FIELD TESTING AND EVALUATION OF A TWO LAYER SOIL WATER BALANCE MODEL

By

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THESIS

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Department of Irrigation and Drainage Engineering

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1997

DECLARATION

I hereby declare that this thesis entitled **Field testing and evaluation of a two layer soil water balance model** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship, or other similar title, of any other University, or Society.

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CERTIFICATE

Certified that the thesis, entitled **Field Testing and Evaluation of a Two Layer Soil Water Balance Model** is a record of research work done independently by **Sri. Mohanan. C.K.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship, or associateship to him.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

SYMBOLS AND ABBREVIATIONS

AET	=	Actual Evapotranspiration
AICRP	=	All India Co-ordinated Research Project
cm	=	centimetre
°C	=	degree celsius
DAS	=	Days after sowing
Dr	=	Doctor
et al.	=	and others
etc.	=	et cetera
fig	=	figure
g/cc	=	gram per cubic centimetre
h	=	hours
KCAET	=	Kelappaji College of Agricultural Engineering and Technology
m	=	metre
m^2	=	square metre
mm	=	millimetre
mm/cm	=	millimetre per centimetre
PET	=	Potential Evapotranspiration
t/ha	=	ton per hectare
USWB	=	United States Weather Bureau
@	=	at the rate of
ie;	=	that is
%	=	Percentage

Introduction

INTRODUCTION

Water is an indispensable resource that finds its use in every aspect of human society. The increase in human population together with rapid industrial and urban development has resulted in ever-increasing demand for water, while the available fresh water supplies have remained more or less constant. Though these available water supplies may seem sufficient, they may not be always easily accessible or evenly distributed in space and time.

Thus it is the effective and judicious utilisation of this resource, rather than the total quantity of available water supplies that has constrained human development.

About 92% of the harnessed water resources are used in agriculture for irrigation (Rao, 1991). Irrigation is the artificial application of water to soil for the purpose of crop production. If is meant to supplement the water available from rainfall and ground water contributions. In many areas of the world, the amount and timing of rainfall are inadequate to satisfy the crop water needs and therefore makes irrigation an essentiality.

In dealing with the comprehensive strategy for the conservation, development and efficient use of water resources, our efforts should aim at making the best use of water so as to make possible a high level of continuous production, ie; to increase agricultural production per unit volume of water per unit area per unit time. This emerges as a dominant factor governing irrigation management. Increasing the water use efficiency in irrigation is therefore crucial.

It is a common observation that irrigation systems do not supply the right quantities of water at the right time for maximum water use efficiency.

To integrate the scientific irrigation practices with irrigation management procedures, we need to generalise the empirical results of field experiments through mathematical models. A mathematically developed soil water balance model can be utilized to determine the optimum quantity of water to be applied and the ideal time for its application.

Several theoretical models in the field of irrigation water management have been developed in the past. But their feasibilities under different specific field conditions are yet to be established. In an attempt to evaluate the practical feasibility of a simple two-layer soil water balance model and its application in irrigation water management, a study was taken up at the Kelappaji College of Agricultural Engineering and Technology, Tavanur with the following specific objectives.

i. to estimate the daily soil moisture conditions in a cropped field using a two layer soil-water balance model.

ii. to evaluate the model with actual field data by raising bhindi.

iii. to modify the components of soil-water balance model utilising the actual field data, if necessary.

Review of Literature

REVIEW OF LITERATURE

This chapter describes about the modelling concepts, general soil-water balance, its various components, the research works carried out in the field of soil water balance, their practical feasibility studies and field testings.

2.1 Concept of a model

Quite often one is confronted with the problem of analysing and designing a project or study with inadequate data or where there are practical limitation in determination of data for a long period. Under the circumstances, planners and engineers have to rely on tools such as synthesis and simulation to generate the desired information with the help of observed historical data so as to make alternative designs for comparison or optimisation in economic analysis. System analysis is the tool usually depended upon in such cases.

A system is a limited part of reality that contains interrelated elements, a model is a simplified representation of a system and simulation is the art of building mathematical models and the study of their properties in reference to those of the system. A mathematical model is simply an equation or set of equations, which represents the behaviour of a system (France and Thornley, 1984).

Testing and evaluation of a model is a continuous process. Testing refers to the correctness of the model, ie; the mathematical equations must correctly represent the stated assumptions. Evaluation is concerned with aspects such as plausibility, goodness-of-fit, elegance, simplicity and utility (France and Thornley, 1984).

2.2. Soil water balance

Water balance is nothing but the book-keeping of the water of a basin or a region in relation to the entire hydrologic cycle or part there of, carried over a specified period of time (Mutreja, 1986). The soil reservoir responds dynamically to rainfall and irrigation inputs by accepting part of the applied moisture, releasing some of it to the atmosphere during evapotranspiration, storing some of it within itself and rejecting a part to the water table by way of percolation. The quantitative relationships among the different components into which the incident rainfall and irrigation water are partitioned is called the soil-water balance (Eagleson, 1978). The components are infiltration, runoff, redistribution, deep percolation out of the root zone, evaporation from the soil and water uptake or transpiration by plants. Evaporation and transpiration can be combined in one term as evapotranspiration, since they are interdependent and occur sequentially or simultaneously within the crop root zone. The soil-water balance models essentially solve the mass balance equation,

$$R+I+U = RO + INF + \Delta S + P + ET, \qquad \ldots(2.1)$$

Where,

R = rainfall,

I = irrigation,

U = upward capillary flux,

RO = runoff,

INF = infiltration,

ΔS = change in the soil moisture storage in the root zone,

P = deep percolation out of the root zone, and

ET = evapotranspiration,

all parameters expressed in units of volume or depth.

2.2.1. Components of soil-water balance

The various components of soil-water balance equation, diagrammatically represented in fig.2.1 are analysed as follows.

2.2.1.1. Rainfall

Rainfall is one of the major inputs in the soil-water balance equation. It occurs due to condensation of moist air. Adiabatic cooling is the main cause of condensation, and it is seen that the vertical transport of air is required for the occurrence of rainfall.

Measurement of rainfall is done by rain gauges. A wide variety of rain gauge types are available and are broadly classified under the heads non recording gauges, recording gauges and weather radars. Simon's gauge is the most commonly used raingauge and its readings are taken usually at 24 h interval, at 8 O' clock in the morning.

2.2.1.2. Irrigation

Irrigation is the artificial application of water to the soil to promote plant growth. Irrigation water is conveyed from the storage reservoirs, ponds, wells or diversion head works to the field by a network of canals, pipes or combination of both.

Measurement of flow through canals can be done in many ways. Rectangular or triangular weirs and parshall flume are well suited for open channels. Orifices or metergates are used for measuring comparatively small discharges through open channels. Velocity of flow measured by the use of current meters can be used to find out the discharge of channels and streams

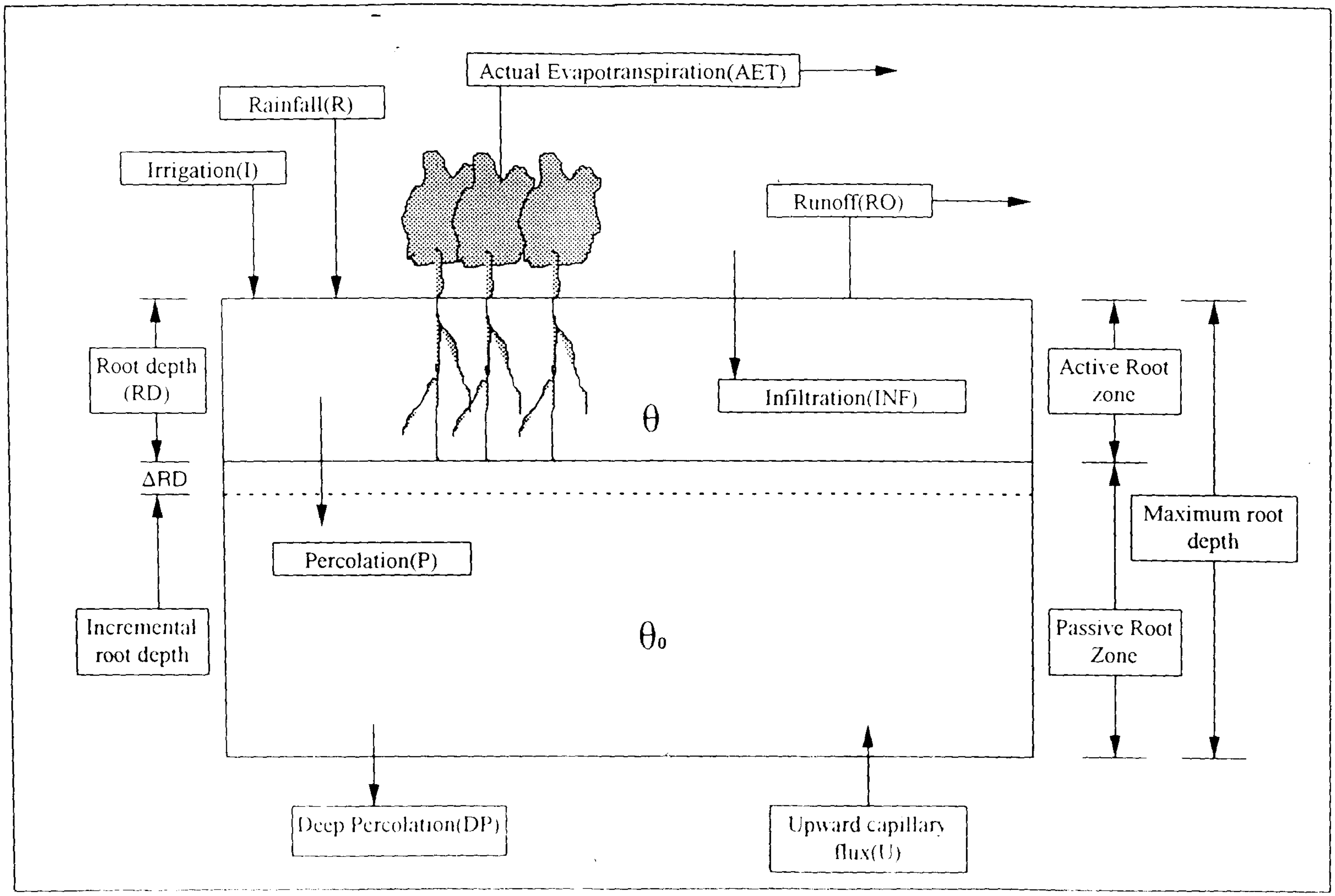


Fig. 2.1 Components of soil water balance

whose area of cross section is known. If the discharge through a pipe is more or less constant, it is obtained experimentally by collecting the water in a container for a specified period of time. Watermeter is a device that measures the quantity of water passing through it and records cumulatively. It can be connected to pipe outlets and it operates satisfactorily, even in varying discharge conditions.

2.2.1.3. Upward capillary flux into the root zone

The upward movement of soil water from the water table can be estimated by empirical equations, based on hydrophysical properties of the soil (Eagleson, 1978). Numerical solutions of Richard's equation of flow through unsaturated porous medium, with the lower boundary as the water table, can also be employed to estimate the upward capillary flux (Dierckx et al., 1986). Sometimes simple analytic solutions derived for steady state flow are used (Hillel, 1980). However this component is usually insignificant, and can be ignored if the ground water table is more than seven metres below the ground surface for heavy soils and more than three metres for light soils (Walker and Skogerboe,1987).

2.2.1.4. Runoff

Runoff is that portion of rainfall or irrigation water applied which leaves the field either as surface or subsurface flow. As long as the rate at which rainfall or irrigation water reaching the soil surface is less than the infiltration capacity, all the water is absorbed into the soil.

Methods of estimation of runoff ranges from simple empirical formulae like the rational method to complex catchment models, like the Stanford watershed model (Crawford and Linsley, 1966). The United States Department of Agriculture, Soil Conservation Service (1972), developed a method of computing runoff from ungauged watersheds, called curve number method. This method has been adopted with certain modifications to Indian watersheds by the Ministry of Agriculture (1972). The procedure consists of selecting the curve number which depends on the antecedent rainfall, the hydrologic soil group, land management and cover and reading the runoff directly from appropriate graphs. This model was further improved by linking retention parameter or curve number, with the soil moisture status (Hawkins, 1978, Sharpley and Williams, 1990).

It is not uncommon in soil-water balance to ignore the runoff totally or to take it as a small, reasonable fraction of rainfall (Rao, 1991).

2.2.1.5. Infiltration and redistribution

The portion of rainfall or irrigation water, which is not lost as runoff infiltrates into the soil reservoir. Infiltration rate is governed by the characteristics of the soil as well as of the rainfall or irrigation.

After infiltration process comes to an end the downward movement of water continues for a long time as the infiltrated water redistributes itself within the soil profile. This process determines the moisture storage in different depths of the soil profile that is available for plant uptake. The rate of redistribution depends on the hydraulic properties of the soil and the initial wetting depth. After some time, the rate of redistribution decrease rapidly and the wetted soil profile retains its moisture until it is evaporated or taken up by plants. The water content at which the redistribution ceases is called the field capacity. It has been accepted as a physical characteristic and constant for a given soil. Soil profile is divided into different layers and each layer is assumed to fill to field capacity and then pass any remaining water to the layer below. It is also assumed that the redistribution of water in the soil profile is instantaneous. If the evapotranspiration continues with no additional input of water, the water content in the soil depletes and reaches such a stage that no more water is available from the soil, for the plant metabolic activities. The water content in the soil at this stage, is called the permanent wilting point. Thus the field capacity and permanent wilting point defines the limits of moisture storage in the soil reservoir.

2.2.1.6. Deep percolation

Deep percolation water is a part of infiltrated water that escapes below the root zone of the plant. There are many empirical relations developed using the soil characteristics to estimate the quantity of water lost due to deep percolation. Eagleson (1978) derived a general empirical expression for the percolation rate P as

$$P = K_s \, (\Theta / \Theta_{sat})^c - w \qquad \ldots(2.2)$$

in which,

K_s = saturated hydraulic conductivity of the soil,

Θ = soil moisture content in the root zone,

Θ_{sat} = soil moisture content at saturation,

c = pore connectivity index,

w = rate of capillary rise,

Piston flow concept of simple soil-water balance models used for the redistribution of soil moisture can be extended to estimate the deep percolation. By this procedure the moisture in excess of field capacity in the bottom most layer of plant root zone is considered to be lost from the soil reservoir as deep percolation (Rao, 1987; Arora et al., 1987).

The equation proposed by Raes et al. (1988) expresses the percolation rate as

$$P = \frac{C(\theta_{sat} - FC)\,[\exp(\theta - FC) - 1]}{[\exp(\theta_{sat} - FC) - 1]} \qquad \ldots(2.3)$$

where, C is a constant depending on the soil type and FC is the field capacity.

2.2.1.7. Evapotranspiration

Evaporation is the process by which liquid water is converted into vapour. It occurs when the molecules of water have sufficient kinetic energy to overcome the attractive forces tending to hold them in the body of liquid water.

Transpiration is defined as the natural plant physiological process where by water is taken from the soil moisture storage by roots and pass through the plant structure and is evaporated from the cells in the leaf called stomata.

Land, on which plants grow, loses water by both evaporation and transpiration. In most of the cases the effects of evaporation and transpiration are combined together and is called evapotranspiration. It is defined as the water vapour lost from a land as a result of the growth of plants in that land.

When the soil water is freely available to the crop and canopy covers the ground completely, the rate of water loss depends entirely on meteorological factors. This evaportranpiration is commonly expressed as reference evapotranspiration. Even when the soil water is freely available, the evapotranspiration is less than the reference evapotranspiration, when the crop cover is incomplete. This evapotranspiration, is termed as potential evapotranspiration and defines the upper limit of evapotranspiration from a soilvegetation unit at any time. It is possible to estimate the value of potential evapotranspiration, from the reference evapotranspiration, using empirically derived crop coefficients.

$$PET = K_c \, ETO \qquad \ldots(2.4)$$

where,

PET = potential evapotranspiration,

ETO = reference evapotranspiration, and

K_c = crop coefficient derived empirically for each crop, location and irrigation management condition.

When the available soil moisture in the root zone of the crop becomes limiting, the actual evapotranspiration falls below its potential rate. Several hypotheses of plant water uptake under different conditions of available soil moisture have been put forward to estimate the actual evapotranspiration.

The earliest concept of soil water availability to plants was that advocated by Veihmeyer and Hendrickson (1955). According to this concept, soil water is equally available to plants throughout a definite range of soil wetness from an upper limit of field capacity to a lower limit of permanent wilting point.

Thornthwaite and Mather (1955) suggested that the soil water availability to plants decreased linearly with decreasing soil water content in the range of field capacity to permanent wilting point.

Denmead and Shaw (1960) carried out several experiments and found a critical point somewhere between the field capacity and permanent wilting point, above which the evapotranspiration occurs at its potential rate, and below which it is a decreasing function of the moisture content. Thus, for a given potential evaporation rate there is a threshold average soil water content in the root zone, below which the soil water conditions begin to limit the evapotranspiration process.

Based on an analysis of several experiments carried out at different locations, Doorenbos and Kassam (1979) have presented a simplified linear model, which is mathematically represented as

$$AET = PET, \text{ if } D.\,MC \geq (1\text{-}P)\,(ASW.D) \qquad \ldots(2.5)$$

$$AET = \frac{D.MC}{(1\text{-}P)\,ASW.D}\; PET, \text{ if } D.MC < (1\text{-}P)\,(ASW.D) \qquad \ldots(2.6)$$

where,

D	=	depth of the root zone, cm
AET	=	actual evapotranspiration, mm
PET	=	potential evapotranspiration, mm
MC	=	moisture content in the root zone, mm/cm
P	=	soil water depletion factor,
ASW	=	the difference between field capacity and permanent wilting point, ie; the maximum available soil water per unit soil depth, mm/cm.

In this relation the soil moisture contents are measured with respect to permanent wilting point. In general, the tolerable range of soil water depletion, (1-P) ASW.D is narrow for crops where the harvested part is fleshy or in the fresh form, but is wider for crops where the harvested part is dry.

Based on results of field and laboratory experiments conducted world-wide, Doornbos and Kassam (1979) have proposed that, the soil water depletion factor depends on the type of crop and potential evapotranspiration.

Bras and Cordova (1981) developed a general mathematical relationship,

$$AET = PET, MC \geq CMC \qquad ...(2.7)$$

$$AET = PET. (MC/CMC)^b, MC < CMC \qquad ...(2.8)$$

where, CMC is the critical moisture content. Each set of crop, soil, growth stage and climatic combinations will have a different set of parameters b and critical moisture content.

