_n - K + SM_{n-1}$

and $SM_n = K - AE_n$ = (Soil moisture at the end of the week)

* Group Names of soils included	Estimated soil moisture holding capacities(mm) Available	Total
A Clays, clay loams Deep black cotton, Regur	200	450
B Loamy, light black cotton	150	310
C Sandy, shallow Red, Chalka (Red Sandy Loam), Laterite, Masper (Medium Red)	150	180

If $SM_{n-1}+ P_n - RO_n < K$ then $D_n = 0$

and $SM_n = SM_{n-1} + P_n - RO_n - AE_n$

In this analysis initially SM_{n-1} is considered as Zero (i.e. on 1st week of 1976). Then following the above procedure the values of SM_n and D_n also computed and presented in Table 3.

From this table it is seen that the soil moisture reserve at the end of the season over that of the beginning of the season is 25.0 mm. This is also seen from neutron probe results* (-On 25th and 8th weeks the soil moisture status of the soil is respectively 650 mm and 690 mm nearly).

*All the observed data viz. soil moisture estimates (BW3 A) from neutron probes, $(AE)_0$ from Hydraulic lysimeter (BW3 A) and piezometer data (BW4) have been taken from the "Annual Report of FSRP for 1975 -'76, "ICRISAT.

Table 3 : Comparison of observed and estimated AE, SM and D values over BW3 A watershed (Based on Weekly data).

Period: 1975-76 (Kharif & rabi) K = 200 mm

Week No.	E_n mm/week	P_n mm/week	RO_n mm	D_n mm	SM_n mm o	$(AE)_n$ o mm/week	$\frac{(AE)}{(E)_n}$ o	Soil moisture* mm	Remarks
1	34.3	0.0							
2	36.7	0.0							
3	41.3	0.0							
4	32.2	35.0			14.1	20.9	0.65		
5	37.8	0.0			9.7	4.4	0.12		
6	39.9	0.0			8.9	0.8	0.12		
7	39.9	0.0			8.9				
8	45.5	0.0			8.9				
9	49.7	0.0			8.9				
10	46.2	19.5			8.0	20.4	0.44		
11	63.7	4.1			8.0	4.1	0.06		FALLOW
12	74.9	0.0			8.0				
13	63.0	0.0			8.0				
14	76.3	0.0			8.0				
15	88.9	0.0			8.0				
16	74.9	0.0			8.0				
17	83.3	0.0			8.0				
18	85.4	0.0			8.0				
19	102.9	0.0			8.0				
20	107.1	0.0			8.0				
21	107.1	0.0			8.0				
22	79.1	48.1			8.8	47.3	0.60		
23	81.9	0.7			2.2	7.3	0.09		
24	59.5	8.2			0.9	9.5	0.16		
25	64.4	2.5			0.0	3.4	0.04	656/357	
26	51.1	38.9			0.0	39.8	0.78		SOWING
27	22.4	99.1	0.4		78.1	20.6	0.92		
28	30.8	22.1			71.7	28.5	0.93		
29	41.3	10.6			51.1	31.2	0.76		
30	38.5	3.9			30.7	24.3	0.63		L_1=100 days (kharif)
31	24.5	108.2	1.1		113.6	24.2	0.99		
32	29.4	5.8			192.9	26.5	0.90		
33	31.5	47.1			109.5	30.5	0.97		
34	35.0	4.6			85.1	29.0	0.83	762/392	
35	24.5	51.1			112.0	24.2	0.99		
36	21.7	234.3	93.8	52.5	178.4	21.6	0.99		
37	29.4	35.6		14.0	171.8	28.2	0.96		
38	31.5	21.0			163.3	29.5	0.94		
39	16.1	113.5	22.9	53.9	184.5	15.5	0.97		HARVEST
40	26.6	39.1		23.6	177.1	22.9	0.86		

Contd..... pg. 18

1	2	3	4	5	6	7	8	9	10	11
41	25.2	9.4			173.8	12.7		0.51		
42	34.3	59.8	0.7	22.9	170.9	29.1	36.4	0.85	820/420	SOWING
43	25.2	55.2		26.1	176.9	23.1	37.4	0.92		
44	19.6	10.5	0.2		169.5	17.7	34.3	0.91		
45	28.7	14.5			160.0	24.0	26.2	0.84		
46	34.3				139.4	20.6	20.9	0.60		
47	32.9				121.1	18.3	16.3	0.56		
48	31.5				104.2	16.9	16.5	0.54		
49	32.9				88.3	15.9	15.5	0.48	743/396	L_2 = 130days
50	35.0				74.6	13.7	12.3	0.39		
51	33.6				62.5	12.1	15.5	0.36		(Rabi)
52	36.8				51.5	11.0	11.5	0.30		
1	30.8				43.1	8.4	7.1	0.27		
2	35.7				35.6	7.5	9.4	0.21		
3	32.2				29.8	5.8	6.2	0.18		
4	35.0				26.7	3.1	4.4	0.09		
5	38.5				25.6	1.1	5.8	0.03		
6	44.8				25.6	0.0	9.8	0.00		
7	48.3				25.6	0.0	11.0	0.00		
8	55.3				25.6	0.0	-	0.00		HARVEST
10									691/388	

* Top value - 0-180 cm layer value, bottom value - 0-90 cm layer value

E_n = Pan evaporation of the week, mm/week;

P_n = Precipitation " " " , mm;

RO_n = Runoff " " " , mm; 12.1%

D_n = Deep drainage " " " , mm; 20.6%

SM_n = Soil moisture status at the end of the week, mm;

C = Computed

O = Observed

AE_n = Actual evapotranspiration of the week, mm/week.

Abnormally high values

Out of the total rainfall 984 mm received in this period 12.1 and 20.6 per cent respectively are contributed to surface runoff and deep drainage and 68.7 per cent to actual evapotranspiration. The near actual evapotranspiration for the two seasons is only 64% of the pan evaporation. The results of piezometer measurements suggests that the amount of water percolated down to ground water under double cropped conditions on the deep black soils is approximately 20% of the seasonal rainfall. The estimated value (20.6) is comparable with this observed value.

Where the high soil moisture and deep drainage is recorded in these computations are also supported by soil moisture results estimated by neutron probes.

The AE values estimated in this case for rabi crop are also comparable with the observed AE values from week no. 46 to 4th week. In the case of observed data supplemental irrigation was given at 12 weeks after seeding and also the first three values show abnormally high values.

On the whole these results suggest that this method can be used quite accurately for the estimation of AE, SM and D values. However, this has to be verified over other soil types also.

Case (iii): Comparison of observed and estimated values of AE - Based on Hydraulic lysimeter experiments at SAMARU:

Figs. 5a, b, c & d representss the cumulative totals of observed and estimated values of AE for four years (1971 - '74) under four different crops (viz. Cotton, Maize, Groundnut and Gero Millet) along with the cumulative totals of E (estimated using Penman's method - presented by Kowal et al.,1973, 1975, 1975, 1975) and rainfall at different decades (as presented by Kowal et al., 1973, 1975, 1975 1975). In all these four cases the estimated values don't show much deviation from observed values, however, the computed values are slightly less than observed AE values. It is because, in the computation of AE, the rainfall has been assumed to have been occurred on the first day of that decade.

