WATER USE BY EIGHT ANNUAL CROPS
AT KABETE, KENYA 1978/79

FLORENCE KANZE LENGA

A Thesis submitted in partial fulfilment
for the Degree of Master of Science
in the University of Nairobi,
Department of Soil Science

OCTOBER 1979

DEDICATED TO MY PARENTS,

WITH LOVE

DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

Signed: FKLenga

FLORENCE KANZE LENGA

This thesis has been submitted for examination with our approval as University Supervisors.

Signed

PROFESSOR P. M. AHN
(PRINCIPAL SUPERVISOR)

DR. A. M. GURNAH

MR. S. M. KINYALI

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

I am very grateful to the International Development Research Centre (I.D.R.C.) for providing a two-year Master of Science Scholarship and also to the University of Nairobi for providing facilities which enabled this work to be carried out.

I wish to express my sincere appreciation to Prof. P. M. Ahn (Principal Supervisor) and to Mr. S. M. Kinyali of the Department of Soil Science and Dr. A. M. Gurnah of the Department of Crop Science, all of the University of Nairobi, under whose supervision this work was conducted. Their inspiration, guidance, helpful suggestions and criticisms are greatly appreciated. I am indebted to Mr.Gitonga of the National Agricultural Laboratories (Ministry of Agriculture) for providing the Neutron Probe machine and also his technical assistance, to the staff of Kenya Meteorological Department (Agromet Section, Dagoretti) for providing the necessary climatic data, and to Sir Charles Pereira for his advice and valuable suggestions.

Thanks are also due to the entire staff of the Soil Science Department and Field Station, for both their technical and general assistance and also all the workers who did most of the routine field work for very little pay. Last but not least, the work of Mrs. Esther A. Onim, who typed the thesis is very much appreciated.

LIST OF ABBREVIATIONS AND SYMBOLS

$\hat{\beta}$	Estimate of the slope of the regression line
^oC	Degree Centigrade
CAN	Calcium ammonium nitrate
cm	Centimetre
cm^2	Square centimetres
cm^3	Cubic centimetres
E_o	Open water evaporation
E_t	Actual evapotranspiration
g	Gram
ha	Hectare
hr	Hour
Kg	Kilogramme
K_2O	Potassium Oxide
LR	Long rains
M	Metre
M.C.	Moisture Content
mm	Millimetre

MnO_2	Manganese dioxide
N	Nitrogen
P_2O_5	Phosphorus Pentaoxide
r	Correlation coefficient
r^2	Square of correlation coefficient
S	Standard error
S^2	Variance
SR	Short rains
$\bar{X}$	Mean of x-values
$\bar{Y}$	Mean of y-values
%	Percentage

SYMBOLS FOR CROPS

FB	Field beans
IP	Irish potatoes
M	Maize
SP	Sweet potatoes
LS	Linseed
SB	Soya beans
SF	Sunflower
W	Wheat

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF APPENDICES

Page

ABSTRACT

Investigations involving mainly food crops adapted to the Kabete area (the complete range of crops investigated being maize, field beans, Irish potatoes, sweet potatoes, wheat, sunflower, soyabeans and linseed) sought to obtain data on particular moisture aspects. These aspects included:

(1) seasonal water use at different stages of growth by the different crops in relation to the natural rainfall, in both the short and long rains;

(2) the relationship between open free water evaporation, as calculated by the modified Penman method and Pan A data, and the actual water use of the crops; and

(3) the yield of the crops studied during the time of the experiment as affected by water and other factors.

Two methods were employed, namely the neutron probe and gravimetric methods for determining moisture

content of the soil to a depth of 180 centimetres. Calibration of the probe machine showed that this method may not be very accurate for predicting volumetric moisture content in the Kabete soil, due to lack of precision at the higher moisture range (above 37%) and greater soil depths (90 + cm depth) due to high clay content. However, it was shown that volumetric moisture content and probe count ratio are linearly related ($r = 0.8675$ for a 0 - 30 centimetre depth and $r = 0.7432$ for 30 - 180 cm depth). Because of the difficulties encountered in obtaining adequate calibration curves, water use calculations for the crops were based on gravimetric samplings.