Direct methods for measurement of evapotranspiration are lysimeter experiments, field experimental plots, soil moisture depletion studies and water balance method, all of which are laborious, costly and time consuming. Determination of evapotranspiration by the use of standard USWB class A open pan evaporimeter or sunken screen open pan evaporimeter (Sharma and Dastane, 1968) include in the indirect methods. Climatological data are the major inputs for the evapotranspiration models developed by Thornthwaite (1948), Penmann (1948), Blanney and Criddle (1950) and Christiansen (1968).

2.3. Depth of root zone

The depth of active soil reservoir from which crops extract water depends on the effective depth of penetration of the roots into the soil. This depth increases with the crop growth and attains a maximum value by the end of the flowering period for most of the crops. Soil moisture balance studies employ root growth models, to describe the increasing depth of root zone with time during the crop growing season.

The root growth models may be linear, piecewise linear or sigmoidal.

Borg and Grimes (1986) reviewed field data of root growth for several crop series and locations and proposed a sigmoidal relationship,

$$Z = 0.5\, Z_{max} + 0.5\, (3.03 \sin (t/t_{max}) - 1.47) \quad ...(2.9)$$

where, t_{max} = time in days to attain the maximum depth, Z_{max}

Z_{max} and t_{max} are the required input data for this model. If impeding soil layers are present at any depth within the root zone, Z_{max} is set equal to this depth.

The piecewise linear model reported by Rao (1987) need data of root growth at intermediate periods of crop growth. The growth between data points is assumed to be linear with time.

2.4. Soil moisture measurement

The soil moisture content is expressed in terms of (i). the amount of water in a given amount of soil, or (ii). the stress or tension with which the water is held in the soil. Based on these the soil moisture may be measured by (i). gravimetric method (ii). using tensiometers (iii). pressure membrane and pressure plate technique (iv). electrical resistance method (v). neutron moisture meter method etc.

In gravimetric method, soil samples taken in airtight container are weighed, dried in the oven at 105°C for 24 h, cooled slowly to room temperature and weighed again, the difference in weight being the amount of moisture in the soil.

The tensiometer consists of a porous ceramic cup filled with water, which is buried at any desired depth in the soil. A water filled tube connects the ceramic cup to a vacuum gauge, which indicates the drop in hydrostatic pressure as the water in the cup tend to equilibrate with soil water, which is at subatmospheric pressures.

The electrical resistance method makes use of the electrical conductivity of a porous solid on the water content. Porous gypsum blocks containing electrodes when embedded in the soil, its moisture content comes in equilibrium with soil moisture. A resistance meter measures the electrical resistance between the electrodes which varies with the moisture content of the block. The resistance meter which is calibrated against a range of moisture contents gives the required readings.

2.5. Soil water balance models and their applicability

From an agronomic point of view, in its simplest form soil water balance calls for an explanation of the critical state variable of the crop growth namely soil water content. From a mechanical consideration, we could explain it in terms of law of conservation of matter. The water content in a given volume of soil cannot increase without addition from outside, nor it can diminish unless transported to atmosphere by evaporation or to deeper zones by drainage (Hillel, 1977). From the concept of continuity it follows that, the difference between input to the system and output from the system is the change in the storage in the system. Change in storage is positive if gains exceeded losses and conversely it is negative when losses exceed gains.

It is worth to remember that, though the soil water balance approach is a general one, the estimation of its various components is location specific. The data input to the model depends on type of crop, soil conditions, regional differentiation and climatic conditions.

In execution, it is extremely difficult to have complete knowledge of all the components of soil water balance equation. If all the components except one are known, the unknown component can be estimated from soil water balance. Hence modelling of soil water balance becomes a favourite tool for planners and irrigation engineers.

Soil water balance models primarily help us to know when to irrigate and how much to irrigate. It is based on soil moisture content that results from simultaneous effect of all variables and constraints on the decision variable. When the soil water content falls below a critical value, the water availability to plants is affected and it is the ideal time to give irrigation.

The type of model we select depends on the degree of complexity of the system modelled, with the simplest case of simulating water infiltration in bare soil, secondly energy balance at bare soil surface including process of evaporation and lastly, simulation models that include plants and process of transpiration. Research in these fields are carried out by many in recent years.

A simple conceptual model of soil water balance which could be incorporated into larger computer based irrigation management models was proposed and tested in the field by Rao (1987). It estimated the actual evapotranspiration and the soil moisture content at the end of each week using available information on soil water availability and plant water uptake. The values of available moisture in the root zone predicted by the model and observed in the field were comparable.

Porwal and Rao (1988) simulated soil water balance model, which determined for each day of crop growing season, the runoff, root depth, actual evapotranspiration and soil moisture content. The model was tested with field data of two years obtained from Nagarjunasagar irrigation project area. Soil moisture observations taken at weekly intervals upto 60 cm depth in the field were used for testing the model. The model was found to simulate the field water balance adequately.

Some of the recent studies considered high variability of rainfall from year after year especially in semi-arid and sub humid areas. Villalobos and Fereres (1989) proposed a stochastic irrigation scheduling model, which has predictive capability at a level of probability chosen by user and could be used for planning and design. The model couples a rainfall generator to a water balance model that determines irrigation dates and amounts. It used average monthly data to generate daily precipitation and average reference evapotranspiration values to estimate evaporation, transpiration and allowable depletion.

Simalenga and Have (1991) used a soil water balance model which estimates soil water content on a daily basis to predict suitable days for tillage operations in semi-arid areas. A workability criteria was established and it was found that the soil is workable when the soil moisture content is at or below 95% of field capacity.

Hajilal et al. (1994) used a two layer soil water balance model to determine the soil water status at the end of each day of the growing season for each of the crop in the Jayakwadi irrigation project area. Historical rainfall data were used to examine the influence of 3-5 days advance information of rainfall on irrigation scheduling of crops. (Cotton, sugarcane, sorghum and banana).

Sarkar and Kar (1994) tested the accuracy of a diffusion based soil water simulation model under wet, moderately wet and dry soil regimes in a coarse textured lateritic soil using peanut as test crop. During the early part of the drying cycle simulated values of water content were closer to the observed values than they during the later part of the drying cycle. Under the wet regime the simulated values were close to the observed values.

Paz et al. (1995) used an empirical model ISAREG to simulate the soil water balance in a rainfed grass land in the Spanish humid zone. There was good agreement between the predicted soil water storage and that measured by the neutron probe.

Soil water content in a crop root zone depends on soil parameters such as soil texture, infiltration rate, field capacity, waterholding capacity, void ratio etc. Local climatic conditions also affects the soil water balance. Eventhough the soil water balance models have already proven their ability to simulate the field water balance, the location specific parameters of the model demands the establishment of the model under various field conditions.

Materials and Methods

MATERIALS AND METHODS

The concept of soil water balance modelling and the review of research works carried out are discussed in the previous chapter. The detailed description of the model used, and the methodology adopted for field testing and evaluation of the model are presented in this chapter.

3.1. The soil water balance model

The daily soil water balance model described in section 2.2 is utilized for the development of model used for the present study with one day time span. The root zone is assumed to be divided into two layers namely active root zone and passive root zone. Active root zone defines that depth of root zone upto which the roots have been developed at a particular time and passive root zone being the remaining depth of root zone. The daily soil water balance as explained in fig. 3.1 is defined as

$$\theta_i = (\theta_{i-1} RD_{i-1} + ER_i + IRR_i + dRD_i \theta_0 - P_i - AET_i) / RD_i \quad ...(3.1)$$

i = 1 to N, days

N = number of days in the crop season

i = index number for the day

θ_i = average soil moisture content per unit depth at the end of ith day, mm/cm

RD_i = root depth at the end of ith day, cm

ER_i = effective rainfall depth on ith day, mm

IRR_i = depth of irrigation applied on ith day, mm

P_i = Percolation out of the root zone in ith day, mm

AET_i = actual evapotranspiration on ith day, mm

θ_0 = uniform soil moisture content at the beginning of the season mm/cm

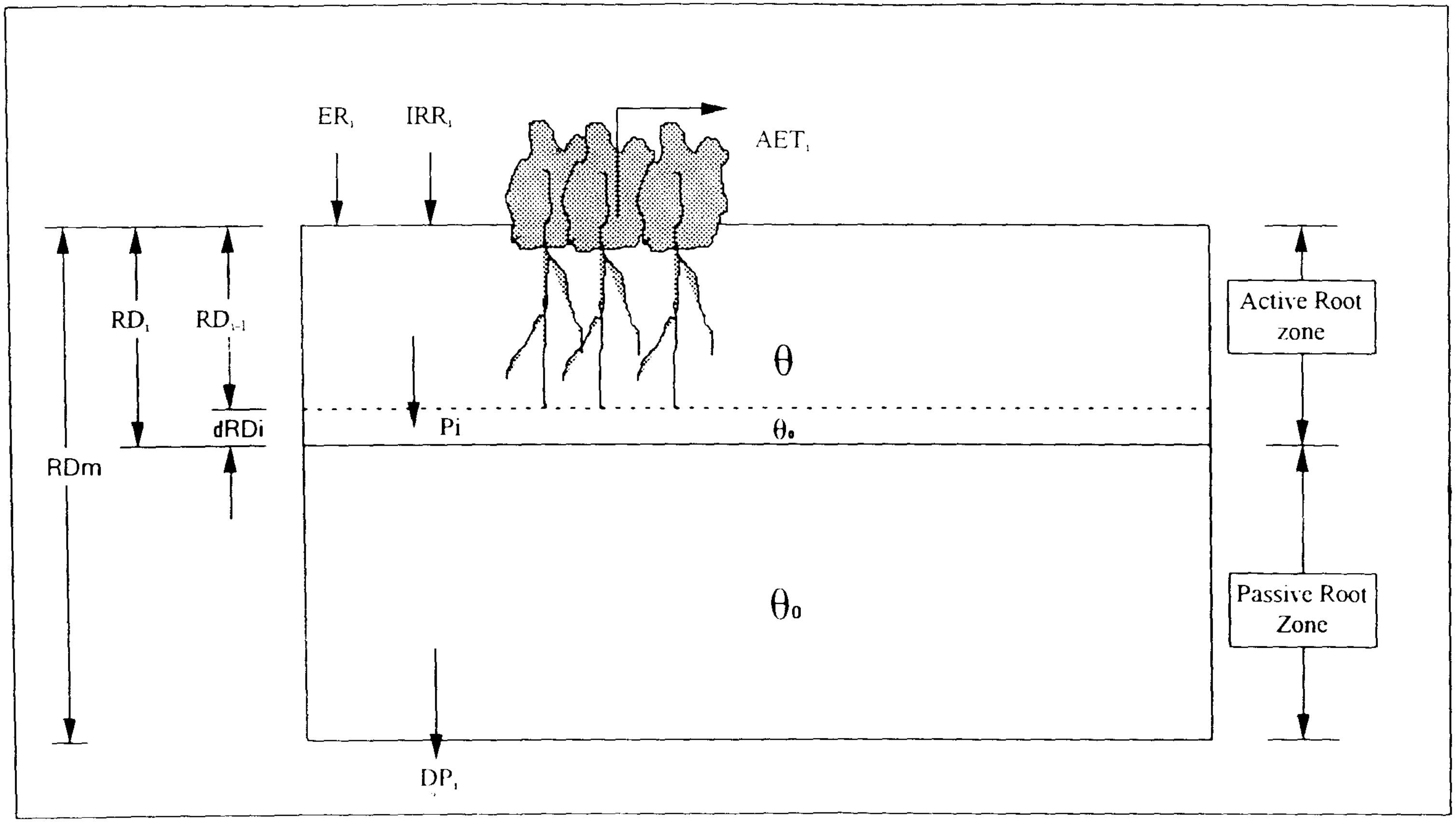


Fig. 3.1 The Soil water balance model

RD_i = incremental root depth on ith day, cm

In equation 3.1

$$ER_i = R_i - Q_i \qquad ...(3.2)$$

R_i = rainfall on ith day, mm

Q_i = runoff from the rainfall on ith day, mm

$$dRD_i = RD_i - RD_{i-1} \qquad ...(3.3)$$

$$P_i = ER_i + IRR_i - (FC - \theta_{i-1})\,RD_{i-1} + (FC - \theta_0)\,dRD_i \qquad ...(3.4)$$

if $(ER_i + IRR_i) > [(FC - \theta_{i-1})\,RD_{i-1} + (FC - \theta_0)\,dRD_i]$

= 0, otherwise

For the passive root zone,

$$\theta_{0i} = \theta_{0i-1} \quad ; \quad \text{if } P_i = 0 \qquad ...(3.5)$$

$$\theta_{0i} = \theta_{0i-1} + P_i/(RD_m - RD_i) - DP_i \quad ; \text{if } P_i > 0 \qquad ...(3.6)$$

in which

$DP_i = P_i - (FC - \theta_{0i-1})\,(RD_m - RD_i)$;

if $P_i > (FC - \theta_{0i-1})(RD_m - RD_i)$

= 0; otherwise ...(3.7)

DP_i = deep percolation out of the passive root zone , mm

RD_m = maximum depth of root zone, cm

In equations 3.1 and 3.4, field capacity and other moisture contents are measured with respect to permanent wilting point. In the model described above, the values of the root depth were determined by using the root depth model described by the equation 2.9. Since evaporation can occur from the top 15 cm of the soil profile, the minimum value of root depth was set equal to 15 cm. Actual evapotranspiration was obtained by adopting the method developed by Doorenbos and Kassam (1979), given by equations 2.5 and 2.6.

Daily runoff values from daily rainfall is estimated using soil conservation service (SCS) curve number technique (USDA, 1972), combined with the soil moisture accounting procedure suggested by Sharpley and Williams (1990). The equation used for estimating daily runoff is given by,

$$Q = \frac{(P-0.3S)^2}{(P+0.7S)} \quad ; \quad \text{if } P > 0.3S \qquad \text{...(3.8)}$$

$$= 0.0 \quad ; \quad \text{otherwise}$$

where

Q	=	actual runoff, mm
S	=	potential maximum retention, mm
P	=	precipitation, mm

The retention parameter 'S' is related to the curve number, 'CN' by the following relationship

$$S = 254\,[(100/CN)-1] \qquad \text{...(3.9)}$$

The curve number for moisture condition II, CN_2 is obtained from tables given in the Handbook of Hydrology (Ministry of Agriculture, Govt. of India, 1972). The value of CN_2 is based on several factors such as the land use, cultivation practices, hydrologic condition and hydrologic soil group. Values of CN_1, the curve number for the moisture condition I, (dry) and CN_3 the curve number for the moisture condition III, (wet) corresponding to those of CN_2 were calculated using the equations (Sharpley and Williams, 1990).

$$CN_1 = CN_2 - \frac{20\,(100-CN_2)}{100-CN_2+\exp\,[2.533-0.0636\,(100-CN_2)]} \qquad \text{...(3.10)}$$

and

$$CN_3 = CN_2 - \exp[0.00673(100-CN_2)] \qquad ...(3.11)$$

Fluctuations in the soil moisture content cause the retention parameter to change according to the equation

$$S = S_1 \left[1 - \frac{FFC}{FFC + \exp[W_1 - W_2(FFC)]}\right] \qquad ...(3.12)$$

where S_1 is the value of S associated with CN_1, FFC is the fraction of field capacity and W_1 and W_2 are the shape parameters.
FFC is computed using the equation

$$FFC = \frac{(SW-WP)}{(FC-WP)} \qquad ...(3.13)$$

Where SW is the soil water content in the root zone and FC and WP are field capacity and permanent willing point respectively. Value of W_1 and W_2 are obtained from the simultaneous solution of the two equations obtained from equation 3.12 according to the assumption that $S=S_2$, when FFC 0.5 and $S=S_3$ when FFC=1.0

$$W_1 = \ln\left(\frac{1.0}{1.0-(S_3/S_1)} - 1.0\right) + W_2 \qquad ...(3.14)$$

$$W_2 = 2\left[\ln\left(\frac{0.5}{1.0-(S_2/S_1)} - 0.5\right) - \ln\left(\frac{1.0}{1.0-(S_3/S_1)} - 1.0\right)\right] \qquad ...(3.15)$$

where S_1, S_2, S_3 are the retention parameters corresponding to CN_1, CN_2 and CN_3 respectively.

The following assumptions are made to simplify the model

i. the soil is deep and uniform.

ii. the total depth of effective rainfall or irrigation on any day infiltrates into the soil reservoir and is redistributed instantaneously and uniformly over the root zone of the crop on that day.

iii. The infiltrated water in excess of the available storage capacity of the root zone percolates out of the zone.

iv. The contribution to the soil moisture storage from the capillary rise is negligible.

3.2. Field testing

3.2.1. Selection of the plot

A plot of 17.6 m x 4.7 m was selected in the instructional farm, KCAET, Tavanur for field testing of the model. The crops usually raised in these fields were paddy and vegetables in the monsoon and summer seasons respectively. The watertable at the plot was at 3.4 m below the ground level, during the period of study. The plot was close to the meteorological observatory of the KCAET farm and had a pond in its neighbourhood. The irrigation pipe line of the farm passed along the edge of the plot and a hydrant was provided to facilitate irrigation.

3.2.2. Layout of the plot

The crop selected for conducting the experiment was bhindi (Abelmoschus esculentus), variety Arka Anamika. The selected plot was arranged in such a manner to accommodate 200 plants in 4 blocks, each containing 5 rows of 10 plants. The distance between consecutive rows was

Plate No. I Location of the experimental plot

Plate No. II The experimental plot

maintained at 0.6 m and the plant to plant distance in a row was 0.3 m. The distance between last row in a block and the first row in the next block was kept at 2m. The experimental plot was given a margin of 1m around the blocks and was separated from the rest of the land to avoid disturbances from the neighbouring lands. The layout of the plants in the experimental plot is given in fig 3.2

3.2.3. Preparation of the field

The field was operated twice with tractor drawn cultivator to make the soil of good tilth. The required furrows were opened manually with spades. The soil in the furrows was made to good tilth before sowing.

3.2.4. Sowing of seeds

The sowing of seeds, soaked in water for 24 h, was done manually at predetermined positions in the furrows on 24th February 1995. Gap filling was done for those seeds which showed poor germination.