Case (iv): Comparison of observed and estimated values of soil evaporation (AE) - Based on Gravimetric lysimeter in BW3A watershed and Hydraulic lysimeter in RW1:

Figs. 6a, b, c, d and e represents the results of five experiments conducted in BW3A watershed (deep black soil) using Gravimetric lysimeter. It can be seen from all these figures that the estimated values do not deviate much from observed values. In all these cases the soil has been wetted initially with supplemental irrigation and allowed to dry.

A comparison has also been made between observed (controlled experiments by soil physics group in deep black soils)* and estimated values of soil moisture at the end of the season for chickpea (one case) and sorghum (three cases) knowing the soil moisture at sowing and water added in between. The difference between observed and estimated soil moisture status is of the order of ± 10 mm (results not presented here).

5. CONCLUSIONS AND FUTURE PLANS:

A new and simple tentative method of computing the evapotranspiration or evaporation from the soil has been suggested and tested with the available observed data and found it good fit. The salient points of this method are: (1) it differentiates between fallow and cropped situation, (2) takes into account the evaporative demand condition (3) soil and crop factors and, (4) crop growth stage factors.

Based on this concept the accounting of soil water balance over watersheds has been suggested. Using this analogy the soil water balance over BW3A watershed for 1975 - '76 period (which comprises kharif and rabi crops) had been computed and compared with the available observed data and found good fit. This method can also be used to estimate deep percolation knowing surface runoff. The main advantage of this method is that it estimates the soil moisture and runoff (surface + deep drainage) knowing the value of K (maximum available soil moisture factor) accurately as the estimates of AE are mainly dependent upon the precipitation, pan evaporation and time.

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It is proposed to conduct field experiments to establish this methodology, where in the crop growth stage coefficients for each crop, cropping patterns are to be determined.

Then using this model, at selected stations that are of primary importance in each climatic zone, the water balance analysis under different soil conditions for different crops/varieties/cropping pattern are to be made. Viz. as it is possible to see with this method that at a station whether kharif fallow helps the rabi crop or rabi fallow helps the kharif crop (in the succeeding season) or double crops (kharif and rabi) are possible or long period crop (kharif or rabi) is possible or late kharif or early rabi is favourable. On the basis of this study, the best possible crop/variety/cropping pattern to be followed in different zones under different rainfall conditions with little of risk under proper land and water management will be suggested.

For this purpose the following procedure has to be adopted.

1. Compute AE/E, SM and (RO + D) using WATBAL for each of the year under different cropping systems for a particular value of sowing week and K.

2. Compute AE/E for different probability levels using gamma distribution. Then fit the crop requirement histograms (Virmani, 1976) of AE/E to the suitable probability level of AE/E. This will suggest the probability of success of that cropping system for that week of sowing.

3. Compute the probability levels of soil moisture status at the end of the every week for 50 and 25% of K. This will help in knowing the probability of survival in case if the next week is dry.

4. Compute mean RO + D for 1 to 52 weeks. This can be utilised to study the probable tank models.

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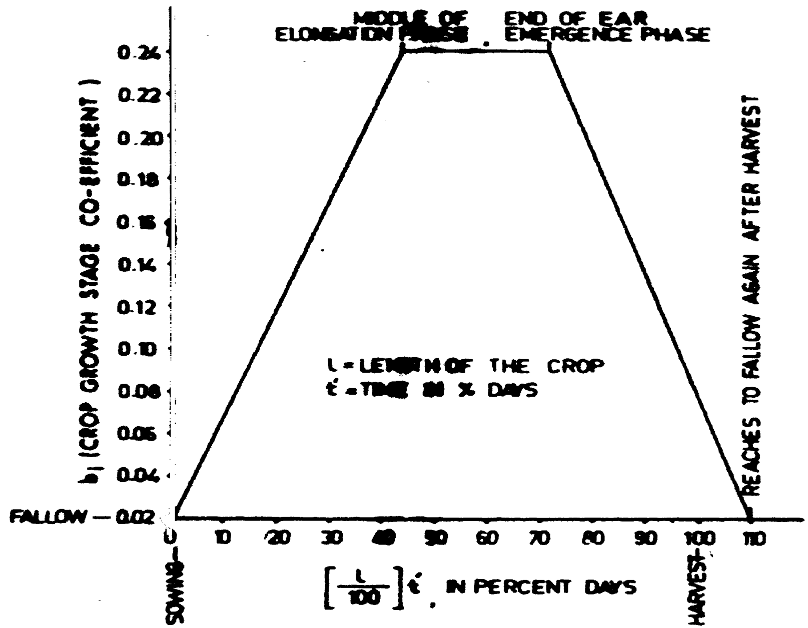


FIG. 1 : VARIATION OF b_i WITH GROWTH STAGES OF A CROP

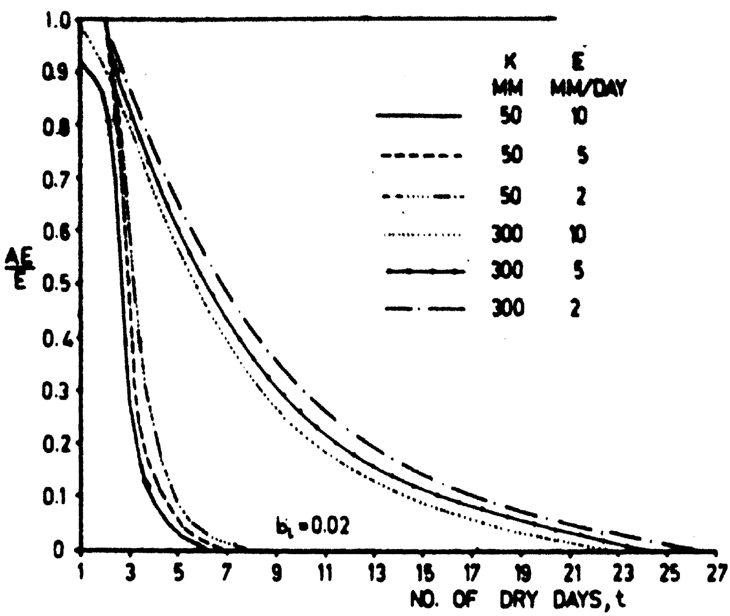


FIG. 2a : VARIATION OF AE/E WITH TIME UNDER FALLOW CONDITION.