The available moisture for the Kabete soil in a profile of 180 centimetres was about 161.5 millimetres which was in close agreement with what Pereira (1957) found for similar soils.

Periodic and seasonal total water use by crops was found to be affected by the length of the crop's growing season, amount and frequency of the rainfall, soil dryness (mainly soil water availability) and crop development.

Irish potatoes used the least amount of water (266.1 millimetres (mm) in the short rains and

477.5 mm in the long rains). These were followed by field beans (299.5 mm (SR) and 478.9 mm (LR)), wheat (324.8 mm) linseed (400.1 mm), soyabeans (478.8 mm) sunflower (516.6 mm), maize (518.4 mm (SR) and 619.2 mm (LR)) and sweet potatoes (629.3 mm (SR) and 641.4 mm (LR)), respectively.

Irish potatoes and field beans had short effective rooting depths of 50 - 70 cm range, followed by linseed which had 90 - 120 cm range of effective rooting depth. Wheat, maize, sweet potatoes, soyabeans and sunflower had effective rooting depth of 150 - 180 cm.

Open free water evaporation values obtained from Pan A data were found to be consistently lower than those calculated from the modified Penman method (McCulloch, 1965). Thus the crop coefficients (E_t/E_o Penman) were consistently lower during the two seasons, for all crops, than the pan coefficients (E_t/E_o Pan A). These coefficients were found to be influenced by the frequency of wetting and amount of rainfall as found by Kowal and Andrews (1973) and Wangati (1972), in addition to being influenced by the crops development and phenology. They were also found to be closely related to water consumption.

The most efficient crop in terms of water use was Irish potatoes, 36.42 kg/ha/mm of water use and

20.50 kg/ha/mm of water use were realised during the short and long rains respectively. Maize was the next most efficient crop, with 9.50 kg/ha/mm and 7.22 kg/ha/mm of water use during the short and long rains respectively. These were followed by sweet potatoes which had 6.93 kg/ha/mm and 5.13 kg/ha/mm, field beans (2.42 kg/ha/mm and 2.80 kg/ha/mm) during the short and long rains respectively. Wheat, sunflower, soyabeans and linseed had 2.10, 1.24, 1.03 and 0.23 kg/ha/mm of water use during the short rains, respectively. However, water use efficiency reflected total yields and therefore moisture availability, in addition to other factors, such as pests and diseases, influencing yields.

CHAPTER I

1. INTRODUCTION

1:1: GENERAL

Of all the climatic factors which influence the pattern and productivity of rainfed agriculture in Kenya, availability of water to crops is by far the most important (Griffiths, 1972). Pronounced differences exist in the length of growing season in Kenya due to differences in the distribution and amount of annual rainfall. Year to year variation is also large (Kenworthy, 1964).

Kabete, in the Central Province of Kenya, has a wet bimodal rainfall regime. The main growing season begins about the middle of March, the actual date varying from year to year, and continues to July/August, with the crops using stored water in the later months. The second, minor, season extends from mid October to January/February. The length of the growing season ranges from three months (for example beans, Canadian wonder variety) to six months (for example sweet potatoes) depending on the crop. Early maturing crops are therefore required and are planted twice each year. Medium maturing maize such as the Embu hybrids (H 511 and H 512) and potatoes all do well.

Crop water use studies are carried out on the basis of energy balance or water balance concepts. In most areas, the frequency and persistence of favourable water balances is determined by the rainfall within the bimodal/monomodal pattern and the water holding capacity of the soil profile. The matching of crop duration with the rainfall season, which largely determines the total water available to different crops, is therefore the key to high and consistent yields (Dagg, 1972). Seasonal water use is related to the soil water available at planting, seasonal precipitation, and to crop factors such as leaf area and root penetration (Jensen, 1968). Consequently, it is important to choose the date of planting to coincide with the onset of the rains (Dagg, 1965).