3.2.5 Fertilizer application

Farm yard manure @ 12 t/ha, ammonium sulphate @ 125 kg/ha, muriate of potash @ 50 kg/ha and super phosphate @ 50 kg/ha were applied as the basal dose in the field. Another dose of ammonium sulphate @ 125 kg/ha was applied one month after sowing.

3.2.6. Crop protection

Granule form of carbofuran @ 0.5 kg/ha was applied at the time of seeding to control the attack of pests.

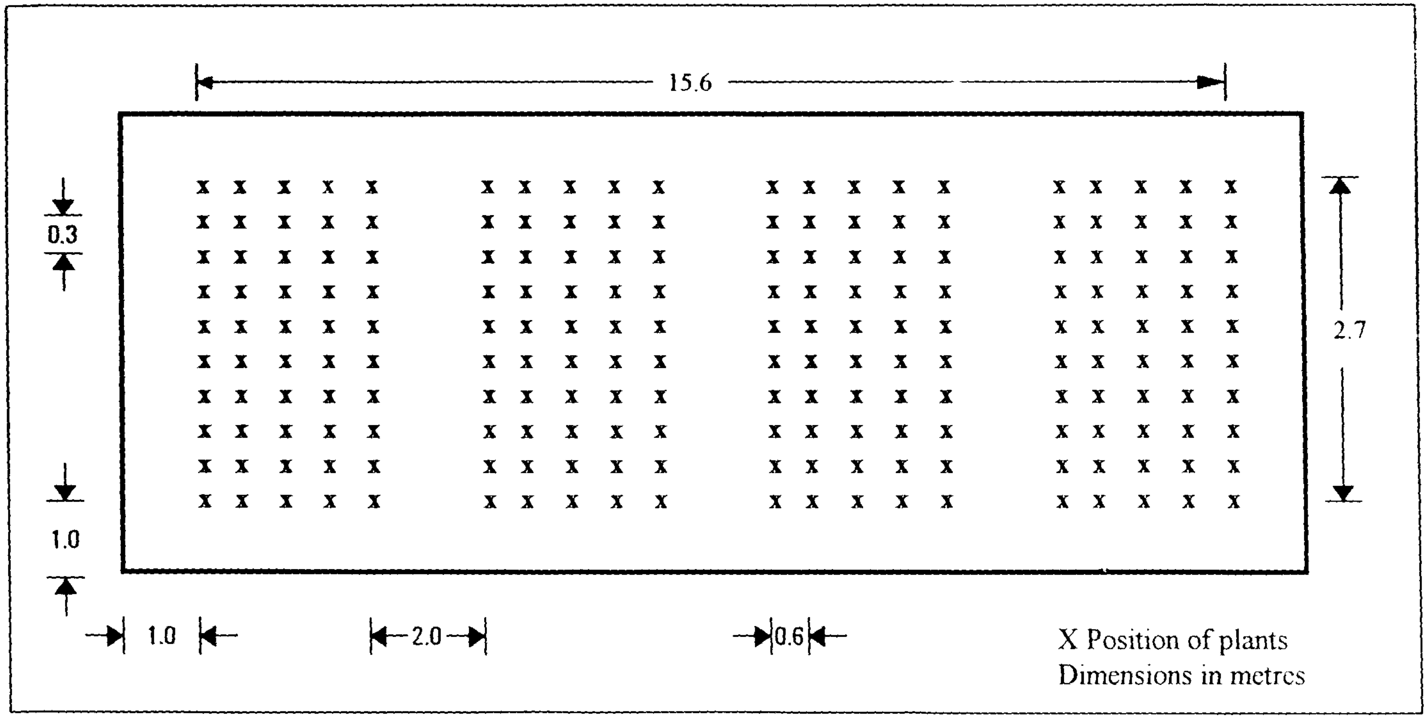


Fig. 3.2 Layout of plants in the field

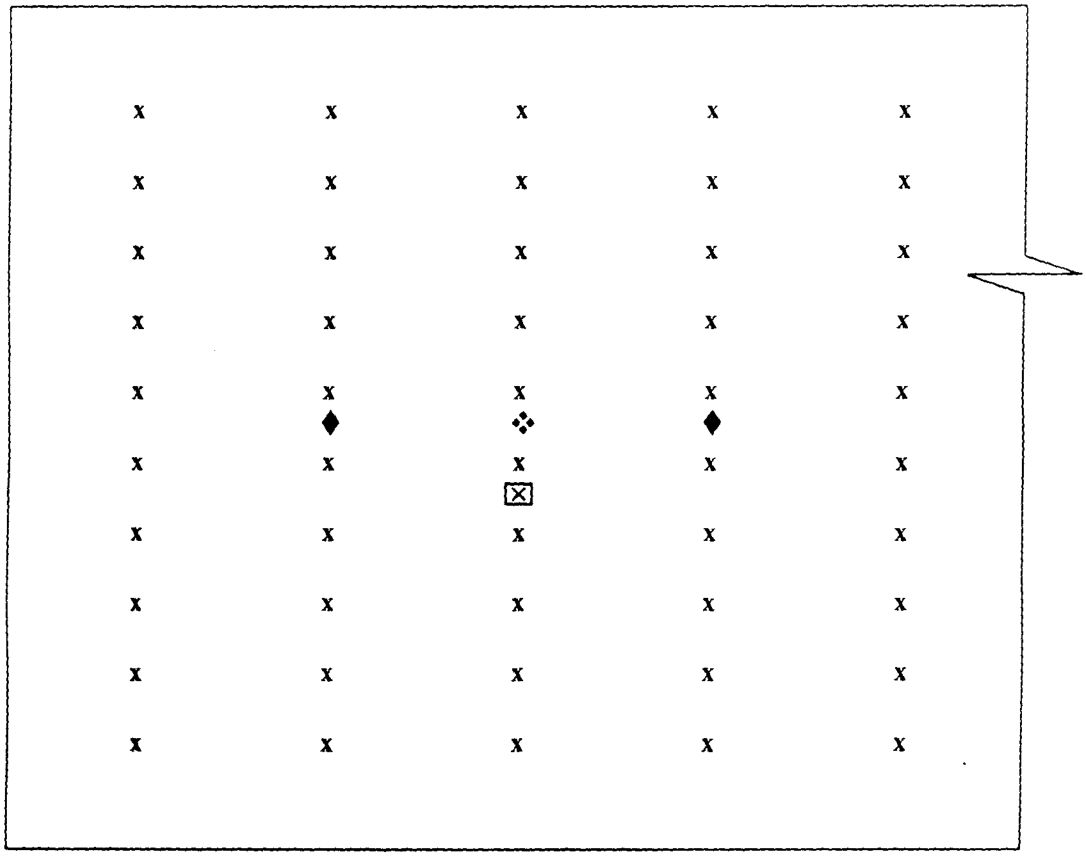
3.3. Measurement of parameters of the model

3.3.1. Moisture content

The initial soil moisture contents at 15 cm and 30 cm depths were determined using gravimetric method. The daily soil moisture contents in the root zone were measured using electrical resistivity method and tensiometer method. The gypsum blocks for the electrical resistance method, and the tensiometers were calibrated before being used for measurements. The gypsum blocks and tensiometers were placed at 15 cm and 30 cm depths from the soil surface at positions shown in fig. 3.3. The readings of the tensiometers were noted everyday. The resistance between the two terminals of each gypsum block was measured everyday using a resistance meter. The observations were recorded and the soil moisture contents were obtained by the use of calibration charts already prepared. Soil samples from these depths were collected once in a week and the moisture contents were obtained by gravimetric method.

3.3.2. Irrigation

Irrigation, being an input for the model, was applied in measured quantities. The measurement was done by the use of watermeter which gave the cumulative quantity of water passing through it. In the initial stages of plant growth, irrigation was done in small quantities and once the plants got established, the quantity of water applied at a time was increased to suit the requirements.



♦ Gypsum Blocks at two depths, 15 cm and 30 cm.
❖ Tensiometer at 15 cm depth.
⊠ Tensiometer at 30 cm depth.
x Plants

Fig. 3.3 Positions of gypsum blocks and tensiometers.

Plate No. III Tensiometers installed in the experimental plot

Plate No. IV Resistance meter measuring the Conductivity of gypsum block

3.3.3. Root depth

To verify the adaptability of the Borg and Grimes root depth model, one among the four blocks of the plot was used for destructive sampling to measure the length of root at various stages of growth of the plant. The uprooted plants were placed on a flat surface and the length of root was measured using a steel rule, and recorded against the number of days after planting.

3.3.4. Rainfall

The daily rainfall readings, from a Symon's gauge were collected from the meteorological observatory of the KCAET farm. Rainfalls observed were of such intensity and duration, that they produced no runoff from the plot during the experimental period.

3.3.5. Evaporation

The USWB class A pan evaporimeter was used to measure daily evaporation data. The corresponding PET values were obtained by multiplying each reading by a coefficient corresponding to different growth stages of bhindi.

3.3.6. Field capacity

A representative spot of 2.5 m^2 area was selected in the field. Fifteen centimetre high bunds were raised around this. All weeds and plants were removed from the selected spot. Water was applied to the spot till the soil there was completely saturated. The spot was then covered with polyethylene sheet.

Soil samples at a depth of 20 cm were taken daily at 10 AM and the moisture content was determined by gravimetric method. This was continued for 5 days and the moisture content was plotted against time. The low point on the curve represented the value of field capacity.

3.3.7. Permanent wilting point

A bhindi plant was separately grown near the test plot under identical conditions. When the plant attained maturity, irrigation to the plant was cut off. After a few days, when the plant began showing symptoms of wilting, the moisture content in the root zone was measured by gravimetric method. This moisture content was taken as the permanent wilting point.

3.4 Analysis and comparison of data

A computer programme for the model in FORTRAN language was developed and the analysis of the recorded input data resulted in the simulated daily moisture contents. The simulated and observed values of the soil moisture contents were compared to draw conclusion on the feasibility of the model under the field conditions of the study.

Results and Discussion

RESULTS AND DISCUSSION

Soil water balance models are being increasingly used in recent years for various applications. Its use in estimating the water requirement is a new approach in irrigation management. Soil water balance models primarily help us to know, when to irrigate and how much to irrigate. The results of the experiment conducted to test the feasibility of two layer soil water balance model in the field, with bhindi as the test crop are discussed here under.

4.1. Calibration

Tensiometers and gypsum blocks used to measure the soil moisture content were calibrated and the results are presented in Appendix I. Comparision of the moisture contents measured at 15 cm depth of the first block using different methods is shown in fig. 4.1. Moisture contents measured with tensiometers and gypsum blocks were in close agreement with that measured using gravimetric method, with correlation coefficients 0.96 and 0.97 respectively.

4.2. Soil parameters

Field capacity (fig. 4.2) and permanent wilting point of the soil under study is 2.79 mm/cm (17.4%) and 0.99 mm/cm (6.1%) respectively. The maximum available soil water was estimated as 1.8 mm/cm. The initial soil moisture contents at 15 cm depth and 30 cm depth were 0.25 mm/cm and 0.38 mm/cm respectively with respect to the permanent wilting point. Bulk density of the soil is 1.606 g/cc. Mechanical composition of the soil is given in table 4.1.

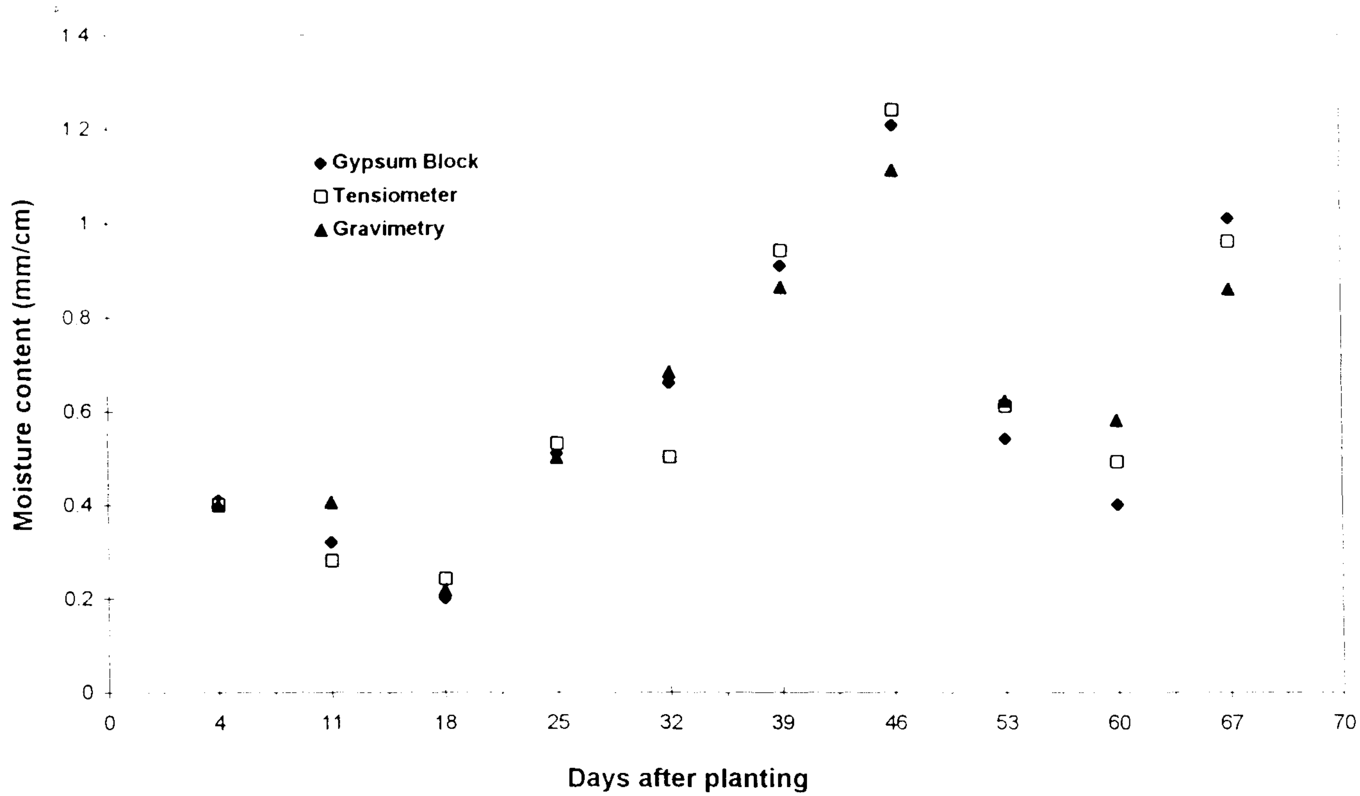


Fig. 4.1a Moisture contents measured at 15 cm depth

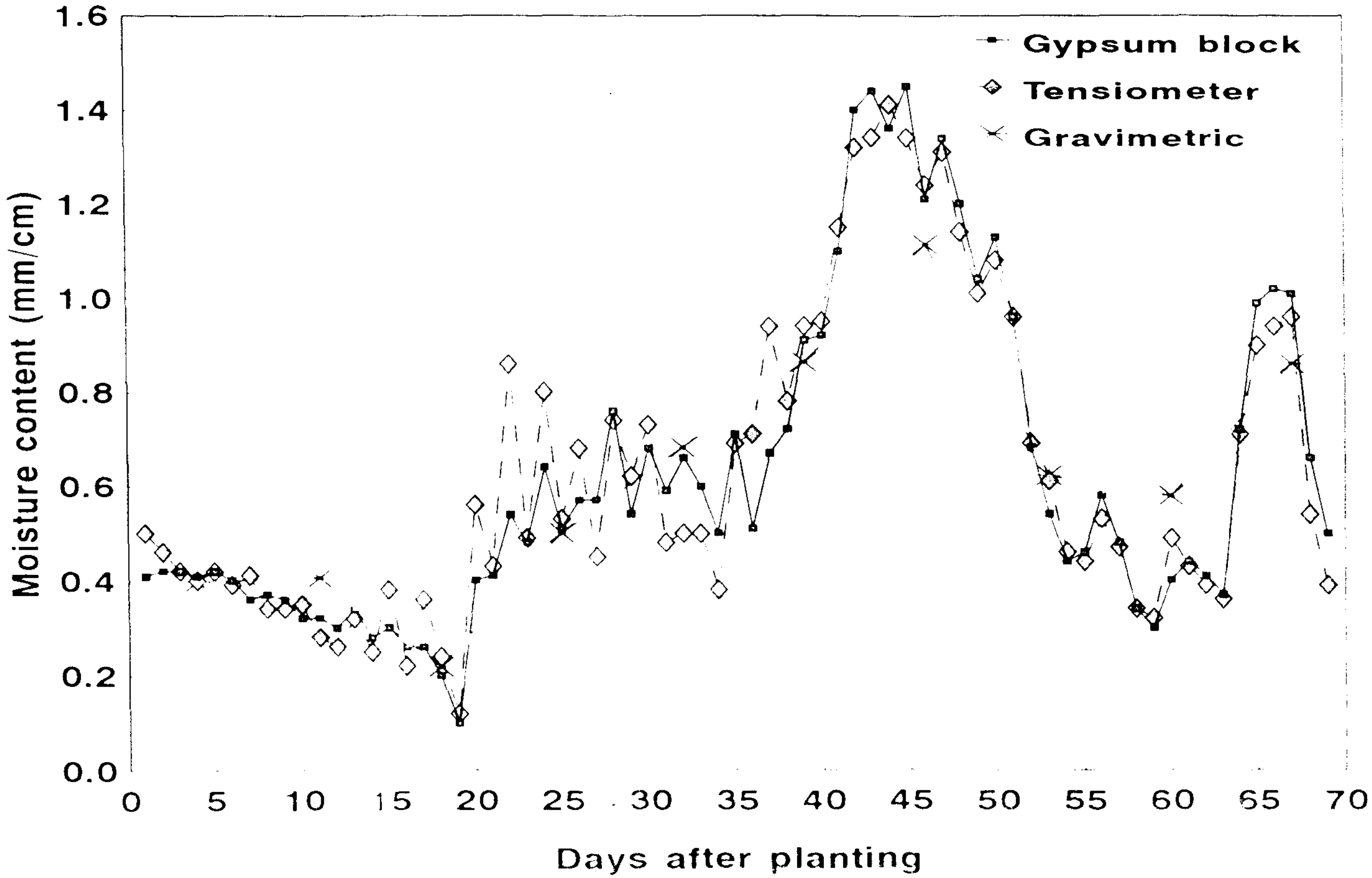


Fig.4.1.b Moisture contents measured at 15 cm depth

Table 4.1 Mechanical composition of soil

Sl.No.	Soil material	Percentage
1	Gravel	3.81
2	Coarse sand	5.62
3	Medium sand	13.89
4	Fine sand	61.50
5	Silt and clay	15.18

4.3. Rainfall and runoff

Total rainfall received during the period of the study was 41 mm and the number of rainy days was 5. The precipitation received were of such duration and intensity that they produced no runoff out of it. Rainfall for each rainy day is presented in fig. 4.3

4.4. Upward capillary flux

The water table in the study area was at a depth of 3.4 m from the ground level, during the period of study. Contribution of moisture to the root zone, through upward capillary flux was assumed to be insignificant and therefore neglected in this study.