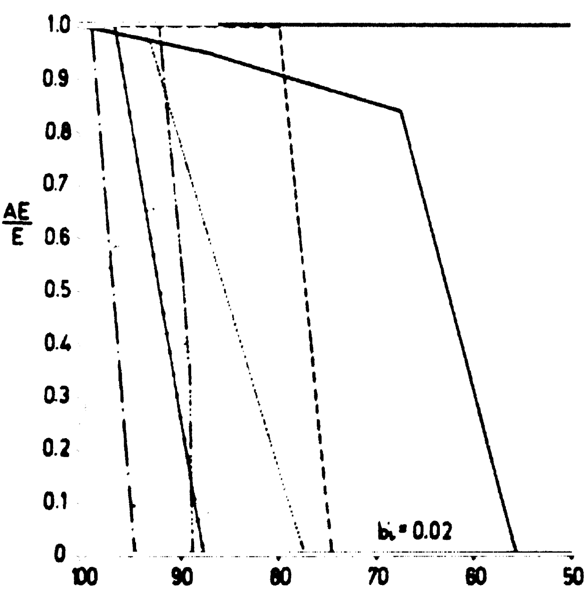


FIG. 2 b: VARIATION OF AE/E WITH % AVAILABLE SOIL MOISTURE UNDER FALLOW CONDITION.

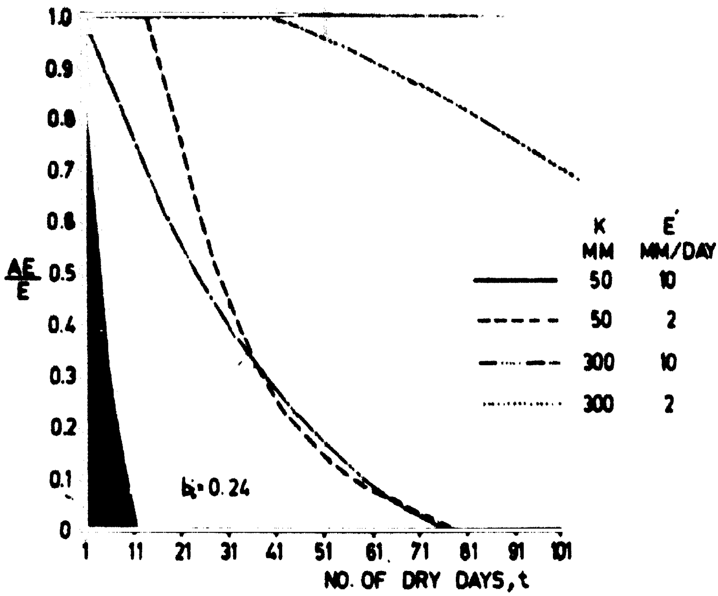


FIG. 3a: VARIATION OF AE/E WITH TIME UNDER MAX. TRANSPIRATION CONDITION.

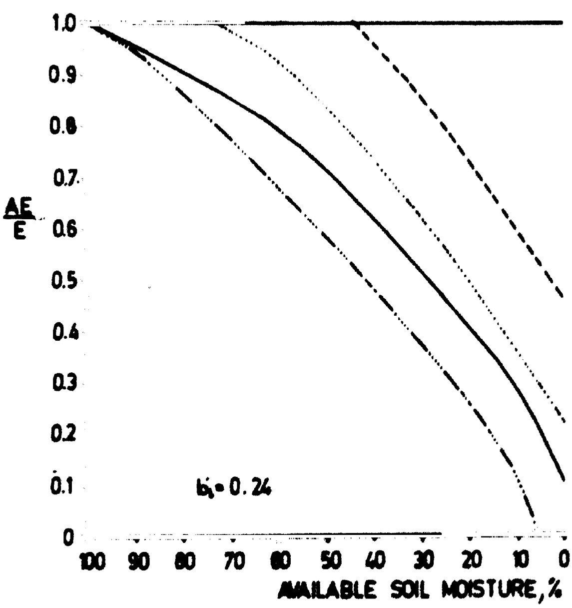


FIG. 3b: VARIATION OF AE/E WITH % OF AVAILABLE SOIL MOISTURE UNDER MAX. TRANSPIRATION CODITION.

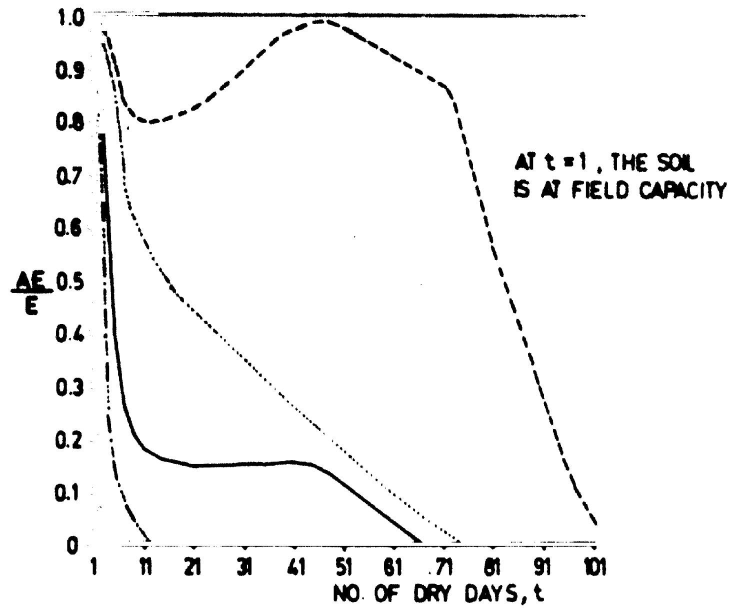


FIG. 4a : VARIATION OF AE/E WITH TIME UNDER CROP SITUATION.

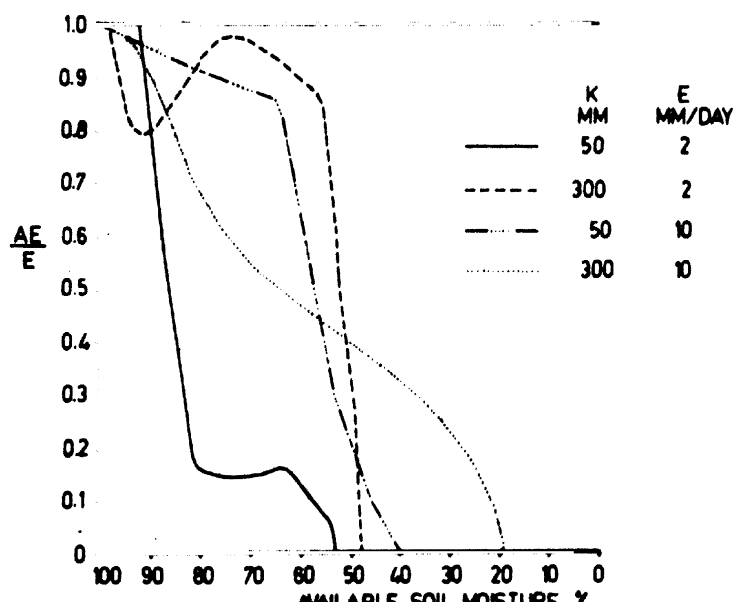


FIG. 4b: VARIATION OF AE/E WITH % OF AVAILABLE SOIL MOISTURE UNDER CROP SITUATION.