The concepts of crop water use, water use efficiency and productivity, which combine studies of crop water use and drought response, have gained prominence especially when dealing with the selection of crops for adaptation to new cropping systems for a given climate especially in marginal rainfall areas. It is known that different crops respond differently to drought due to differences in characteristics such as leaf area and rooting habit. Because of the differences in rooting habit, crops utilise water from different soil depths under the same environment. Moisture use from different soil depths by different crops is one factor resulting in differences in moisture carry over from one season to the next. Conversely, the depth of soil and rooting habit of a crop are important criteria in assessing the suitability of a crop to a given meteorological environment. Different crops again have different nutrient requirements and will extract nutrients from the same soil, given the same climate, to varying degrees. This will again affect the nutrients status in the soil at the end of the growing season, which will in turn affect the next season's crop. The recent cropping history in a given environment will therefore affect the succeeding crop. These are some of the considerations relevant to the development of local crop rotations for Kabete.

1:2: NATURE OF THE INVESTIGATION

The current project designed to provide basic information for the development of local crop rotations is aimed at rainfed crop production on small farms at Kabete. It began in May 1976 through the financial support of International Development Research Centre (I.D.R.C.) and is being carried out at Kabete Field Station by the Soil and Crop Science Departments of the University of Nairobi.

The objectives of the crop sequence trials, as the project is often termed, were to see the effects of a crop on the succeeding crop, or the effects of the recent cropping history on a crop. This general investigation mainly involves food crops adapted to the Kabete area; the complete range of crops investigated being maize, field beans, Irish potatoes, sweet potatoes, wheat,sun-flower, soya beans and linseed.

The investigations described in this thesis fall within the general framework of the crop sequence trials, and seek to obtain data on particular moisture aspects. These aspects include:

(1) Seasonal water use at different stages of growth by the different crops in relation to the natural rainfall, in both the short and the long rains.

(2) The relationship between open free water evaporation, as calculated by the modified Penman Method and Pan data, and the actual water use of the crops.

(3) The yield of the crops studied during the time of the experiment as affected by water and other factors.

1:3: CROPS INCLUDED IN THE INVESTIGATION

Maize (*Zea mays*) has become the major grain crop in Kenya. In the western part of the Rift Valley Province and part of Western Province, maize is grown in pure stands. It may also be found mixed with beans, potatoes, cow-peas and pigeon peas in certain parts of the country. Expanded production caters for the country and also allows accumulation of a reserve for years of poor production, for exports and for alternative uses within the country.

These uses include corn oil production, as a food grain, preparation of livestock feed and starch production (Acland, 1971).

Field beans (Phaseolus vulgaris) are the most important pulse crop in Kenya and are mostly inter-sown with maize or other cereals. They are important in all agricultural areas except at the Coast. During the short rains, pure stands of beans may be sown.

Irish potatoes (Solanum tuberosum) are an important root crop in some of the Eastern highlands of Kenya. Most Irish potatoes are consumed as a subsistence crop although some are marketed internally.

Sweet potato (Ipomoea batatas) is one of the most important root crops in the country other than Irish potatoes and cassava. Sweet potato vines are used as animal feed in areas of high small holder stock husbandry, especially during the dry season because they are very drought resistant (Acland, 1971).

Wheat (Triticum aestivum) is one of the major crops in the country. Domestic use of wheat for bread, biscuits and macaroni products is well established. It is mainly grown in large farms in the Rift Valley although small scale production has begun in areas around Mount Kenya (Acland, 1971; Pinto and Hurd, 1970).

There is a demand for edible oil seeds for export and for local oil expelling plants (Hills, 1947). Sunflower (Helianthus annuus), soyabeans (Glycine soja) and linseed (Linum usitatissimum) are oil crops which can be grown successfully in Kenya. They are grown in some parts of the country but production is still very low. If adapted to the cropping systems, they could be used for the expansion of the oil extraction industry, cattle cake and poultry feeds preparation. They can also provide the much needed oil and protein in the diet. Possibly the farmer might be interested in these crops as cash crops.

Maize, field beans, Irish potatoes and sweet potatoes are already well established at Kabete. Wheat, sunflower, and, to a small extent, soyabeans and linseed are grown elsewhere in Kenya but are not well established in the cropping systems at Kabete. They can however do well there.