4.5 Percolation

Whenever water is added to the soil reservoir, it is assumed to distribute evenly in the active root zone and water percolates to the passive root zone, after saturating the active root zone. Only after saturating the passive root zone, the

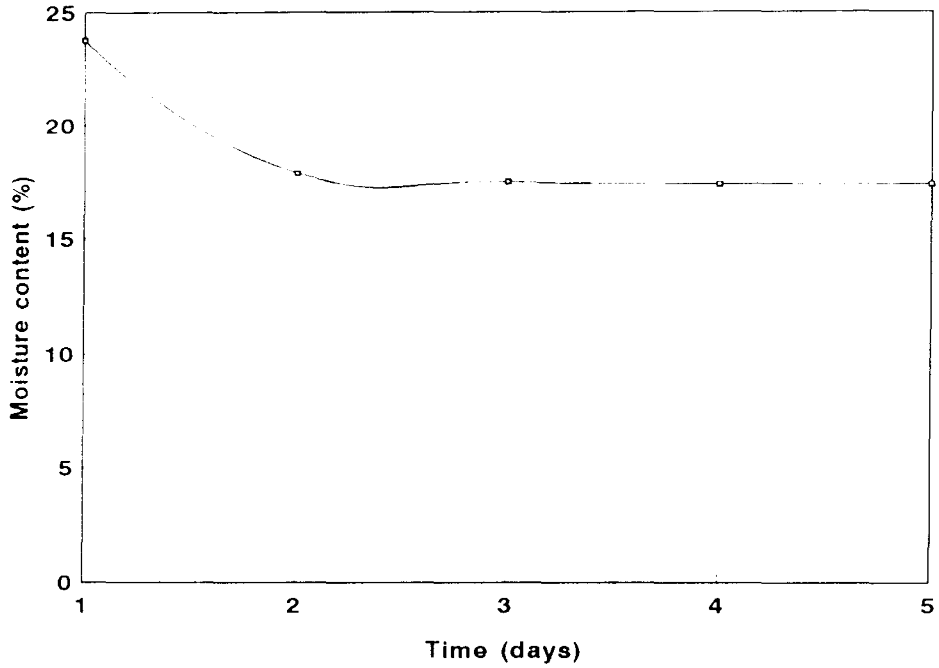


Fig.4.2. Field capacity of the soil

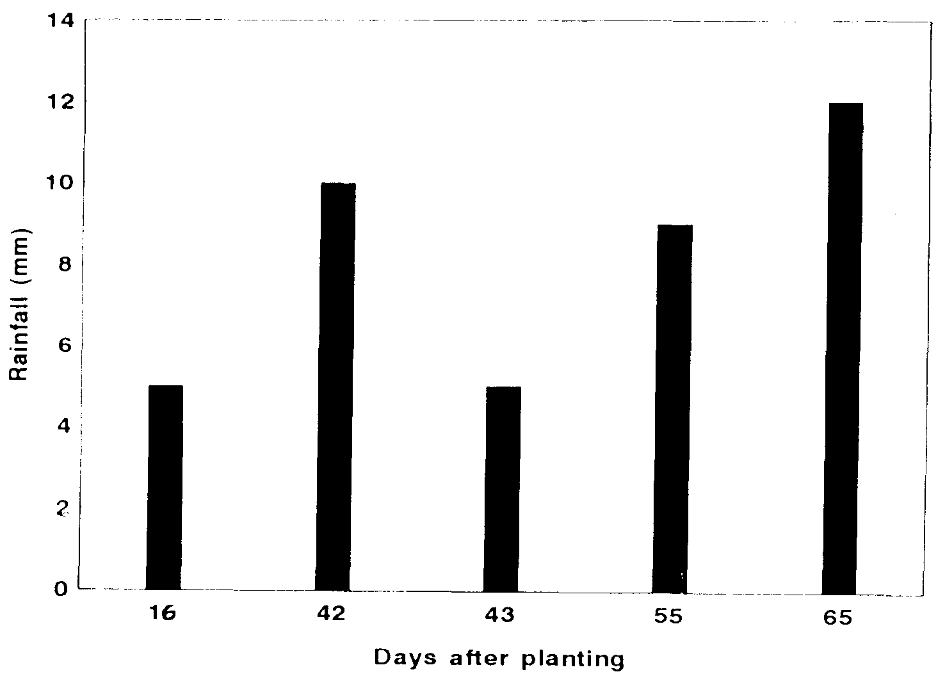


Fig.4.3. Rainfall during the period of study

excess water escapes out of the root zone as deep percolation. Of the total input water of 337.6 mm, only 8.15 mm (2.69 mm on 45th day and 5.46 mm on 47th day) has percolated down the active root zone and from this 2.6 mm drained out of the passive root zone as deep percolation (Table 4.2). This was because of the consecutive rain falls on 42nd and 43rd days and subsequent irrigations on 45th and 47th days.

4.6 Evapotranspiration

Actual evapotranspiration and potential evapotranspiration were computed for the whole period of study. Maximum PET of 9.68 mm was recorded on 50th DAS and a minimum of 2.11 mm was on 16th DAS. Whenever the moisture content in the active root zone dropped below the critical value the AET was less than PET. The AET and PET values for the study period are shown in fig. 4.4. During the whole period of study, the AET dropped below the PET for 6 days. The analysis suggested that for a given PET value, there is a threshold average moisture content in the root zone, below which the soil moisture condition begin to limit the evapotranspiration process. When the soil moisture content falls below the critical value, the water availability to plants is affected, and it is the ideal time for irrigation.

4.7. Root depth

For each day of the growing season root depth was calculated using the root growth model. Since evaporation can occur from the top 15 cm soil layer, the minimum root depth was set equal to 15 cm. The incremental root depth was also calculated for the entire crop season. The daily root growth was rapid during initial stages, when compared to other stages of growth.

TABLE 4.2. DAILY SOIL WATER BALANCE

IDAP	RD	DRD	THETO	DRDTG	PERC	ASW	PET	AET	SMI	FSM	RF	QIRR	CKC	ETO	THETA	P	THETR
1	15.00	0.00	0.25	0.00	0.00	13.15	3.60	3.60	0.250	0.637	0.00	9.40	0.45	8.00	0.88	0.74	0.47
2	15.00	0.00	0.25	0.00	0.00	9.55	3.42	3.42	0.637	0.409	0.00	0.00	0.45	7.6	0.64	0.76	0.44
3	15.00	0.00	0.25	0.00	0.00	10.83	3.11	3.11	0.409	0.515	0.00	4.70	0.45	6.90	0.72	0.79	0.38
4	15.00	0.00	0.25	0.00	0.00	7.72	2.65	2.65	0.515	0.338	0.00	0.00	0.45	5.90	0.51	0.83	0.31
5	15.00	0.00	0.25	0.00	0.00	9.77	2.56	2.56	0.338	0.430	0.00	4.70	0.45	5.70	0.65	0.83	0.30
6	15.00	0.00	0.25	0.00	0.00	7.20	2.20	2.20	0.480	0.333	0.00	0.00	0.45	4.90	0.48	0.86	0.25
7	15.00	0.00	0.25	0.00	0.00	9.70	2.94	2.94	0.333	0.491	0.00	4.70	0.45	5.20	0.65	0.85	0.26
8	15.00	0.00	0.25	0.00	0.00	7.36	2.74	2.74	0.491	0.308	0.00	0.00	0.45	6.10	0.49	0.82	0.32
9	15.00	0.00	0.25	0.00	0.00	9.31	3.19	3.19	0.308	0.408	0.00	4.70	0.45	7.10	0.62	0.78	0.40
10	15.00	0.00	0.25	0.00	0.00	6.12	2.70	2.70	0.408	0.228	0.00	0.00	0.45	6.00	0.41	0.82	0.32
11	15.00	0.00	0.25	0.00	0.00	8.12	2.70	2.70	0.228	0.361	0.00	4.70	0.45	6.00	0.54	0.82	0.32
12	15.00	0.00	0.25	0.00	0.00	5.42	2.38	2.38	0.361	0.202	0.00	0.00	0.45	5.30	0.36	0.85	0.27
13	15.00	0.00	0.25	0.00	0.00	7.73	2.16	2.16	0.202	0.372	0.00	4.70	0.45	4.80	0.52	0.87	0.24
14	15.00	0.00	0.25	0.00	0.00	5.57	2.79	2.79	0.372	0.186	0.00	0.00	0.45	6.20	0.37	0.82	0.33
15	15.00	0.00	0.25	0.00	0.00	7.48	2.29	2.29	0.186	0.346	0.00	4.70	0.45	5.10	0.50	0.86	0.26
16	15.00	0.00	0.25	0.00	0.00	5.19	2.11	2.11	0.346	0.205	5.00	0.00	0.45	4.70	0.35	0.87	0.23
17	15.00	0.00	0.25	0.00	0.00	8.07	2.38	2.38	0.205	0.379	0.00	0.00	0.45	5.30	0.54	0.85	0.27
18	15.00	0.00	0.25	0.00	0.00	5.69	2.79	2.79	0.379	0.193	0.00	0.00	0.45	6.20	0.38	0.82	0.33
19	15.00	0.00	0.25	0.00	0.00	2.90	2.70	1.65	0.193	0.083	0.00	0.00	0.45	6.00	0.19	0.82	0.32
20	15.00	0.00	0.25	0.00	0.00	13.15	2.74	2.74	0.083	0.694	0.00	11.90	0.45	6.10	0.88	0.82	0.32
21	15.00	0.00	0.25	0.00	0.00	10.41	5.63	5.03	0.694	0.359	0.00	0.00	0.75	7.50	0.69	0.57	0.78
22	15.39	0.39	0.25	0.10	0.00	17.38	5.40	5.40	0.359	0.778	0.00	11.90	0.75	7.20	1.13	0.58	0.76
23	16.49	1.10	0.25	0.27	0.00	12.25	5.85	5.46	0.778	0.412	0.00	0.00	0.75	7.80	0.74	0.56	0.80
24	17.59	1.11	0.25	0.28	0.00	18.97	5.32	5.32	0.412	0.776	0.00	11.90	0.75	7.10	1.08	0.58	0.75

(CONTD...)

TABLE 4.2. DAILY SOIL WATER BALANCE (CONTD..)

IDAP	RD	DRD	THE [illegible]	DRDIO	PERC	ASW	PET	AET	SMI	FSM	RI	QIRR	CKC	ETO	THEFA	P	THETR
25	18.71	1.11	[illegible]	0.28	0.00	13.92	5.40	5.32	0.776	0.460	0.00	0.00	0.75	7.20	0.74	0.58	0.76
26	19.82	1.11	[illegible]	0.28	0.00	20.79	5.10	5.10	0.460	0.791	0.00	11.90	0.75	6.80	1.05	0.60	0.73
27	20.98	1.11	0.28	0.28	0.00	15.96	4.43	4.43	0.791	0.551	0.00	0.00	0.75	5.90	0.76	0.66	0.62
28	22.04	1.11	0.28	0.28	0.00	23.72	5.40	5.40	0.551	0.831	0.00	11.90	0.75	7.20	1.08	0.58	0.76
29	23.14	1.10	0.38	0.42	0.00	18.73	5.63	5.63	0.831	0.566	0.00	0.00	0.75	7.50	0.81	0.57	0.78
30	24.23	1.09	0.38	0.41	0.00	25.42	5.85	5.85	0.566	0.808	0.00	11.90	0.75	7.80	1.05	0.56	0.80
31	25.30	1.07	0.38	0.41	0.00	19.98	5.63	5.63	0.808	0.567	0.00	0.00	0.75	7.50	0.79	0.57	0.78
32	26.36	1.05	0.38	0.40	0.00	26.66	5.70	5.70	0.567	0.795	0.00	11.90	0.75	7.60	1.01	0.57	0.78
33	27.39	1.03	0.38	0.39	0.00	21.35	5.25	5.25	0.795	0.588	0.00	0.00	0.75	7.00	0.78	0.59	0.74
34	28.40	1.01	0.38	0.38	0.00	16.48	5.93	4.20	0.588	0.430	0.00	0.00	0.75	7.90	0.58	0.55	0.80
35	29.37	0.98	0.38	0.37	0.00	31.57	5.70	5.70	0.430	0.881	0.00	19.00	0.75	7.60	1.07	0.57	0.78
36	30.32	0.94	0.38	0.36	0.00	26.23	6.08	6.08	0.881	0.665	0.00	0.00	0.75	8.10	0.87	0.55	0.82
37	31.23	0.91	0.38	0.35	0.00	39.50	5.40	5.40	0.665	1.092	0.00	19.00	0.75	7.20	1.26	0.58	0.76
38	32.10	0.87	0.38	0.33	0.00	34.40	6.08	6.08	1.092	0.883	0.00	0.00	0.75	8.10	1.07	0.55	0.82
39	32.93	0.83	0.38	0.32	0.00	47.67	4.73	4.73	0.883	1.304	0.00	19.00	0.75	6.30	1.45	0.63	0.67
40	33.71	0.79	0.38	0.30	0.00	43.25	3.15	3.15	1.304	1.189	0.00	0.00	0.75	4.20	1.28	0.79	0.39
41	34.45	0.74	0.38	0.28	0.00	59.38	7.04	7.04	1.189	1.519	0.00	19.00	1.10	6.40	1.72	0.50	0.90
42	35.14	0.69	0.38	0.26	0.00	62.60	5.28	5.28	1.519	1.631	10.00	0.00	1.10	4.80	1.78	0.59	0.75
43	35.78	0.64	0.38	0.24	0.00	62.56	7.59	7.59	1.631	1.536	5.00	0.00	1.10	6.90	1.75	0.47	0.95
44	36.37	0.59	0.38	[illegible]	0.00	55.19	5.28	5.28	1.536	1.372	0.00	0.00	1.10	4.80	1.52	0.59	0.75
45	36.90	0.53	0.38	[illegible]	2.69	66.42	6.82	6.82	1.372	1.615	0.00	19.00	1.10	6.20	1.80	0.51	0.88
46	37.38	0.47	1.66	[illegible]	0.00	60.39	6.60	6.60	1.615	1.439	0.00	0.00	1.10	6.00	1.62	0.52	0.86
47	37.79	0.42	1.66	[illegible]	5.46	68.03	7.37	7.37	1.439	1.605	0.00	19.00	1.10	6.70	1.80	0.48	0.93
48	38.15	0.36	1.80	[illegible]	0.00	61.30	7.81	7.81	1.605	1.402	0.00	0.00	1.10	7.10	1.61	0.46	0.97

(CONTD...)

TABLE 4.2. DAILY SOIL WATER BALANCE (CONTD...)

IDAP	RD	DRD	THETO	DRDTO	PERC	ASW	PET	AET	SMI	FSM	RF	QIRR	CKC	ETO	THETA	P	THETR
49	38.44	0.30	1.80	0.53	0.00	54.02	9.24	9.24	1.402	1.165	0.00	0.00	1.10	8.40	1.41	0.42	1.04
50	38.68	0.23	1.80	0.42	0.00	64.20	9.68	9.58	1.165	1.401	0.00	19.00	1.10	8.80	1.66	0.41	1.06
51	38.85	0.17	1.80	0.31	0.00	54.83	9.02	9.02	1.410	1.179	0.00	0.00	1.10	8.20	1.41	0.43	1.03
52	38.95	0.11	1.80	0.19	0.00	46.00	8.36	8.36	1.179	0.966	0.00	0.00	1.10	7.60	1.18	0.44	1.00
53	39.00	0.05	1.80	0.08	0.00	37.72	6.38	6.38	0.966	0.804	0.00	0.00	1.10	5.80	0.97	0.53	0.84
54	39.00	0.00	0.00	0.00	0.00	31.34	7.48	6.37	0.804	0.640	0.00	0.00	1.10	6.80	0.80	0.48	0.94
55	39.00	0.00	0.00	0.00	0.00	33.97	4.29	4.29	0.640	0.761	9.00	0.00	1.10	3.90	0.87	0.67	[illegible]
56	39.00	0.00	0.00	0.00	0.00	29.68	3.84	3.84	0.761	0.662	0.00	0.00	0.60	6.40	0.76	0.72	0.51
57	39.00	0.00	0.00	0.00	0.00	25.84	3.90	3.90	0.662	0.562	0.00	0.00	0.60	6.50	0.66	0.71	0.52
58	39.00	0.00	0.00	0.00	0.00	21.94	3.60	3.60	0.562	0.470	0.00	0.00	0.60	6.00	0.56	0.74	0.47
59	39.00	0.00	0.00	0.00	0.00	18.34	2.34	2.34	0.470	0.410	0.00	0.00	0.60	3.90	0.47	0.85	0.26
60	39.00	0.00	0.00	0.00	0.00	35.00	3.36	3.36	0.410	0.811	0.00	19.00	0.60	5.60	0.90	0.76	0.42
61	39.00	0.00	0.00	0.00	0.00	31.64	4.20	4.20	0.811	0.704	0.00	0.00	0.60	7.00	0.81	0.68	0.58
62	39.00	0.00	0.00	0.00	0.00	27.44	2.64	2.64	0.704	0.636	0.00	0.00	0.60	4.40	0.70	0.83	0.31
63	39.00	0.00	0.00	0.00	0.00	24.80	2.82	2.82	0.636	0.564	0.00	0.00	0.60	4.70	0.64	0.81	0.33
64	39.00	0.00	0.00	0.00	0.00	40.98	3.12	3.12	0.564	0.971	0.00	19.00	0.60	5.20	1.05	0.79	0.38
65	39.00	0.00	0.00	0.00	0.00	49.86	3.72	3.72	0.971	1.183	12.00	0.00	0.60	6.20	1.28	0.73	0.49
66	39.00	0.00	0.00	0.00	0.00	46.14	2.76	2.76	1.183	1.112	0.00	0.00	0.60	4.60	1.18	0.82	0.33
67	39.00	0.00	0.00	0.00	0.00	43.38	4.32	4.32	1.112	1.001	0.00	0.00	0.60	7.20	1.11	0.67	0.60
68	39.00	0.00	0.00	0.00	0.00	39.06	4.26	4.26	1.001	0.892	0.00	0.00	0.60	7.10	1.00	0.67	0.59
69	39.00	0.00	0.00	0.00	0.00	34.80	4.20	4.20	0.892	0.785	0.00	0.00	0.60	7.00	0.89	0.68	0.58