STATION: SAMARU
YEAR : 1971

CROP: COTTON
L: 165 DAYS K = 150 MM

E = PAN EVAPORATION; AE = EVAPOTRANSPIRATION; O = OBSERVED; C = COMPUTED

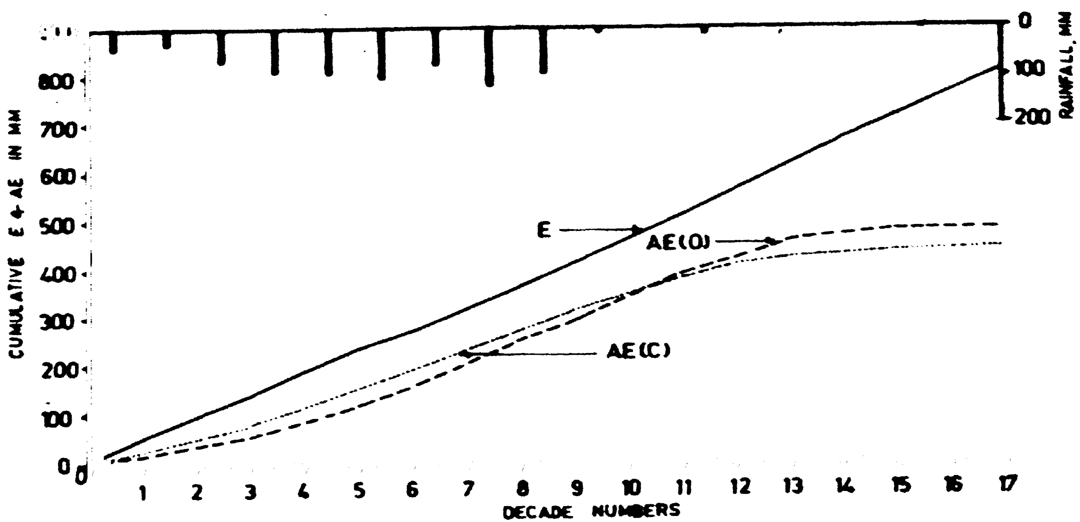


FIG.5a - COMPARISON OF OBSERVED AND ESTIMATED EVAPOTRANSPIRATION VALUES (HYDRAULIC LYSIMETER/SAMARU)

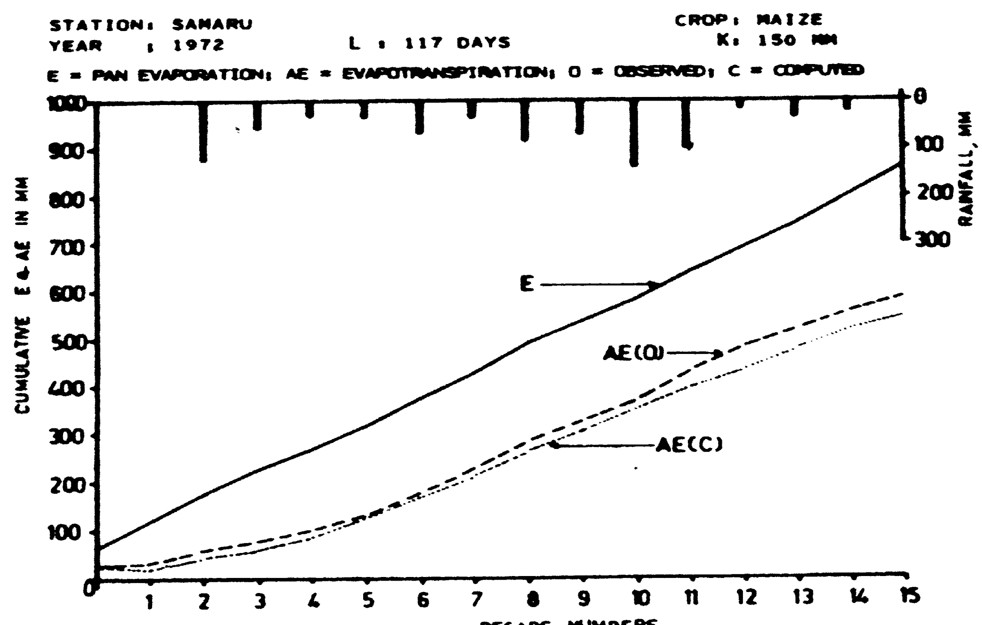


FIG.5b - COMPARISON OF OBSERVED AND ESTIMATED EVAPOTRANSPIRATION VALUES (HYDRAULIC LYSIMETER/SAMARU)

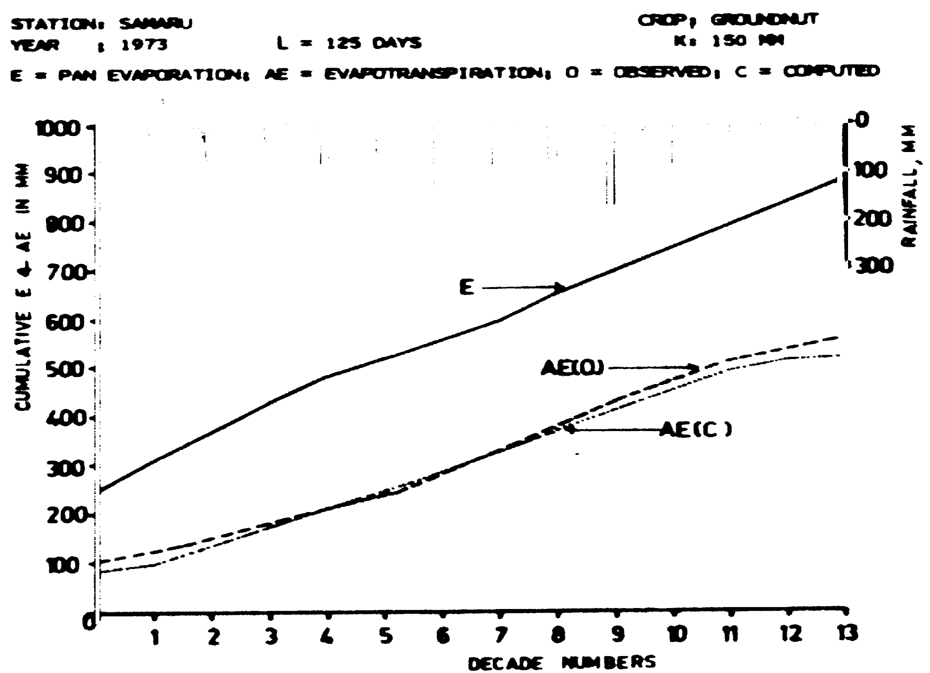


FIG.5c – COMPARISON OF OBSERVED AND ESTIMATED EVAPOTRANSPIRATION VALUES (HYDRAULIC LYSIMETER/SAMARU)