CHAPTER II

2. LITERATURE REVIEW

2:1: CROP WATER USE

2:1:1: IMPORTANCE OF CROP WATER USE DATA

Crop water use data is used mainly for the improvement of water use economy in irrigation projects. Economic returns from irrigation projects and the proper design and operation of irrigation schemes largely depend on the reliability of available figures on actual water use by crops or evapotranspiration estimates (Sarraf, 1972).

Under rainfed agriculture, crop water use data can be used to minimise the adverse effects of dry periods by selecting the right crop for the right season in a given environment. Thus crops, including seasonal crops such as maize, can be matched to the environment as defined by effective rainfall and soil water storage characteristics (Dagg, 1965).

2:1:2: CROP WATER USE THEORY

The combined losses by evaporation from the soil surface and by transpiration account for the consumptive use of water (actual evapotranspiration - Dastane, 1974),which constitutes the total water lost by evapotranspiration in producing crops (Brady, 1974; Jensen, 1968 and Rijtema, 1966). Evaporation can be defined as the vaporisation of water and removal of such vapour from the source. It is a purely physical process governed by energy inputs, diffusion and bulk aerodynamic movements. Transpiration is the loss of water in the form of vapour from plants. All aerial parts of the plants may lose some water by transpiration, but most water is lost through the leaves in two stages, namely evaporation of water from cell walls into the intercelluler spaces and diffusion through stomates into the atmosphere. Some water vapour also diffuses out through the epidermal cells of leaves and the cuticle.

The rate of water loss by both evaporation from the soil and by transpiration is determined basically by differences in moisture potential identified as the vapour pressure gradient (Brady, 1974). This is the difference between the vapour pressure at the leaf or soil surface and that of the atmosphere. It is related to climatic and soil factors, and to plant characteristics. The level of evapotranspiration is thus controlled mainly by meteorological parameters or evaporative demand, water availability in the soil and plant characteristics which include extent of ground cover, stage of growth, depth of rooting and length of growing season (Doorenbos and Pruitt, 1975; Dastane, 1974 and Rijtema, 1966).

Many observations have shown that the transpiration per unit land area per unit time is largely independent of the nature of the crop, provided that it is supplied with adequate soil water and that the leaf canopy has developed to such an extent as to intercept most of the solar radiation. For this reason the concept of maximum or potential evapotranspiration has been introduced. It is defined as the rate of evapotranspiration dependent on weather conditions, from an extensive surface of a short green crop of uniform height, completely shading the soil and actively growing under conditions of optimum water supply (Penman, 1948).

A number of methods have been evolved to estimate the potential evapotranspiration using meteorological parameters. The evaporimeter pan method is the simplest. The evaporation of water from an open tank is measured and water addition by rainfall is collected. Despite its wide use in irrigation scheduling, the pan is subject to unreproducible errors such as advection effects at some times of the year when it is fairly dry. Dagg (1969) was sceptical of the usefulness of pans under East African conditions.

Some of the methods are based on an empirical correlation with the mean monthly air temperature and day length (Thornthwaite, 1948; Blaney and Criddle, 1950). No method based on monthly temperature and day length alone, as the only weather elements, can be expected to give reliable results for climatologically different regions.

The Penman (1948) method or one of its subsequent modifications, for example the modified Penman method as presented by Doorenbos and Pruitt (1975), has gained wider application than any of the other methods. The modified Penman method (Doorenbos and Pruitt, 1975) has been adapted by F.A.O. for determining crop water requirements for practical irrigation scheduling.

The original Penman (1948) equation predicted the loss of water by evaporation from an open water surface, E_o. Data on radiation flux or sunshine duration, air temperature, humidity and wind speed are required. Potential evapotranspiration is then empirically determined by:

$$E_t = f E_o \qquad (2:1)$$

where f is the crop coefficient. This has a value ranging from 0.6 to 0.8 in England, depending on the time of the year. Glover and Forsgate (1964) at Muguga in Kenya found that f had a value of 0.75 for short grass kept moist and did not depend on the time of the year. Pereira et al. (1962) found that f had a value of 0.9 for high altitude moist evergreen tropical high forest and 0.8 for a wider range of pine, cypress and bamboo forests.