Note Description and units of the parameters given in Appendix-II

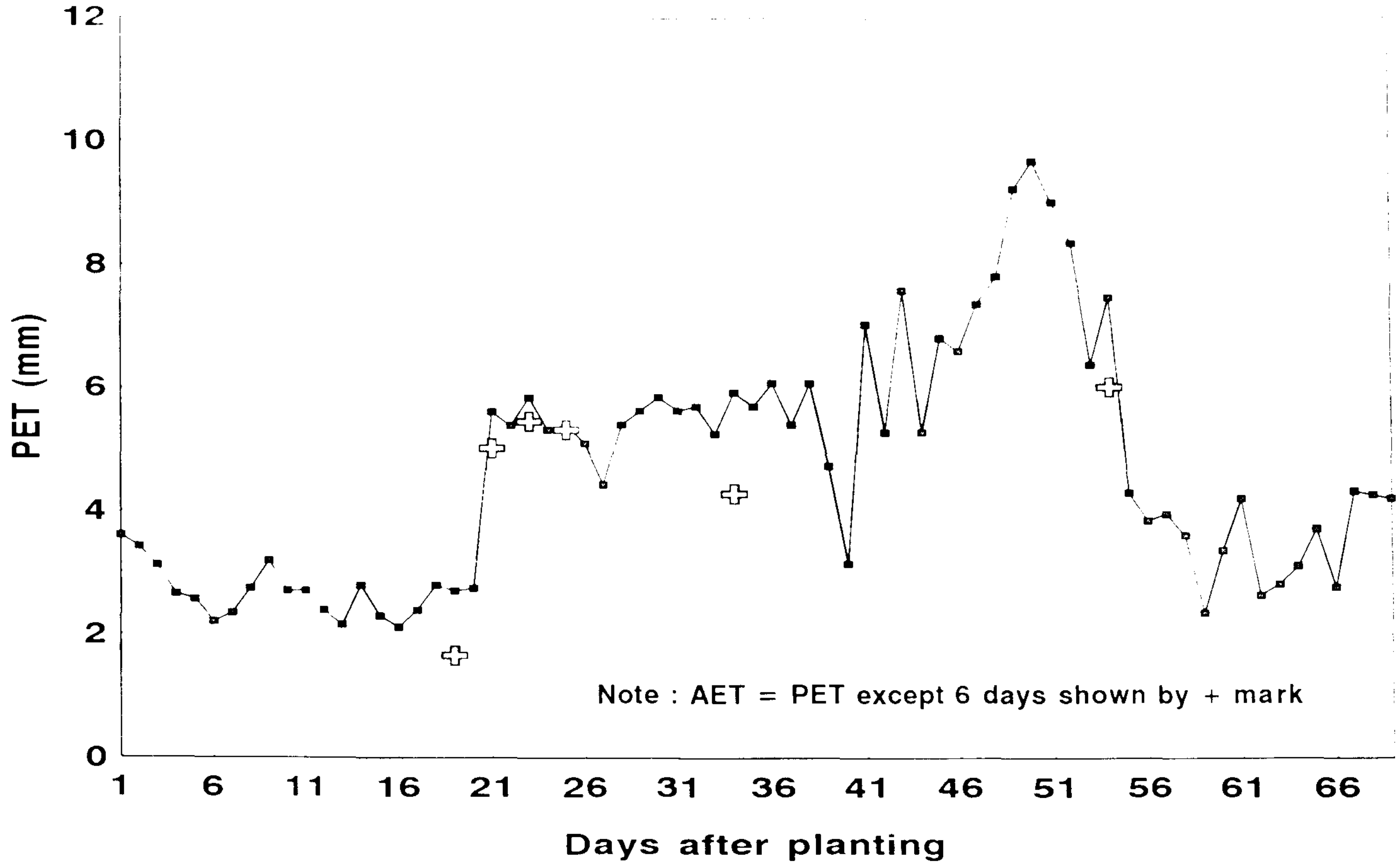


Fig.4.4. PET and AET values during study period

Actual root depths were measured in the field at different stages of growth of the plant. The maximum root depth observed was 39.0 cm on 53rd DAS. The root depth computed by the model and that measured in the field are compared in fig. 4.5. The computed values are slightly higher than the observed values and the correlation coefficient is 0.84.

4.8. Soil moisture content

Moisture contents observed at 15 cm depths of the first three blocks, using tensiometer, gypsum blocks and gravimetric methods were averaged separately. Similarly three average moisture contents were obtained corresponding to 30 cm depth also. Comparison of the computed values of moisture content with the corresponding moisture contents measured by the three methods were done independently and the results are presented in fig. 4.6, 4.7 and 4.8. Upto the 35th DAS the soil moisture contents measured at 15 cm depth were taken as the observed value. From 36th DAS onwards, till the end of the study period, average value of the moisture contents measured at 15 cm depth and 30 cm depth gave the moisture content in the active root zone. In all the three methods of measurement of moisture content, the observed values were found to be in close agreement with the calculated ones. Correlation analysis of the computed and observed values of moisture content was done and the coefficients obtained were 0.976, 0.971 and 0.965 respectively for gravimetric method, tensiometer method and electrical resistivity method.

Plants attained their maximum root depth of 39.0 cm on 53rd DAS. That means the entire root zone is occupied by active root zone and from that day onwards passive root zone did not exist.