STATION: SAMARU CROP: GARD MILLET:
YEAR : 1974 L = 90 DAYS K: 150 MM

E = PAN EVAPORATION; AE = EVAPOTRANSPIRATION; O = OBSERVED;
C = COMPUTED

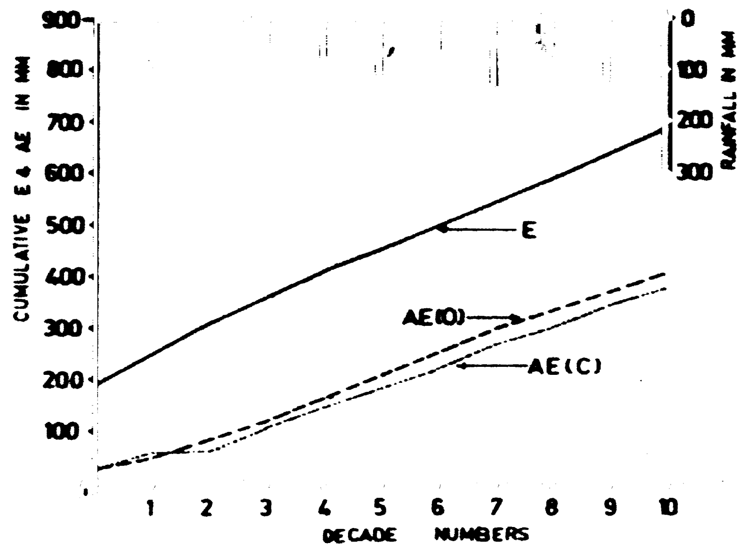


FIG.5d - COMPARISON OF OBSERVED AND ESTIMATED EVAPOTRANSPIRATION VALUES (HYDRAULIC LYSIMETER/SAMARU)

E = PAN EVAPORATION; AE = SOIL EVAPORATION;
O = OBSERVED; C = COMPUTED

PERIOD: 7-1-1977-16-1-1977

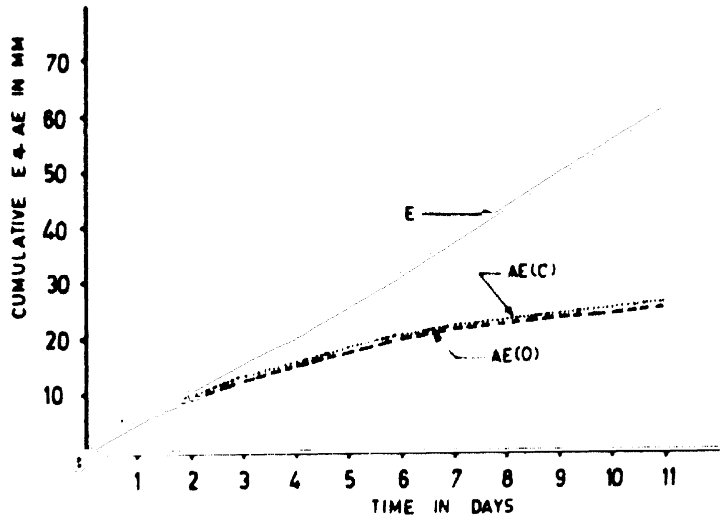


FIG.6B - COMPARISON OF OBSERVED AND ESTIMATED SOIL EVAPORATION (GRAVIMETRIC LYSIMETER/ICRISAT)

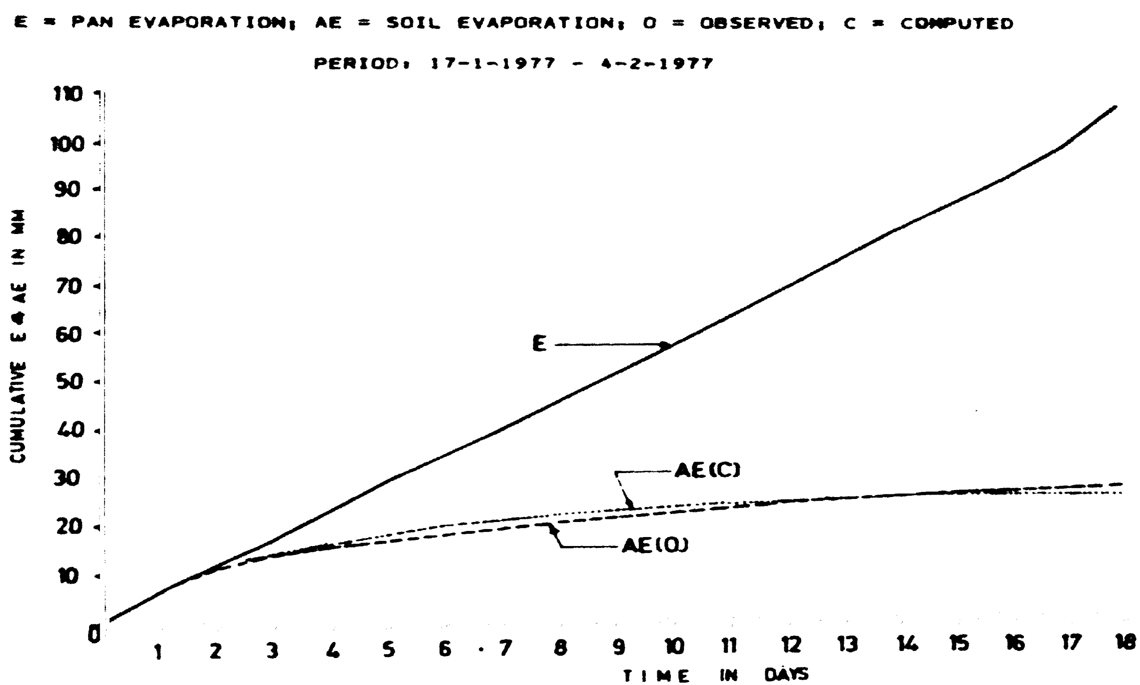


FIG.6b - COMPARISON OF OBSERVED AND ESTIMATED SOIL EVAPORATION (GRAVIMETRIC LYSIMETER/ICRISAT)

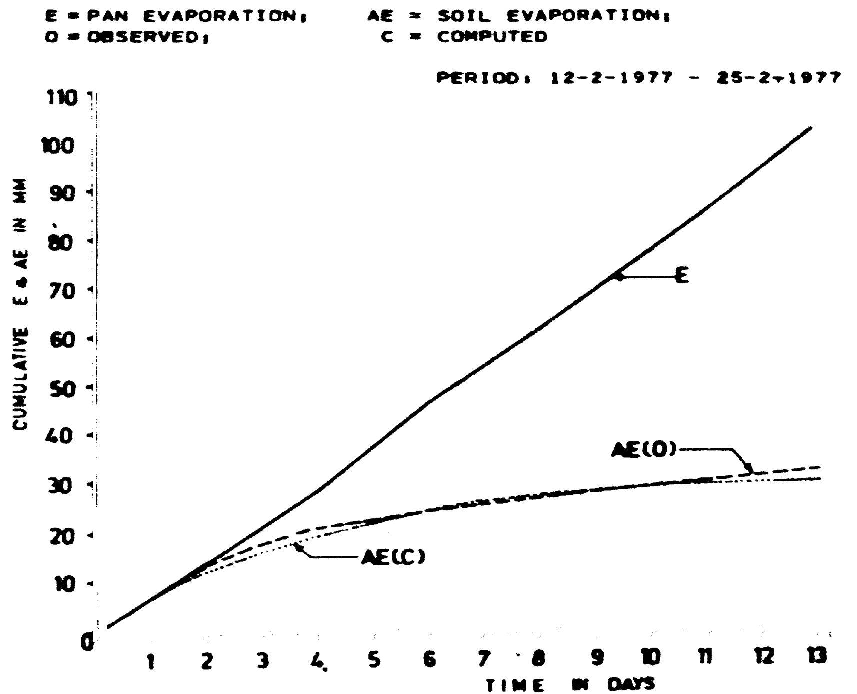


FIG.6c - COMPARISON OF OBSERVED AND ESTIMATED SOIL EVAPORATION (GRAVIMETRIC LYSIMETER/ICRISAT)