Doorenbos and Pruitt (1975) have recently attempted to reconcile the widely divergent approaches to estimating potential evapotranspiration. They have proposed a modification of the Penman formula to calculate directly the reference crop potential evapotranspiration (E_{to}) defined as the evapotranspiration of a short, well watered, green grass sward. Because E_o is calculated for a surface albedo of 5% and the albedo of vegetation is always greater, upto 25% for short grass, though approaching 5% for high forest, E_{to} is less than E_o. This needs to be taken into account when the potential evapotranspiration for a specific crop is considered (Russell, 1973).

In many of the empirical formulae, many assumptions and simplifications are necessary, which may lead to large deviations from the actual evapotranspiration (Sarraf, 1972). This limits their general application. It has also been recognised that crops do not necessarily transpire at the potential rates as defined by Penman (1948). So long as some radiation is incident on bare soil, actual evapotranspiration is less than potential evapotranspiration. This is because water only evaporates at the potential rate from the top few centimeters of the soil surface. Unless the soil is wetted very frequently, the actual evapotranspiration can fall well below the potential without injury to the crop which is able to draw its water through the roots from much deeper soil layers. Recent measurements of actual water use by various crops tend to show that the peak water use may exceed the potential evapotranspiration (Sarraf, 1972). This could be attributed to the role of the crop such as its geometry, roughness and leaf characteristics. Research work is therefore necessary to estimate the actual water balance of a field crop as an aid to determination of crop water requirements, for each crop and for each ecological area.

2:1:3: FACTORS AFFECTING CROP WATER USE

2:1:3:1: GENERAL

Factors affecting crop water use, and therefore their growth and yield may be grouped into soil, plant, climate and others (Salter and Goode, 1967). Soil factors include soil water content, texture, structure, depth, salinity, fertility, aeration, temperature and drainage. The water content at field capacity and at permanent wilting point gives some indication of the availability of water for absorption by plant roots. The difference in soil water content at field capacity and at permanent wilting point defines the range of plant available water. As the soil dries out, the rate of water transmitted through the soil and supplied to the roots will reduce and consequently the rate of water uptake by the plant will be affected.

Soil texture, organic matter content, structure and depth determine the capacity of the soil to store available moisture for plants and the ease with which the soil water may be reached and absorbed by roots. Root growth and extension are also influenced by texture, structure and depth in addition to soil aeration, temperature, fertility and management.

Salt content of the soil can influence soil moisture stress by affecting the osmotic sunction of the soil solution. The osmotic suction tends to increase the wilting coefficient (Brady, 1974), thereby reducing the range of available moisture in saline soils.

The type of plant, its rooting and aerodynamic characteristics and tolerance to drought will affect the crop water use. The root systems vary with respect to volume of soil occupied, growth rate and density and these can affect the plant's response to soil moisture conditions. The physiological age of the crop may affect water use. Plant height largely determines the roughness and thus the aerodynamic properties of the crop, hence affecting the water loss from the crop's surface. Plant density or number of plants per unit area of ground in the field will greatly affect the volume of soil available for root ramification. For a given crop, a high plant population would normally require more water in the early stages of crop development than a low planting density (Doorenbos and Pruitt, 1975). This is due to quicker development of full ground cover of the high plant population crop. Any factor influencing crop vigour such as the health of the plant, virus infestation or pest attack, may be expected to influence crop water use.

Climatic factors such as net radiation, temperature, humidity and wind can greatly influence the water balance of crops by their effects on the rate of transpiration (Kramer, 1949). Rainfall increases soil water availability but may also increase the humidity thereby reducing the transpiration rate. It may also increase disease incidence by changing the crop environment causing a decrease in crop vigour and therefore reduce transpiration rate.