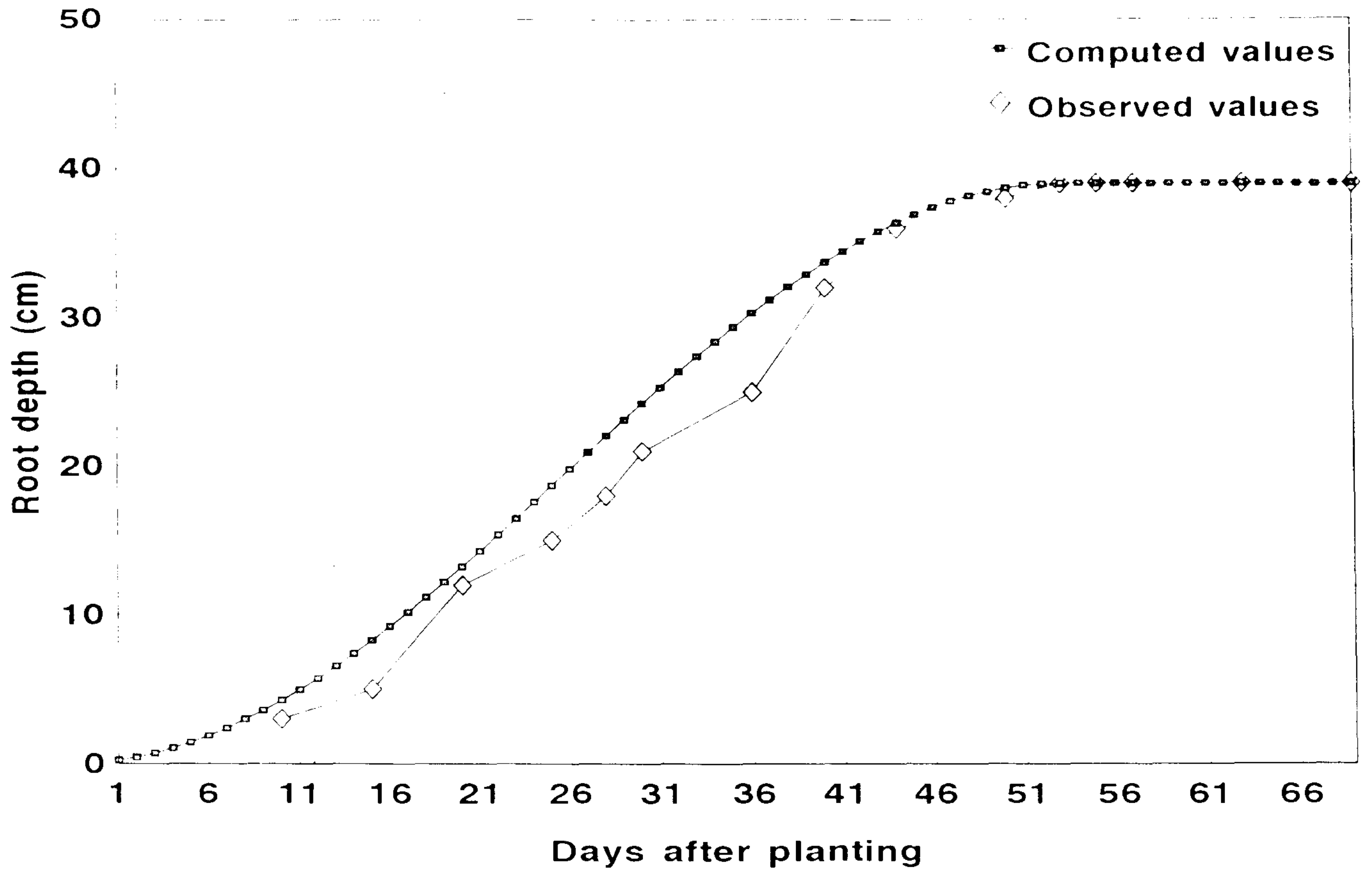


Fig.4.5. Observed and computed values of root depth

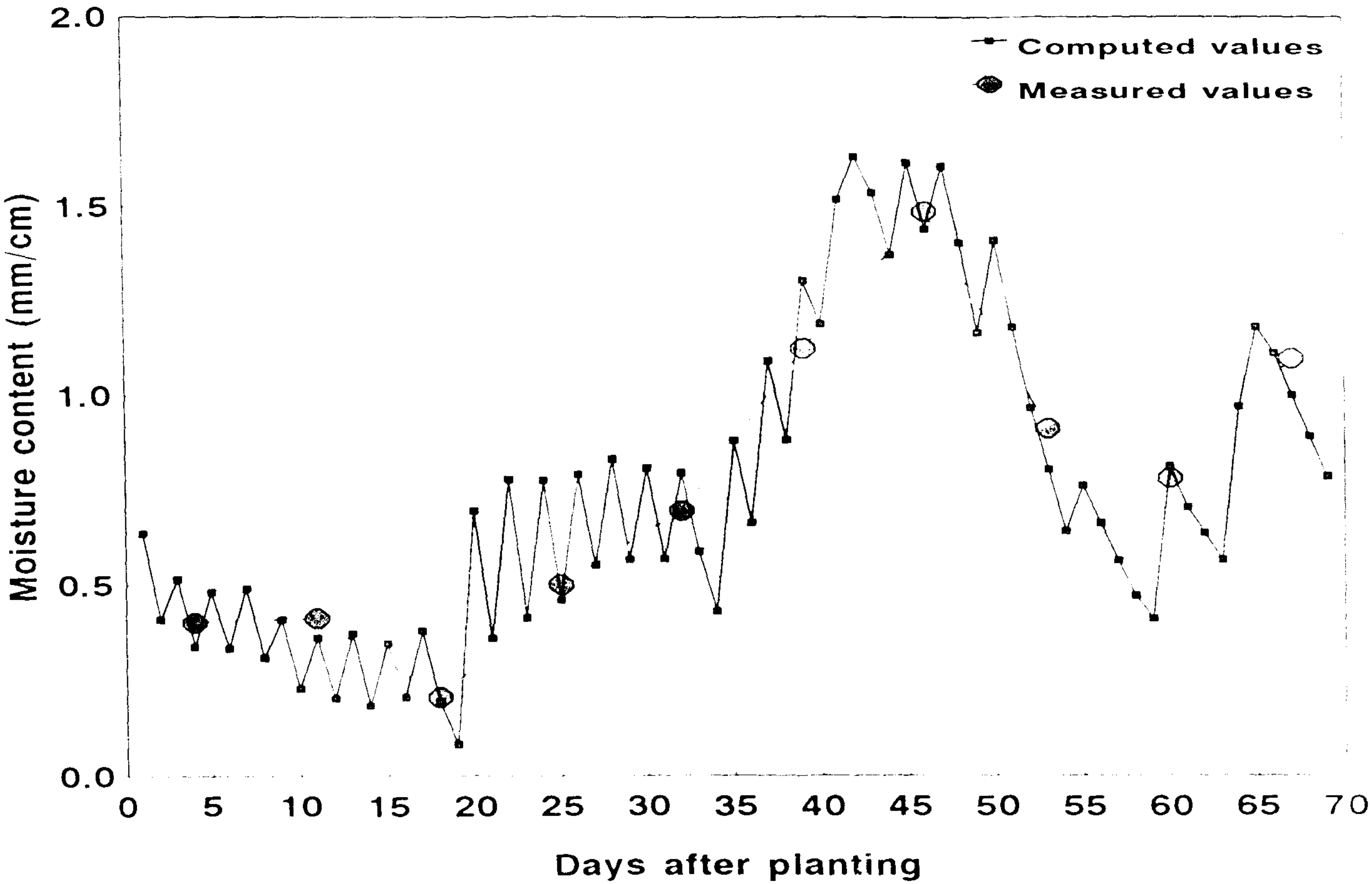


Fig.4.6a. Computed and measured (gravimetric) values of moisture content

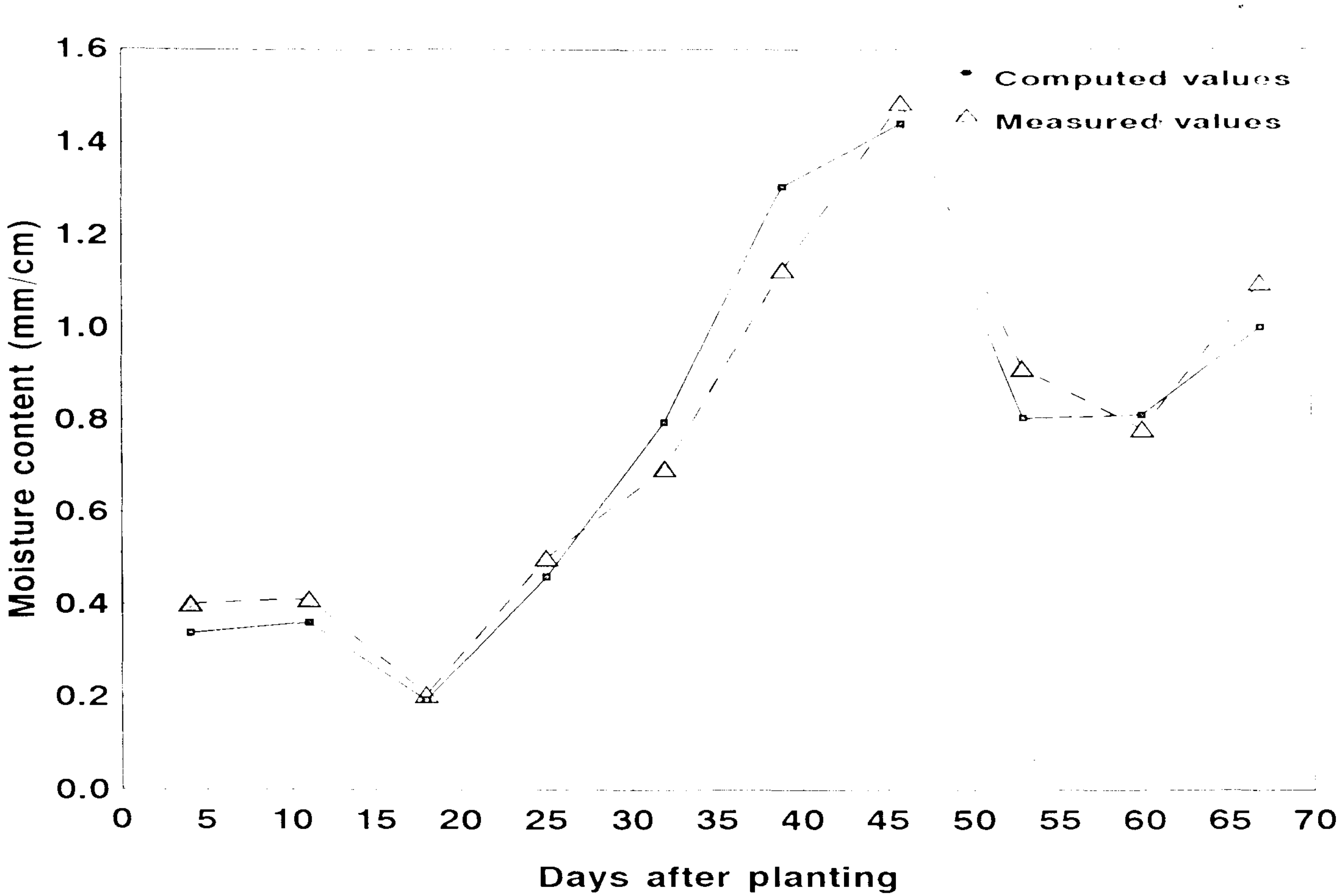


Fig.4.6b. Computed and measured (gravimetric) values of moisture content

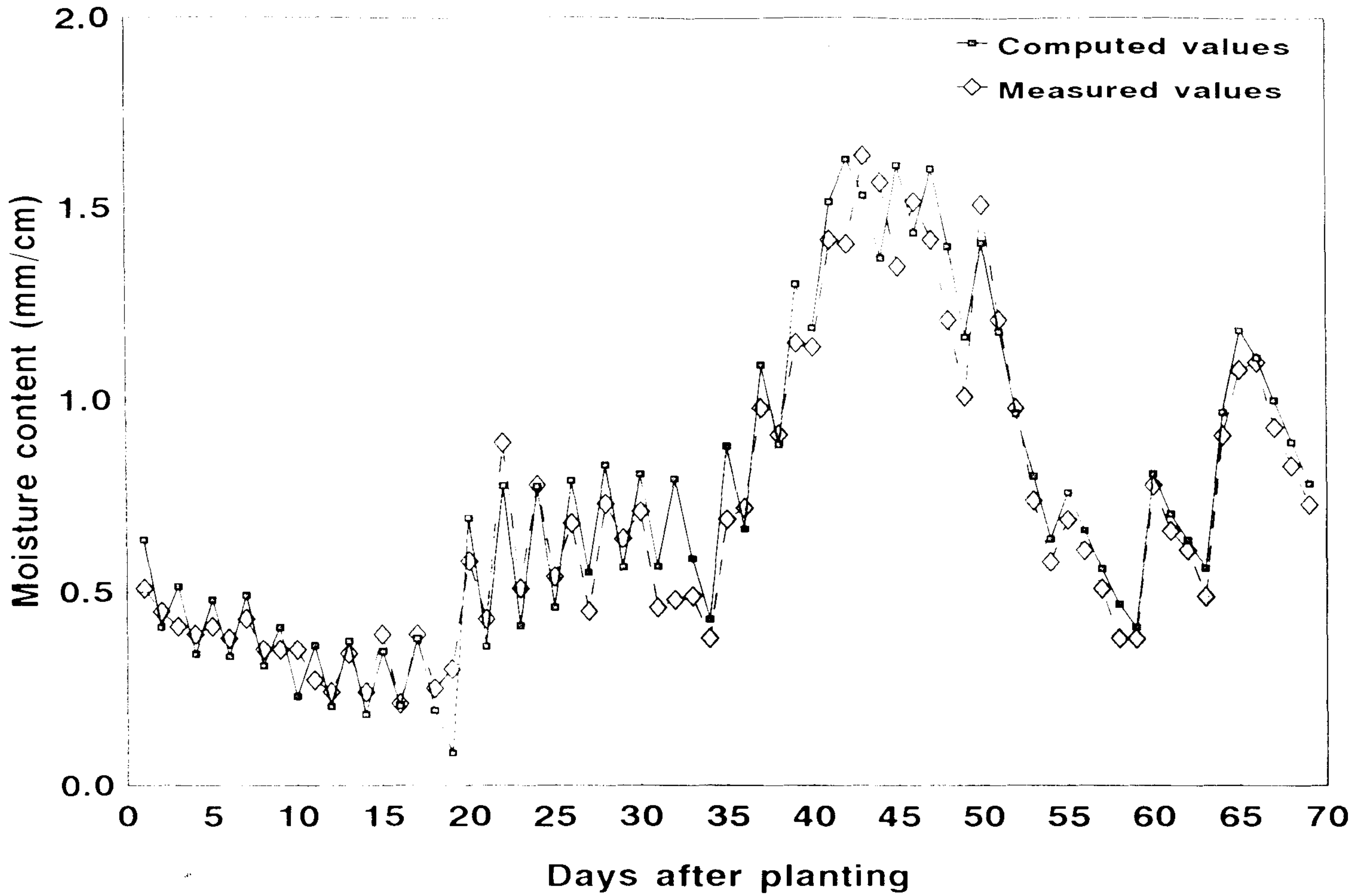


Fig.4.7. Computed and measured (tensiometer) values of moisture content

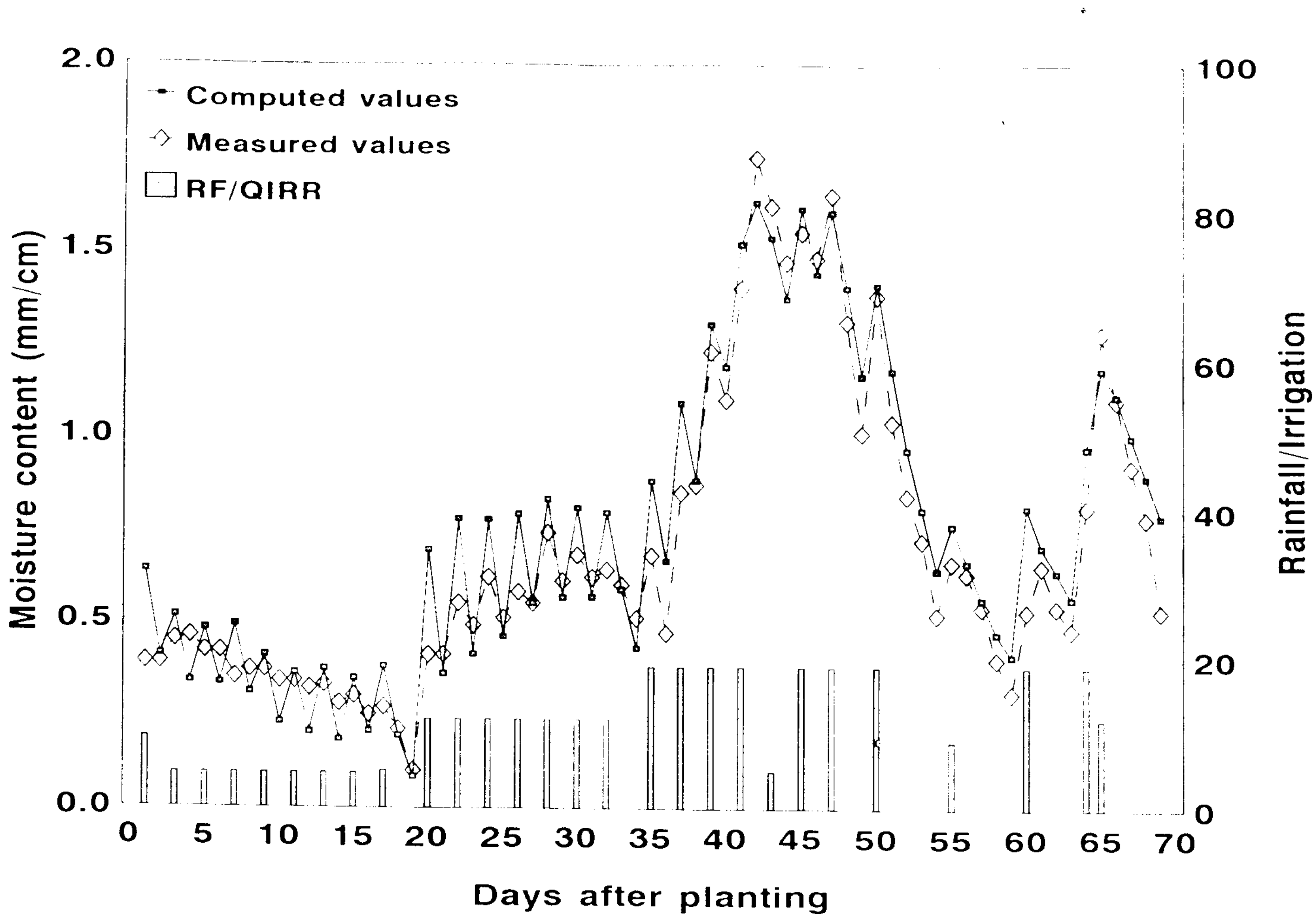


Fig.4.8. Computed and measured (gypsum block) values of moisture content

The study has shown that soil water balance model can effectively be used to predict the daily variation in soil moisture. The model can also be used to visualise the general condition of the field. Once the soil moisture content in the active root zone falls below the critical value, the activities of the plant are affected and it is identified as the ideal time for the application of water. Since the model predicts the moisture content in the root zone with adequate accuracy, the quantity of water required to bring the moisture content in the active root zone to the field capacity or to any desired level is easily obtained and thus the quantity of water to be applied is also known from the model.

The soil water balance model developed can be used for estimating the irrigation requirements of different crops in a command area of an irrigation project. By knowing the types of crops, crop period, crop factor, cropped area and soil properties the crop water requirements of various crops can be estimated using the model with average or predicted climatic factors. Once the crop water requirements at the field are known, the irrigation requirements at the outlet of the reservoir or diversion headworks can be worked out by integrating suitable hydraulic models taking into account the dimensions of the canal network. Thus the soil water balance model developed here has many applications in the field of irrigation water management.

Summary and Conclusions

SUMMARY AND CONCLUSION

Soil water balance models are widely used in recent years to determine the optimum quantity of irrigation water to be applied and the ideal time for its application. A two layer soil water balance model was tested in sandy loam soil with bhindi as the test crop.

The root depth was predicted by a root growth model whose input data were the maximum root depth and the time to attain maximum root depth.

The input data for the soil water balance model were the daily values of rainfall, irrigation, reference evapotranspiration and crop coefficient for different stages of crop growth. The values estimated by the model were the PET, AET, percolation and the soil moisture content at the end of each day. The conclusions drawn from the study conducted are presented here under.

1. The field capacity and permanent wilting point of the soil under study were 2.79 mm/cm and 0.99 mm/cm respectively. The initial moisture content at 15 cm and 30 cm depth were 0.25 mm/cm and 0.38 mm/cm respectively with respect to the permanent wilting point.

2. Total rainfall received during the study period was 41 mm. No runoff was observed from the test plot during the entire crop period.

3. Root depth was calculated using Borg and Grimes root growth model. Maximum root depth of 39.0 cm was attained on 53rd DAS. Though the

measured root depths were slightly less than the computed values, the model was successful in predicting the root depth with moderate accuracy.

4. Of the total input water received, after saturating the active root zone, the remaining percolated to the passive root zone. Total quantity of water percolated down the active root zone during the study period was 8.15 mm. Quantity of water percolated out of the root zone was 2.64 mm.

5. Whenever the input water went out of active root zone as percolation, the moisture content in the passive root zone had changed. The moisture content in the passive root zone reached the field capacity level on 48th DAS and maintained that level till 53rd DAS.

6. Moisture content in the active root zone dropped below the critical value for 6 days during the crop period.

7. The computed values of soil moisture in the active root zone were in good agreement with the measured values with correlation coefficients 0.976, 0.971 and 0.965 for the gravimetric, tensiometer and electrical resistivity methods respectively.

8. As the soil water balance model used here successfully predicted the daily moisture variations in the soil, it can be used for estimating the crop water requirements and for various applications in irrigation water management.

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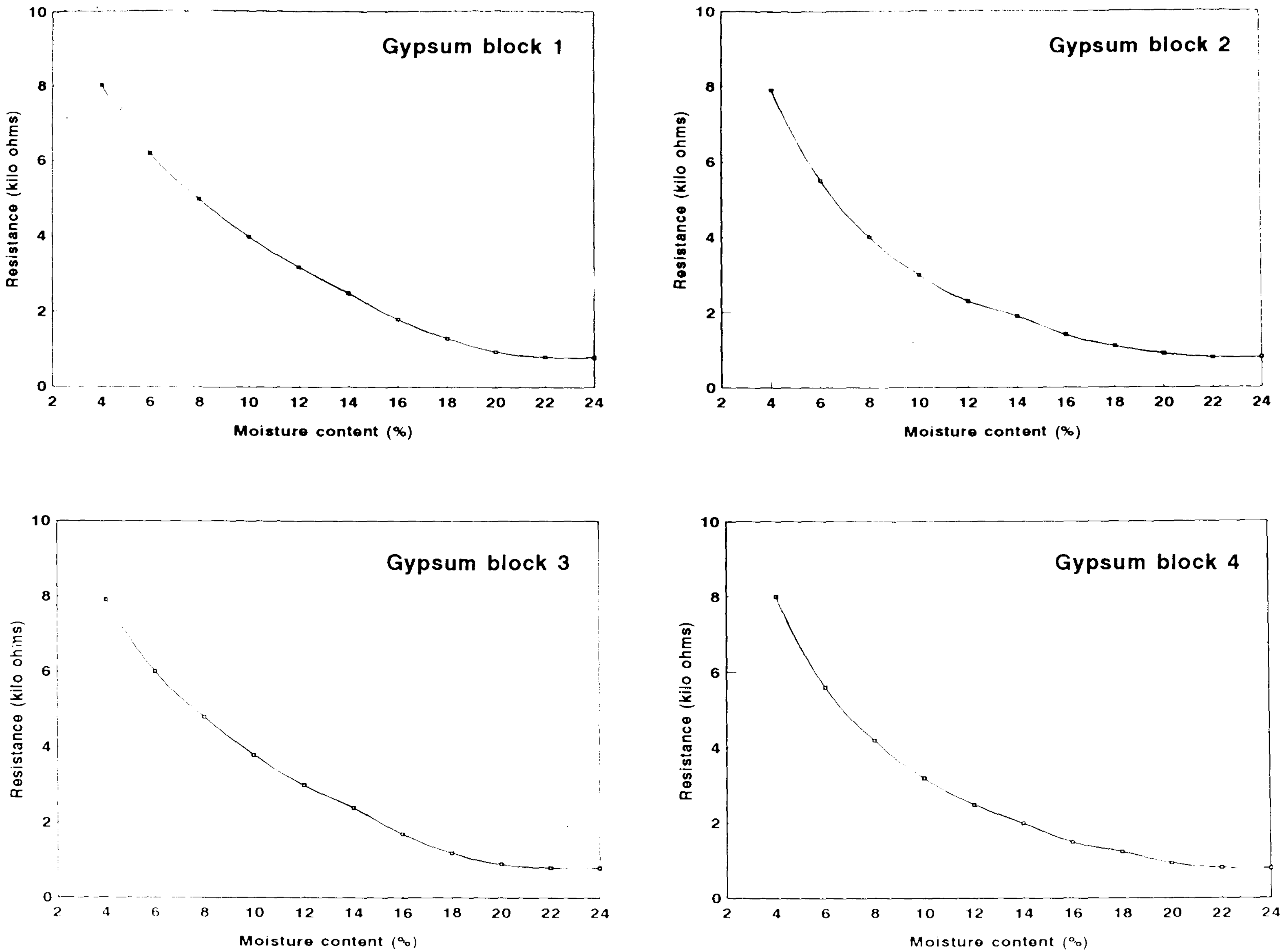
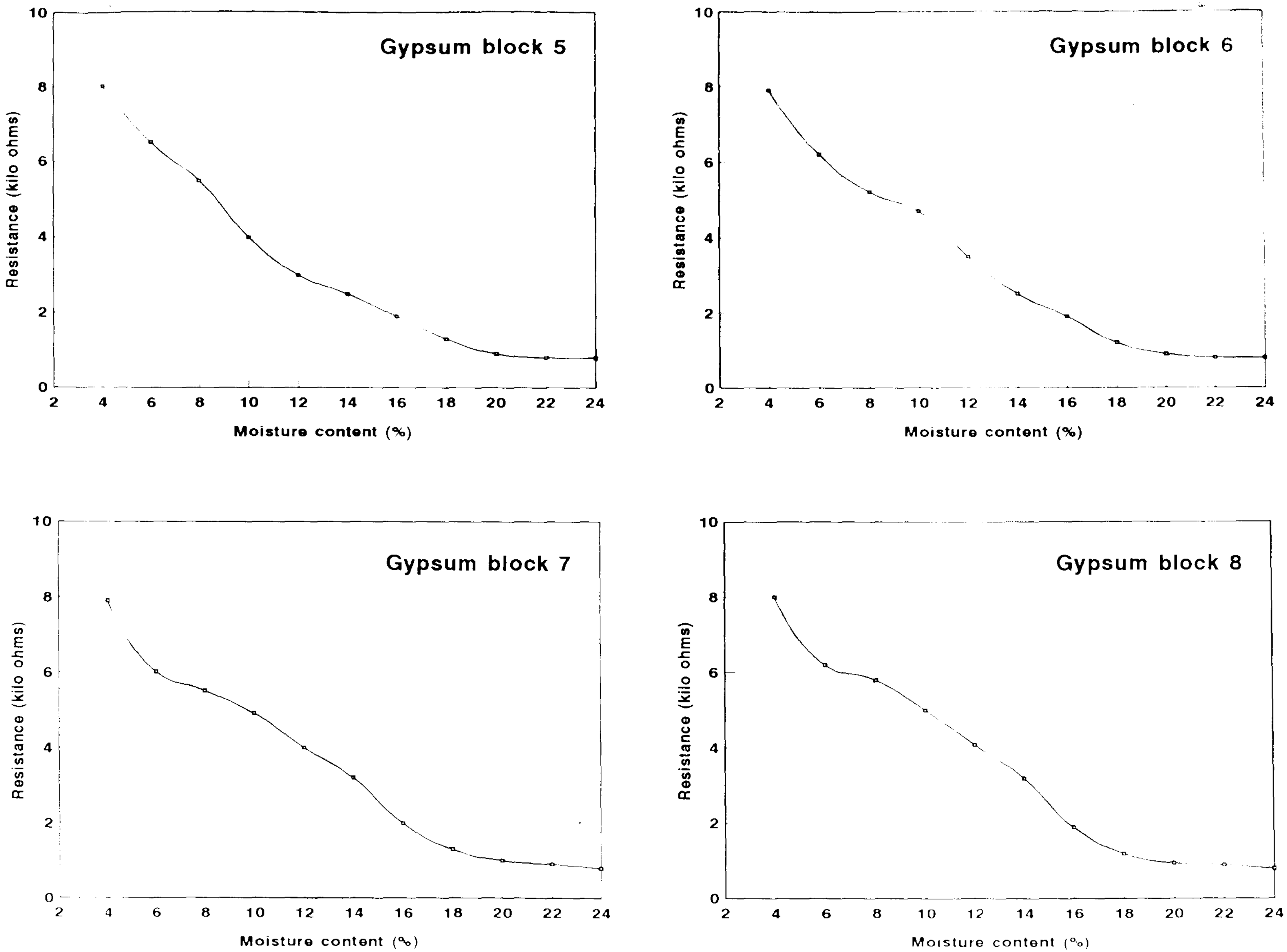
* Originals not seen.