E = PAN EVAPORATION; AE = SOIL EVAPORATION;
O = OBSERVED; C = COMPUTED

PERIOD: 1-3-1977 - 14-3-1977

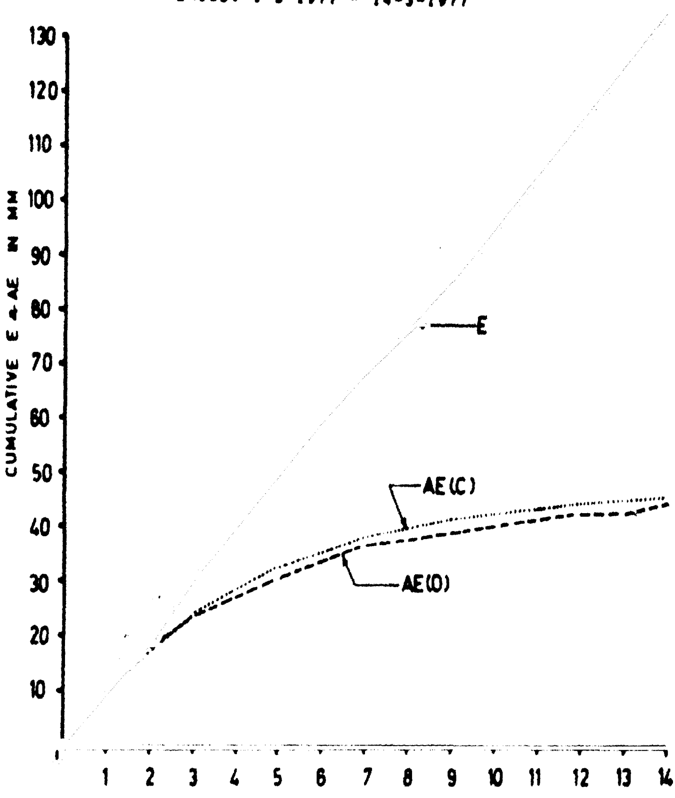


FIG.6d - COMPARISON OF OBSERVED AND ESTIMATED SOIL EVAPORATION (GRAVIMETRIC LYSIMETER/ICRISAT).

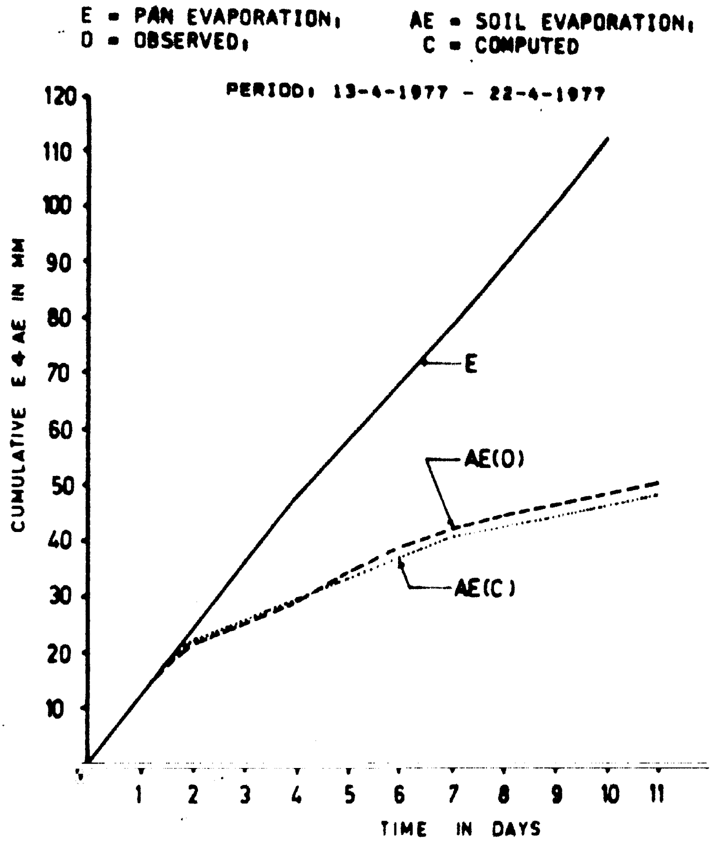


FIG.6e - COMPARISON OF OBSERVED AND ESTIMATED SOIL EVAPORATION (GRAVIMETRIC LYSIMETER/ICRISAT)

APPENDIX-I

Verification of WATBAL Model

An attempt has been made to verify the WATBAL model suggested by Reddy (1977) using the data of ICRISAT Farm for 1977 (15th June to 7 th October) Kharif season. The data used for this analysis are the rainfall records of RW1 (for Red soil) and BW1A (for black soil) and open pan evaporation from Met. observatory. The details of the crop & soil for which the analysis has been made are given below:

S.No.	Place	Soil	K, mm (maximum available soil moisture)	Crop	Length of the crop in days
1.	ST2	Red	100	Fallow	-
2.	ST2	Red	100	Sorghum	92
3.	RW1*	Red	100	Pearl millet	100
4.	BW3A	Deep black	200	Maize + P.pea	80 + 180
5.	BW1A	Deep Black	200	Fallow	-

* (Comparative results are not available)

Figs. 1 and 2 depicts the estimated soil moisture at the end of each day $(SM)_c$, the ratio of evapotranspiration (AE)/evaporation (E), Runoff which includes both surface runoff and deep drainage (RO + D) and observed soil moisture $(SM)_o$ and Rainfall (R). Table 1 presents the observed and estimated soil moisture (The observed soil moisture data has been taken from soil physics group: Drs. Sardar Singh & Piara Singh). It is seen from the figures and the table that the observed and estimated soil moisture data for different dates are found to be in good agreement.