Appendices

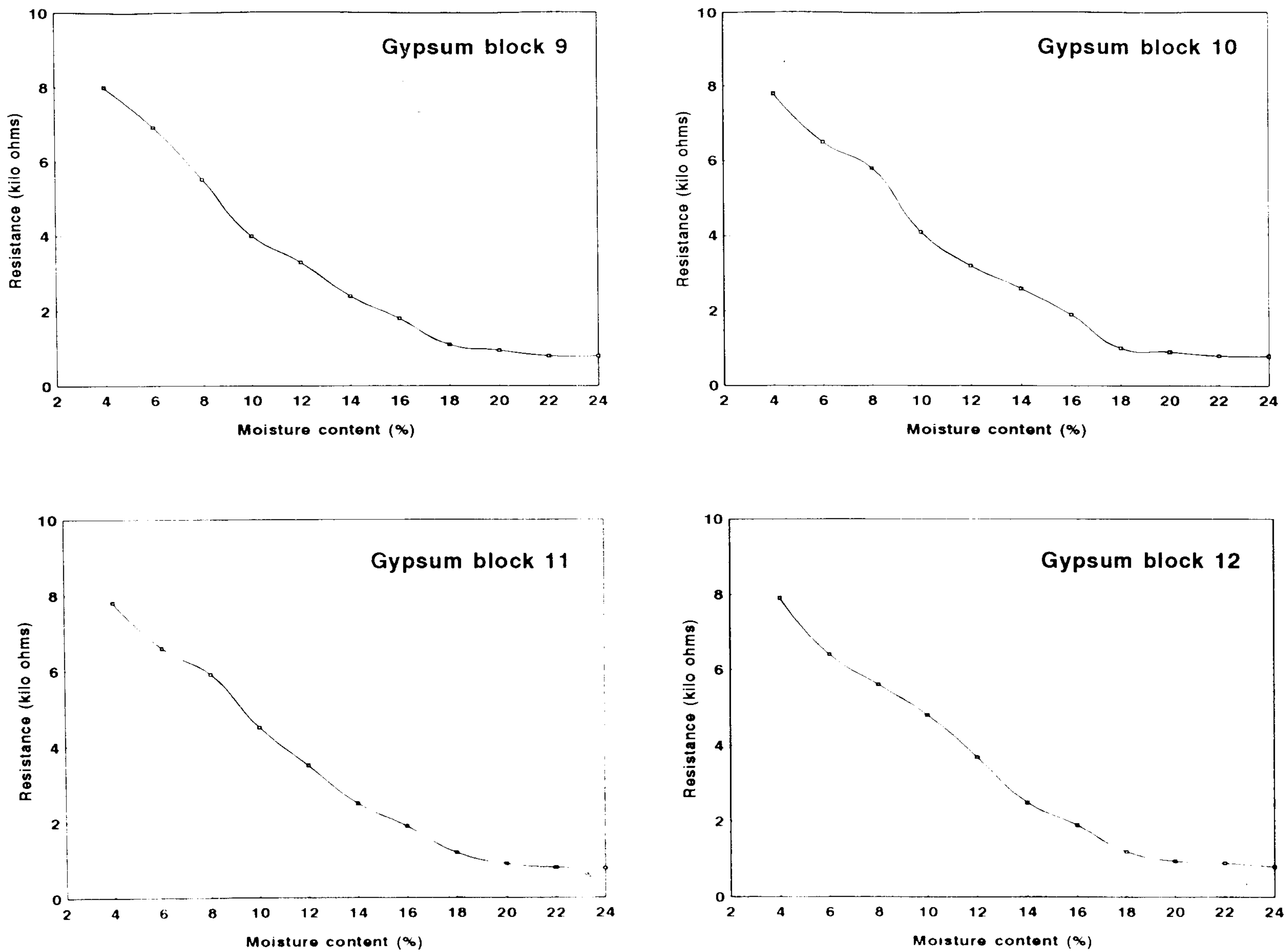
Appendix I(i) Calibration chart for gypsum block



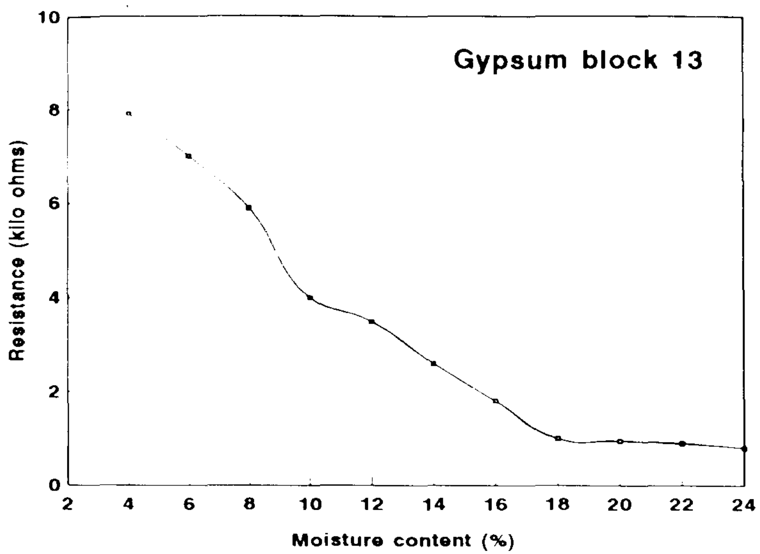
Appendix I(ii) Calibration chart for gypsum block

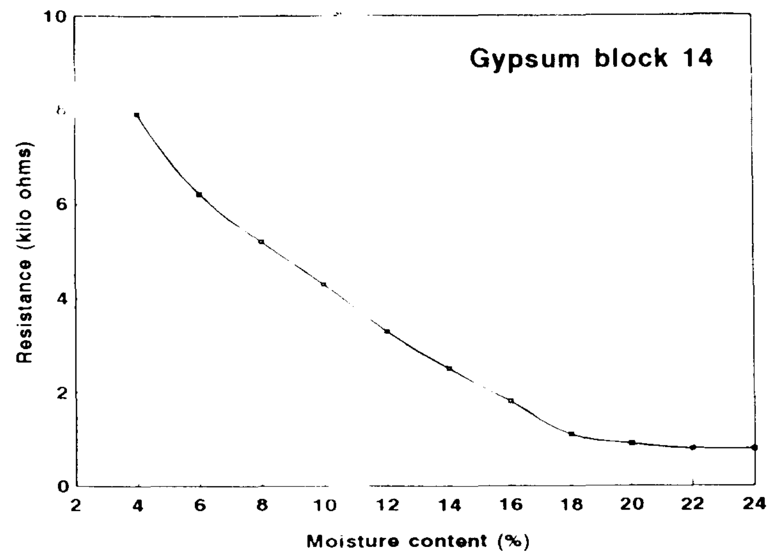


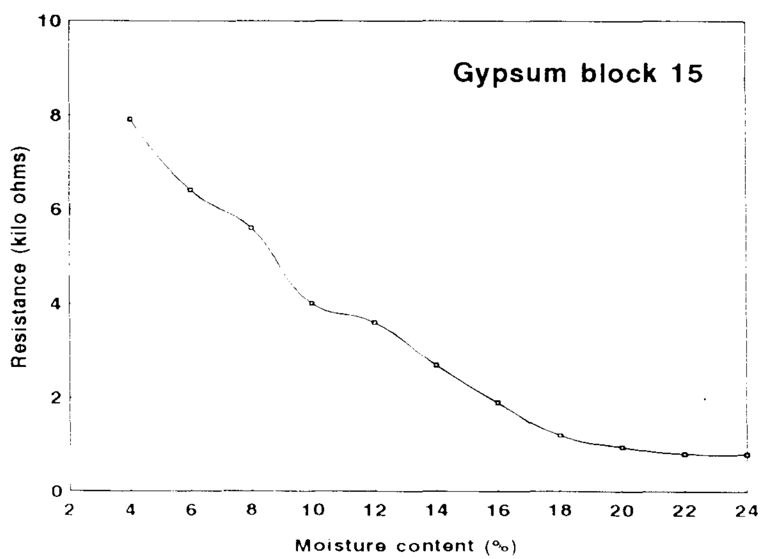
Appendix I(iii) Calibration chart for gypsum block

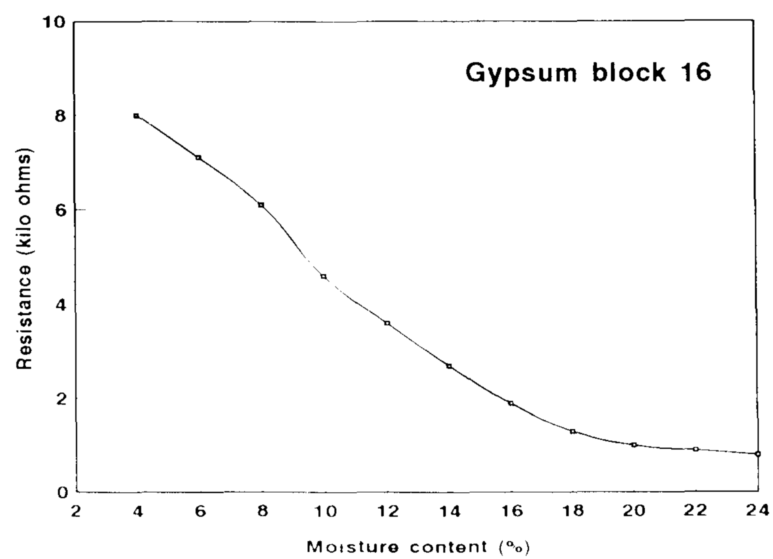


Appendix I(iv) Calibration chart for gypsum block

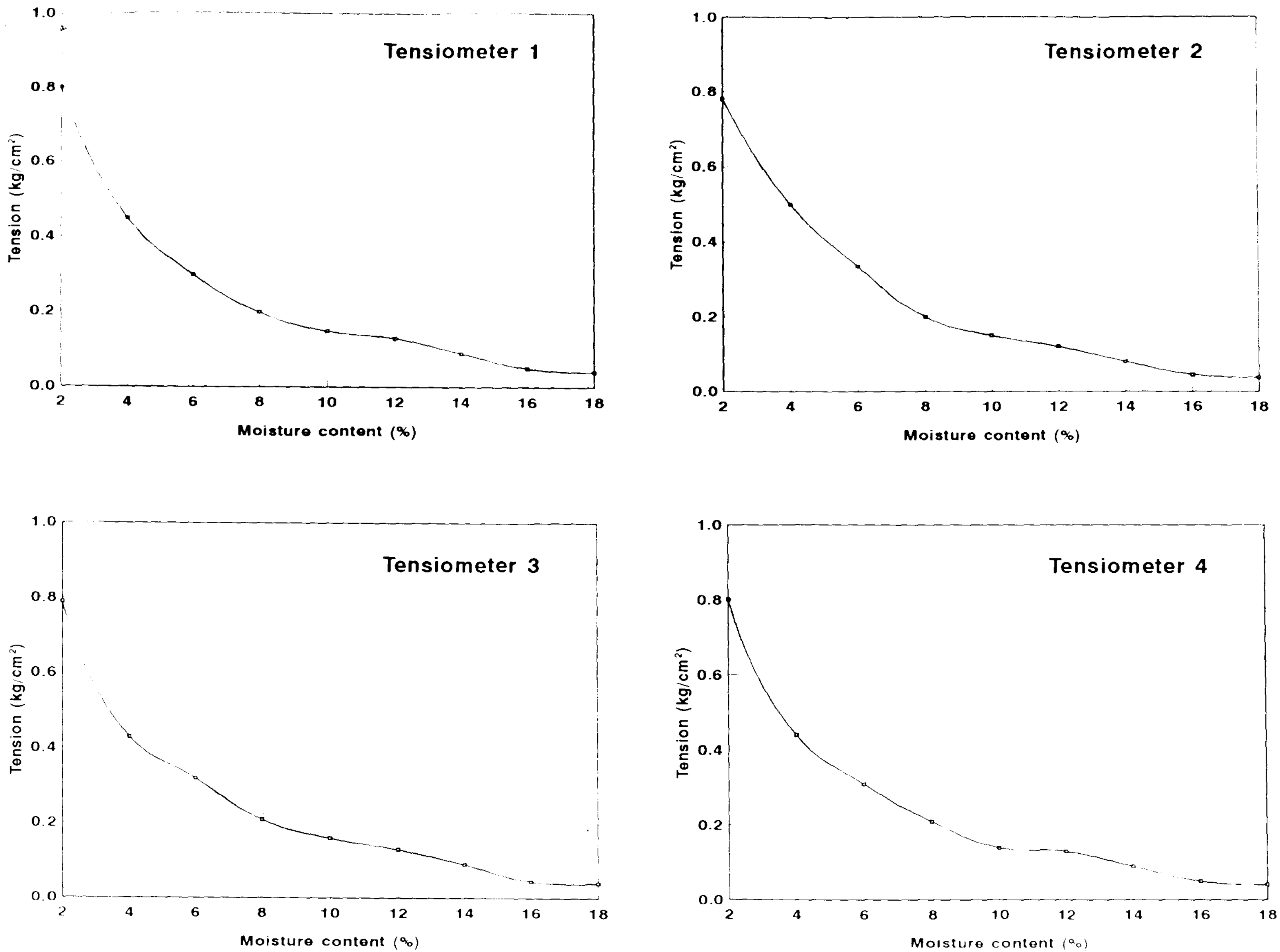




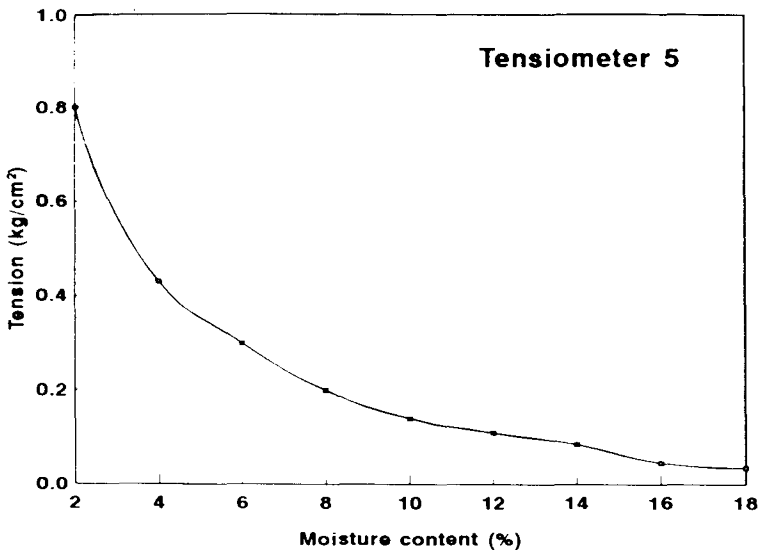


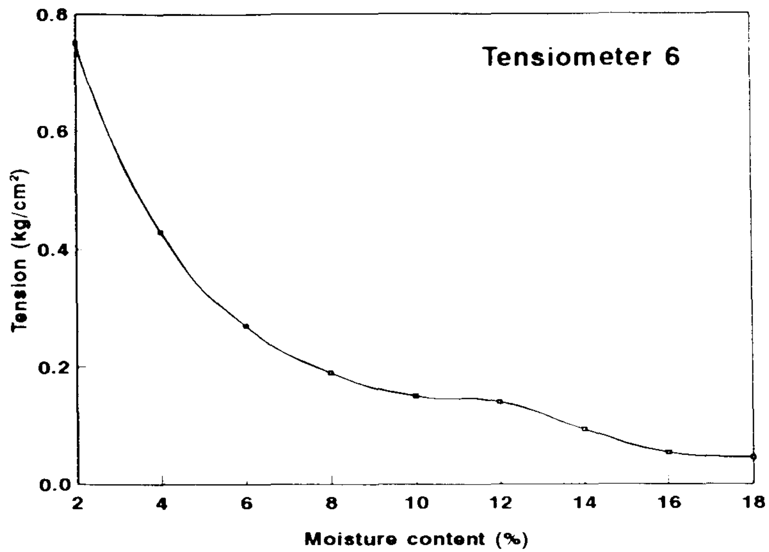


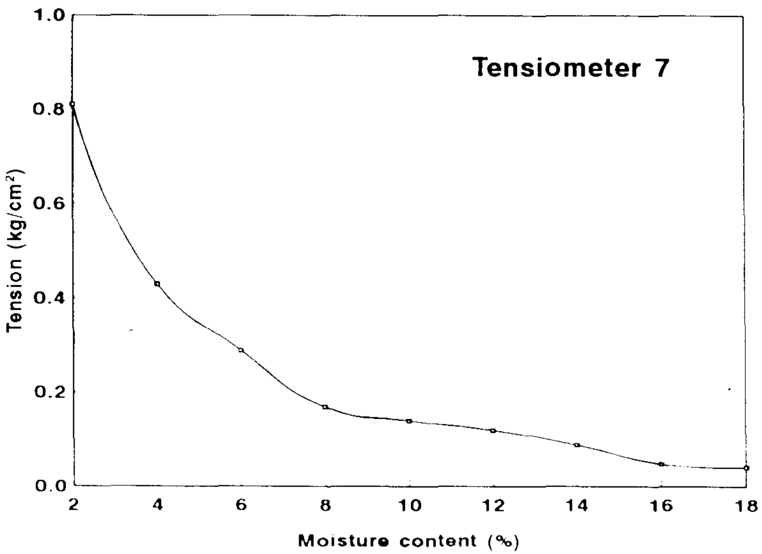
Appendix I(v) Calibration chart for Tensiometer