Symbols:

$(SM)_o$ = Observed soil moisture, mm
$(SM)_c$ = Computed soil moisture, mm
$(AE/E)_c$ = Computed relative evapotranspiration
RO + D = Computed surface runoff + Deep drainage, mm
R = Rainfall
(Figures are self explenatory)

Comparison of observed and estimated soil moisture at ST2 and BW3A watershed (ICRISAT-Farm)

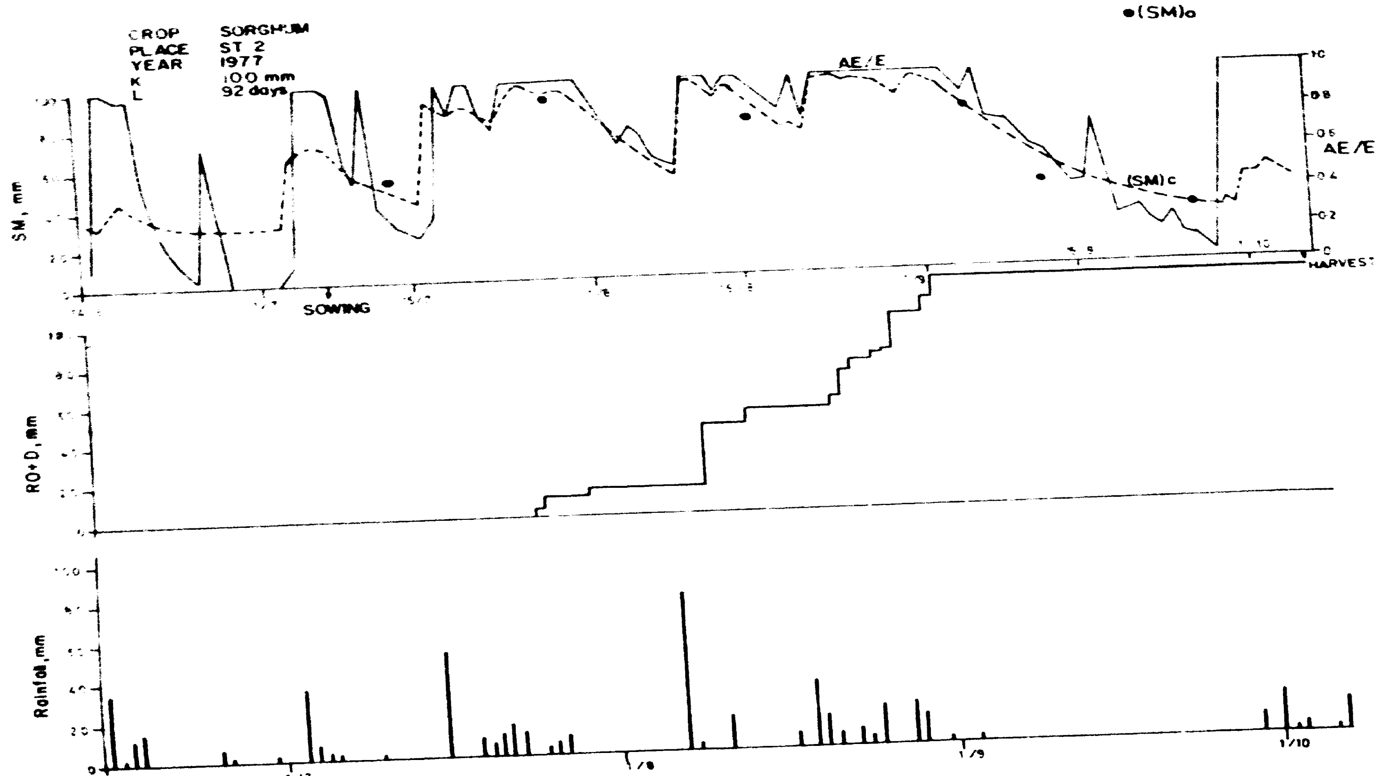
	ST2 (Sorghum)				BW3A (Maize + Pigeonpea)					
	Fallow case		Cropped case		Cropped case				Fallow case	
Date	Observed	Estimated	Observed	Estimated	Date	Observed	Estimated	Date	Observed	Estimated
13/7/77	64.4	54.0	58.1	47.0	22/6/77	47.3	17.6	14/6/77	13.6	0.0
18/7/77	89.6	90.0	86.1	87.3	14/7/77	1.2	0.2	11/7/77	38.0	28.0
28/7/77	98.5	93.7	90.1	93.7	1/8/77	69.9	67.5	19/7/77	70.1	69.8
4/8/77	85.1	83.5	74.1	71.7	18/8/77	82.2	85.8	3/8/77	85.5	83.4
16/8/77	92.7	91.0	80.2	88.9	8/9/77	124.3	137.1	18/8/77	130.2	142.5
5/9/77	85.8	90.3	84.0	84.4	22/9/77	85.3	[illegible]	7/9/77	166.7	186.2
12/9/77	81.1	87.7	46.3	56.0				19/9/77	151.0	177.0
26/9/77	72.5	83.5	32.7	28.6				6/10/77	200.0	184.7
5/10/77	90.8	93.8	55.7	43.0				17/10/77	159.0	176.6

Sorghum: Sowing 7/7/1977; Harvesting 6/10/1977

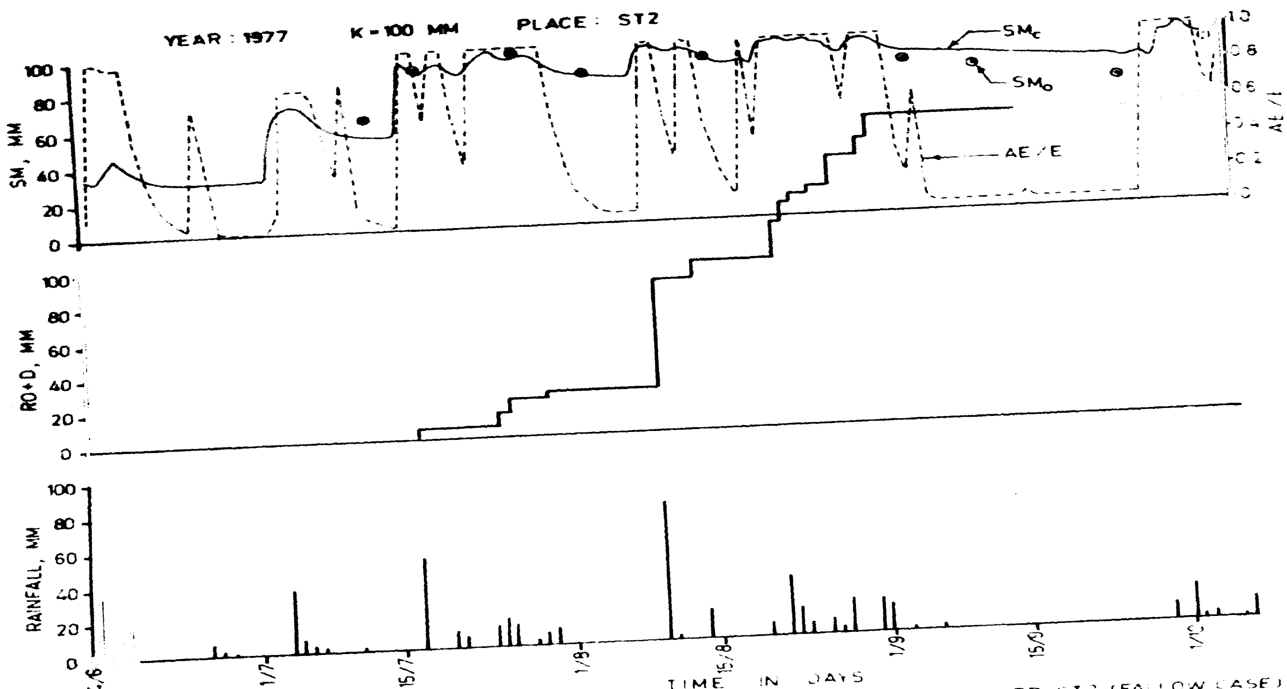
Maize + Pigeonpea: Sowing 14/6/1977; Harvesting of Maize 26/9/1977