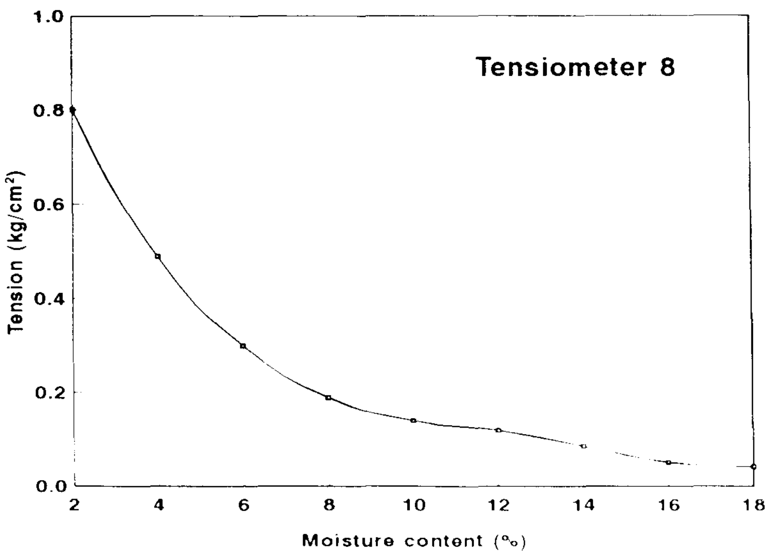


Appendix I(vi) Calibration chart for Tensiometer









APPENDIX II

FORTRAN PROGRAMME DEVELOPED FOR THE MODEL

```
      REAL  FC, PWP, RDM, THETO, MDT, RF, QIRR, CKC, ETO, RD
      DIMENSION RD(150), THETA(150), P(150), THETR(150), RF(150)
      DIMENSION QIRR(150), CKC(150), ETO(150)
```

```
C     FC        = FIELD CAPACITY, mm/cm
C     PWP       = PERMANENT WILTING POINT, mm/cm
C     RDM       = MAXIMUM ROOT DEPTH, cm
C     THETO     = INITIAL MOISTURE CONTENT AT THE BEGINNING OF
                    THE SEASON , mm/cm
C     MDT       = DAYS TO MATURITY, days
C     RF        = RAINFALL, mm
C     QIRR      = IRRIGATION, mm
C     CKC       = CROP COEFFICIENT
C     THETR     = CRITICAL MOISTURE CONTENT, mm/cm
C     P         = DEPLETION FACTOR
C     ETO       = REFERENCE EVAPOTRANSPIRATION, mm
C     RD        = ROOT DEPTH, cm
C     PERC      = PERCOLATION, mm
C     ASW       = AVAILABLE SOIL WATER, mm
C     PET       = POTENTIAL EVAPOTRANSPIRATION, mm
C     AET       = ACTUAL EVAPOTRANSIPIRATION, mm
C     SMI       = INITIAL  MOISTURE CONTENT AT ANY DAY, mm/cm
C     FSM       = FINAL MOISTURE CONTENT AT ANY DAY, mm/cm
C     DRD       = INCREMENTAL ROOT DEPTH, cm
```

```
      OPEN(5, FILE = 'DATA', STATUS = 'OLD', ACCESS = 'SEQUENTIAL')
      DO 20 I=1, 69
      READ (5, *) RF(I), QIRR(I), CKC(I), ETO(I)
20    CONTINUE
      CLOSE(5)
      FC=1.8
      PWP=0.0
      RDM=39.0
      THETO=0.25
      MDT=53
      SMI=0.25
      ASW=FC-PWP
      WRITE(2,11)
      WRITE(2,15)
15    FORMAT (2X, 'IDAP', 2X, 'RD', 5X, 'DRD', 3X, 'THETO', 1X, 'DRDTO',    2X,
     * 'PERC', 2X, 'ASW', 4X, 'PET', 2X, 'AET', 4X, 'SMI', 4X, 'FSM')
      WRITE (2,11)
      DO 100 IDAP=1,69
      RD(IDAP)=RDM * (0.5+0.5*SIN(3.03*IDAP/MDT-1.47))
      IF (RD(IDAP).LT. 15.0)RD(IDAP)=15.0
      IF (IDAP.GE.MDT)THEN
      RD(IDAP)=RDM
      GOTO 5
      ELSE
      ENDIF
      IF (D(IDAP).GE.22.5)THEN
      IF (THETO.LT.0.38)THEN
      THETO=0.38
      ELSE
      THETO=THETO
      ENDIF
      ELSE
```

```
      ENDIF
5     IF (IDAP.EQ.1)THEN
      DRD=0.0
      ELSE
      DRD=RD(IDAP)-RD(IDAP-1)
      ENDIF
      PET=CKC(IDAP) *ETO (IDAP)
      IF (PET.LE.2.0) GOTO 210
      IF (PET.LE.3.0) GOTO 220
      IF (PET.LE.4.0) GOTO 230
      IF (PET.LE.5.0) GOTO 240
      IF (PET.LE.6.0) GOTO 250
      IF (PET.LE.7.0) GOTO 260
      IF (PET.LE.8.0) GOTO 270
      IF (PET.LE. 9.0) GOTO 280
      IF (PET. LE.10.0) GOTO 290
210   P(IDAP)=0.88
      GOTO 50
220   P(IDAP)=0.88-0.08*(PET-2.0)
      GOTO 50
230   P(IDAP)=0.8-0.1*(PET-3.0)
      GOTO 50
240   P(IDAP)=0.7-0.1*(PET-4.0)
      GOTO 50
250   P(IDAP)=0.6-0.05*(PET-5.0)
      GOTO 50
260   P(IDAP)=0.55-0.05*(PET-6.0)
      GOTO 50
270   P(IDAP)=0.5-0.05*(PET-7.0)
      GOTO 50
280   P(IDAP)=0.45-0.02*(PET-8.0)
      GOTO 50
```

```
290    P(IDAP)=0.43-0.03*(PET-9.0)
       GOTO 50
50     DRDTO=DRD*THETO
       A=RF(IDAP) + QIRR(IDAP)
       IF (IDAP.EQ.1) THEN
       B=(FC-SMI)*15.0+(FC-THETO)*DRD
       ELSE
       B=(FC-SMI)*RD(IDAP-1)+(FC-THETO)*DRD
       ENDIF
       IF (A.GT.B)THEN
       PERC=A-B
       ELSE
       PERC=0.0
       ENDIF
       IF (IDAP.EQ.1)THEN
       ABC=15.0*SMI+RF(IDAP)+QIRR(IDAP)+DRDTO-PERC
       ELSE
       ABC=RD(IDAP-1)*SMI+RF(IDAP)+QIRR(IDAP)+DRDTO-PERC
       ENDIF
       THETA(IDAP)=ABC/RD(IDAP)
       THTR(IDAP)=(1.0-P(IDAP))*ASW
       IF (THETR(IDAP).LE.THETA(IDAP))THEN
       AET=PET
       ELSE
       AET=THETA(IDAP)/THETR(IDAP)*PET
       ENDIF
       IF (IDAP.EQ.1)THEN
       XY=(SMI*15.0+RF(IDAP)+QIRR(IDAP)+DRDTO-PERC-AET)
       ELSE
       XY=(SMI*RD(IDAP-1)+RF(IDAP)+QIRR(IDAP)+DRDTO-PERC-AET)
       ENDIF
       FSM=XY/RD(IDAP)
```

```
      WRITE(2,98)IDAP, RD(IDAP), DRD, THETO, DRDTO, PERC, ABC, PET,
      AET,SMI, FSM
98    FORMAT (2X, I3, 2X, F5.2, 2X, 3(F4.2, 2X), 2(F5.2, 2X), 2(F4.2, 2X), F5.3,2X,
      F5.3)
      IF (RD(IDAP). EQ. RDM) THEN
      THETO=0.0
      ELSE
      THETO=THETO+PERC/(RDM-RD(IDAP))
      ENDIF
      IF (THETO.GT.ASW) THETO=ASW
      SMI=FSM
100   CONTINUE
      WRITE(2.11)
      WRITE(2,85)
11    FORMAT(/,1X,73('*'))
85    FORMAT (2X,'IDAP', 3X, 'RF', 5X, 'QIRR', 2X, 'CKC', 3X, 'ETO', 3X,
      'THETA',      1X, 'P',
  *   5X, 'THETR')
      WRITE (2,11)
      DO 78 I=1,69
      WRITE(2,77) I, RF(I), QIRR(I0, CKC(I), ETO(I), THETA(I),  P(I), P(I), THETR(I)
77    FORMAT (2X, I3, 2X, 2(F5.2, 2X), 5(F4.2, 2X))
78    CONTINUE
      WRITE(2,11)
      STOP
      END
```

Note:- Values of the depletion factor ***p*** for bindi is taken as that of cotton (Doorenbos and Kassam,1979) since that of former is not avialable

APPENDIX-III

INPUT FOR THE MODEL

DAS	RF(mm)	IRR(mm)	ETO(mm)	CKC
1	0.00	9.40	8.00	0.45
2	0.00	0.00	7.60	0.45
3	0.00	4.70	6.90	0.45
4	0.00	0.00	5.90	0.45
5	0.00	4.70	5.70	0.45
6	0.00	0.00	4.90	0.45
7	0.00	4.70	5.20	0.45
8	0.00	0.00	6.10	0.45
9	0.00	4.70	7.10	0.45
10	0.00	0.00	6.00	0.45
11	0.00	4.70	6.00	0.45
12	0.00	0.00	5.30	0.45
13	0.00	4.70	4.80	0.45
14	0.00	0.00	6.20	0.45
15	0.00	4.70	5.10	0.45
16	5.00	0.00	4.70	0.45
17	0.00	0.00	5.30	0.45
18	0.00	0.00	6.20	0.45
19	0.00	0.00	6.00	0.45
20	0.00	11.90	6.10	0.45
21	0.00	0.00	7.50	0.75
22	0.00	11.90	7.20	0.75
23	0.00	0.00	7.80	0.75
24	0.00	11.90	7.10	0.75
25	0.00	0.00	7.20	0.75
26	0.00	11.90	6.80	0.75
27	0.00	0.00	5.90	0.75
28	0.00	11.90	7.20	0.75
29	0.00	0.00	7.50	0.75
30	0.00	11.90	7.80	0.75
31	0.00	0.00	7.50	0.75
32	0.00	11.90	7.60	0.75
33	0.00	0.00	7.00	0.75
34	0.00	0.00	7.90	0.75
35	0.00	19.00	7.60	0.75

Contd..

APPENDIX-III(Contd..)

INPUT FOR THE MODEL

DAS	RF(mm)	IRR(mm)	ETO(mm)	CKC
36	0.00	0.00	8.10	0.75
37	0.00	19.00	7.20	0.75
38	0.00	0.00	8.10	0.75
39	0.00	19.00	6.30	0.75
40	0.00	0.00	4.20	0.75
41	0.00	19.00	6.40	1.10
42	10.00	0.00	4.80	1.10
43	5.00	0.00	6.90	1.10
44	0.00	0.00	4.80	1.10
45	0.00	19.00	6.20	1.10
46	0.00	0.00	6.00	1.10
47	0.00	19.00	6.70	1.10
48	0.00	0.00	7.10	1.10
49	0.00	0.00	8.40	1.10
50	0.00	19.00	8.80	1.10
51	0.00	0.00	8.20	1.10
52	0.00	0.00	7.60	1.10
53	0.00	0.00	5.80	1.10
54	0.00	0.00	6.80	1.10
55	9.00	0.00	3.90	1.10
56	0.00	0.00	6.40	0.60
57	0.00	0.00	6.50	0.60
58	0.00	0.00	6.00	0.60
59	0.00	0.00	3.90	0.60
60	0.00	19.00	5.60	0.60
61	0.00	0.00	7.00	0.60
62	0.00	0.00	4.40	0.60
63	0.00	0.00	4.70	0.60
64	0.00	19.00	5.20	0.60
65	12.00	0.00	6.20	0.60
66	0.00	0.00	4.60	0.60
67	0.00	0.00	7.20	0.60
68	0.00	0.00	7.10	0.60
69	0.00	0.00	7.00	0.60

APPENDIX - IV(Contd.)

OUTPUT OF THE MODEL

DAS	RD(cm)	SMI(mm/cm)	PET(mm)	AET(mm)	FSM(mm/cm)
36	30.32	0.881	6.08	6.08	0.665
37	31.23	0.665	5.40	5.40	1.092
38	32.10	1.092	6.08	6.08	0.883
39	32.93	0.883	4.73	4.73	1.304
40	33.71	1.304	3.15	3.15	1.189
41	34.45	1.189	7.04	7.04	1.519
42	35.14	1.519	5.28	5.28	1.631
43	35.78	1.631	7.59	7.59	1.536
44	36.37	1.536	5.28	5.28	1.372
45	36.90	1.372	6.82	6.82	1.615
46	37.38	1.615	6.60	6.60	1.439
47	37.79	1.439	7.37	7.37	1.605
48	38.15	1.605	7.81	7.81	1.402
49	38.44	1.402	9.24	9.24	1.165
50	38.68	1.165	9.68	9.68	1.410
51	38.85	1.410	9.02	9.02	1.179
52	38.95	1.179	8.36	8.36	0.966
53	39.00	0.966	6.38	6.38	0.804
54	39.00	0.804	7.48	6.37	0.640
55	39.00	0.640	4.29	4.29	0.761
56	39.00	0.761	3.84	3.84	0.662
57	39.00	0.662	3.90	3.90	0.562
58	39.00	0.562	3.60	3.60	0.470
59	39.00	0.470	2.34	2.34	0.410
60	39.00	0.410	3.36	3.36	0.811
61	39.00	0.811	4.20	4.20	0.704
62	39.00	0.704	2.64	2.64	0.636
63	39.00	0.636	2.82	2.82	0.564
64	39.00	0.564	3.12	3.12	0.971
65	39.00	0.971	3.72	3.72	1.183
66	39.00	1.183	2.76	2.76	1.112
67	39.00	1.112	4.32	4.32	1.001
68	39.00	1.001	4.26	4.26	0.892
69	39.00	0.892	4.20	4.20	0.785

APPENDIX-V

COMPUTED AND MEASURED MOISTURE CONTENTS

DAS	MOISTURE CONTENTS			
	COMPUTED	MEASURED		
		Gypsm Block	Tensiometer	Gravimetric
	(mm/cm)	(mm/cm)	(mm/cm)	(mm/cm)
1	0.637	0.39	0.51	
2	0.409	0.39	0.45	
3	0.515	0.45	0.41	
4	0.338	0.46	0.39	0.401
5	0.48	0.42	0.41	
6	0.333	0.42	0.38	
7	0.491	0.35	0.43	
8	0.308	0.37	0.35	
9	0.408	0.37	0.35	
10	0.228	0.34	0.35	
11	0.361	0.34	0.27	0.412
12	0.202	0.32	0.24	
13	0.372	0.33	0.34	
14	0.182	0.28	0.24	
15	0.346	0.3	0.39	
16	0.205	0.25	0.21	
17	0.397	0.27	0.39	
18	0.193	0.21	0.25	0.205
19	0.083	0.1	0.13	
20	0.694	0.41	0.58	
21	0.359	0.41	0.43	
22	0.778	0.55	0.89	
23	0.412	0.49	0.51	
24	0.776	0.62	0.78	
25	0.46	0.51	0.54	0.501
26	0.791	0.58	0.68	
27	0.551	0.55	0.45	
28	0.831	0.74	0.73	
29	0.566	0.61	0.64	
30	0.808	0.68	0.71	
31	0.567	0.62	0.46	
32	0.795	0.64	0.48	0.695
33	0.588	0.6	0.49	
34	0.43	0.51	0.38	

Contd...

APPENDIX - IV

OUTPUT OF THE MODEL

DAS	RD(cm)	SMI(mm/cm)	PET(mm)	AET(mm)	FSM(mm/cm)
1	15.00	0.250	3.60	3.60	0.637
2	15.00	0.637	3.42	3.42	0.409
3	15.00	0.409	3.11	3.11	0.515
4	15.00	0.515	2.65	2.65	0.338
5	15.00	0.338	2.56	2.56	0.480
6	15.00	0.480	2.20	2.20	0.333
7	15.00	0.333	2.94	2.94	0.491
8	15.00	0.491	2.74	2.74	0.308
9	15.00	0.308	3.19	3.19	0.408
10	15.00	0.408	2.70	2.70	0.228
11	15.00	0.228	2.70	2.70	0.361
12	15.00	0.361	2.38	2.38	0.202
13	15.00	0.202	2.16	2.16	0.372
14	15.00	0.372	2.79	2.79	0.186
15	15.00	0.186	2.29	2.29	0.346
16	15.00	0.346	2.11	2.11	0.205
17	15.00	0.205	2.38	2.38	0.379
18	15.00	0.379	2.79	2.79	0.193
19	15.00	0.193	2.70	2.70	0.083
20	15.00	0.083	2.74	2.74	0.694
21	15.00	0.694	5.63	5.03	0.359
22	15.39	0.359	5.40	5.40	0.778
23	16.49	0.778	5.85	5.46	0.412
24	17.59	0.412	5.32	5.32	0.776
25	18.71	0.776	5.40	5.32	0.460
26	19.82	0.460	5.10	5.10	0.791
27	20.98	0.791	4.43	4.43	0.551
28	22.04	0.551	5.40	5.40	0.831
29	23.14	0.831	5.63	5.63	0.566
30	24.23	0.566	5.85	5.85	0.808
31	25.30	0.808	5.63	5.63	0.567
32	26.36	0.567	5.70	5.70	0.795
33	27.39	0.795	5.25	5.25	0.588
34	28.40	0.588	5.93	4.20	0.430
35	29.37	0.430	5.70	5.70	0.881

Contd..

APPENDIX-V(Contd.)

COMPUTED AND MEASURED MOISTURE CONTENTS

DAS	MOISTURE CONTENTS			
	COMPUTED	MEASURED		
		Gypsm Block	Tensiometer	Gravimetric
	(mm/cm)	(mm/cm)	(mm/cm)	(mm/cm)
35	0.881	0.68	0.69	
36	0.665	0.47	0.72	
37	1.042	0.85	0.98	
38	0.883	0.87	0.91	
39	1.304	1.23	1.15	1.125
40	1.89	1.1	1.14	
41	1.519	1.4	1.42	
42	1.631	1.75	1.41	
43	1.536	1.62	1.64	
44	1.372	1.47	1.57	
45	1.615	1.55	1.35	
46	1.439	1.48	1.52	1.485
47	1.605	1.65	1.42	
48	1.402	1.31	1.21	
49	1.165	1.01	1.01	
50	1.41	1.38	1.51	
51	1.179	1.04	1.21	
52	0.966	0.84	0.98	
53	0.804	0.72	0.74	0.912
54	0.64	0.52	0.58	
55	0.761	0.66	0.69	
56	0.662	0.63	0.61	
57	0.562	0.54	0.51	
58	0.47	0.4	0.38	
59	0.41	0.31	0.38	
60	0.811	0.53	0.78	0.781
61	0.704	0.65	0.66	
62	0.636	0.54	0.61	
63	0.564	0.48	0.49	
64	0.471	0.81	0.91	
65	1.183	1.28	1.08	
66	1.112	1.1	1.1	
67	1.001	0.92	0.93	1.098
68	0.892	0.78	0.83	
69	0.785	0.53	0.73	

FIELD TESTING AND EVALUATION OF A TWO LAYER SOIL WATER BALANCE MODEL

By

MOHANAN [illegible]

ABSTRACT OF A THESIS

submitted in partial fulfilment of the requirement for the degree

Master of Technology in Agricultural Engineering

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ABSTRACT

A two layer soil water balance model was tested in the field with bhindi as the test crop. The model considers the dynamics of soil water balance by incorporating an empirical model of root growth and an empirically established result of plant response to available soil water.

The input data of the model were daily values of rainfall, irrigation and reference crop evapotranspiration. The model calculated the values of root depth, potential evapotranspiration, actual evapotranspiration, percolation and soil moisture content at the end of each day. The root depth computed by the model was compared with that measured in the field. Maximum root depth of 39.0 cm was attained at 53rd DAS. Total amount of water percolated down the active root zone during the entire crop season was 8.15 mm. The actual evapotranspiration was less than the potential evapotranspiration, whenever the soil moisture content in the active root zone dropped below the critical soil moisture. Totally, AET was less than PET for 6 days during the period of study. The computed and observed values of soil moisture content were in close agreement with correlation coefficients 0.976, 0.971 and 0.965 for gravimetric, tensiometer and electrical resistivity methods respectively.