ST2 : Maximum available water : K = 100 mm

BW3A : " " " = 200 mm



CROP SORGHUM
PLACE ST 2
YEAR 1977
K 100 mm
L 92 days
●(SM)o
AE/E
(SM)c
SM, mm
SOWING
HARVEST
RO+D, mm
Rainfall, mm
1/7
1/8
1/9
1/10

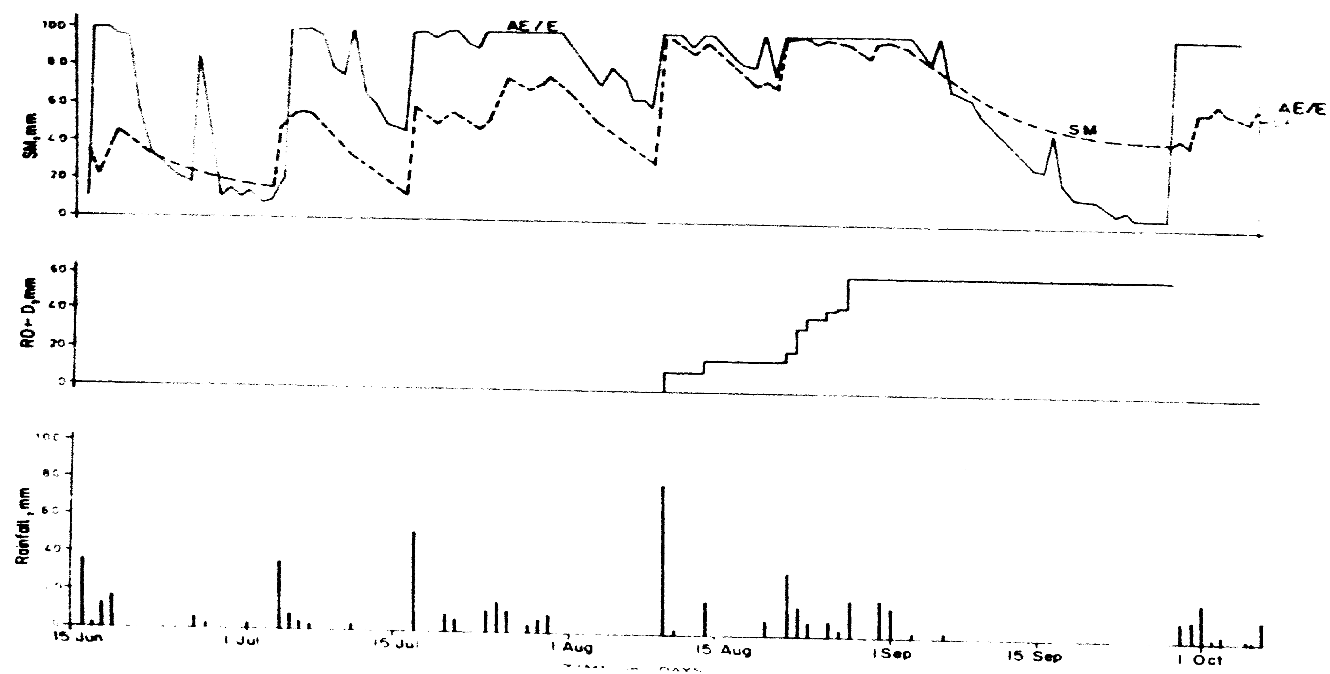


MOISTURE OVER ST2 (FALLOW CASE)

CROP - PEARLMILLET
PLACE - RW I
K - 100 mm

YEAR - 1977
L - 100 days

Fig. 2. WATBAL RESULT OVER RW I



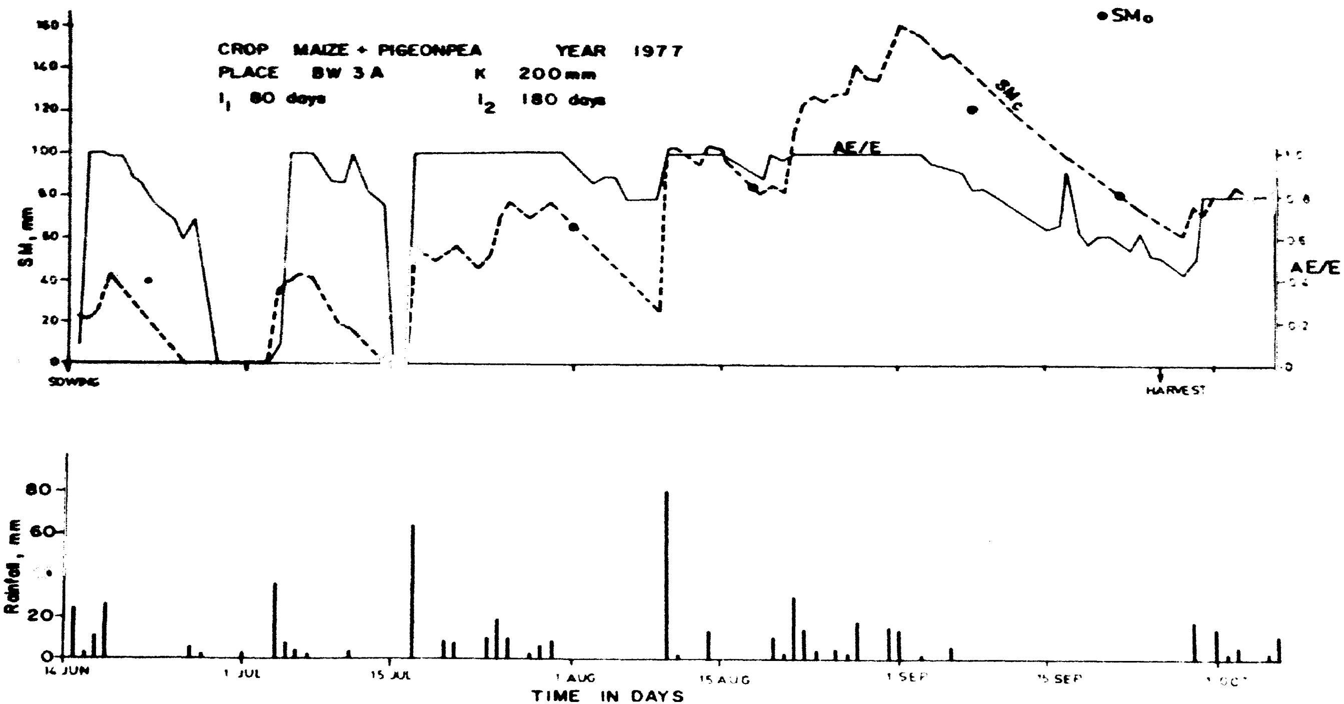


FIG 2 COMPARISON OF ESTIMATED AND OBSERVED SOIL MOITURE OVER BW 3A

svb