2:1:3:2: SOIL WATER AVAILABILITY

Field capacity and wilting point estimates are necessary for obtaining available water content in a soil and therefore how much moisture can be extracted by plant roots. These estimates (or measurements) define the range of plant available water which is usually equated with the difference in soil water content at field capacity (moist end range) and at wilting point (dry end range).

Field capacity has been defined as the "amount of water held in the soil after the excess gravitational water has drained away and after the rate of downward movement of water has materially decreased" (Veihmeyer and Hendrickson, 1931). Permanent wilting point is defined as the water percentage of a soil when plants growing in that soil are first reduced to a wilted condition from which they cannot recover in an approximately saturated atmosphere. It is usually equated with the fifteen atmosphere percentage determined with the pressure membrane apparatus (Richards and Weaver, 1943). Some plants, however, can extract moisture held with a tension of more than fifteen atmospheres.

The concepts of field capacity and wilting point assume static soil water conditions and represent an equilibrium value on soil water content. In fact, soil water through continuous redistribution in the soil profile, under both saturated and unsaturated conditions is a dynamic process. In a physical sense, no static levels can be assumed. Despite this, the concepts are considered useful criteria for determining the soil water available for plant growth.

2:2: SOIL WATER BALANCE CONCEPTS

Water use studies involve the use of the water conservation or water balance equation and hence the determination of all its components. The soil water balance is generally given by the equation:

$$P + I - S = \Delta w + \int E\,dt + \mu \qquad (2:2)$$

where P = precipitation

I = irrigation

S = surface runoff

Δw = change in soil moisture storage

E = evapotranspiration

dt = time

μ = drainage

(Barrada, 1972; Hillel, 1972; Slatyer, 1966a).

The equation can be solved only if all the terms but one are given or can be measured. Precipitation, irrigation and surface runoff can be determined and their measurement can be known. Non-uniformity in aerial distribution of precipitation and irrigation can be overcome by adequate replication. The amount of runoff in principle should be minimal in most agricultural fields. Where it is appreciable, it is rather difficult to measure and even more difficult to ascribe quantitatively to different parts of the watershed above the gauging point (Hillel, 1972).

Soil water storage and its changes can be obtained by sampling, use of the neutron moisture meter, tensiometers and use of electrical resistance blocks (Holmes et al., 1967). Techniques have been developed by micro-meteorologists to measure evapotranspiration. These include the energy-balance-Bowen ratio method, as well as aerodynamic and eddy diffusion methods. Thom (1975), Rosenberg (1974), Monteith (1973) and Tanner (1968) have recently reviewed these methods. However, none of these methods have so far become a working tool in field management.

The most direct method for measuring evapotranspiration is by the use of lysimeters, (e.g. Wangati, 1972; Dagg, 1970; Pruitt and Angus, 1960; Pelton, 1961; van Bavel and Myers, 1962; Black et al., 1968; Hillel et al., 1969). When lysimeters are equipped with weighing and drainage devices, they can measure the total water balance. However, they are bulky and rather expensive to install. They may obstruct normal field practice and seldom provide a reliable representation of the real above ground and soil environment of the field in which they are set. To determine evapotranspiration from the water balance without the direct measurement of evapotranspiration requires the knowledge of the drainage component of this balance, so that the only unknown in the equation is the evapotranspiration.

Initially the drainage component was assumed to be negligible. Gardner et al. (1970) showed that drainage processes following an irrigation could persist for a very long time. Hillel and Guron (1970) showed that the deep percolation process can be bidirectional i.e. alternately downward and upward in response to cyclic irrigation or even rainfall patterns. Thus drainage processes must be measured in the water balance equation.

With the development of water flux metres, direct measurement of the drainage will be possible (Carry, 1968). Watson (1966) evolved a method which he referred to as the instantaneous profile method of measuring the drainage. It is based on an initial measurement of the hydraulic properties of a complete soil profile *in situ*. Detailed work on the measurement of drainage has been carried out by Rose and Stern (1967a, b), van Bavel *et al.* (1968a, b), Barrada (1972) and Gardener (1970). The instantaneous profile method is however, complex and the simplest definition of drainage is that it is the amount of water passing beyond the root zone, or, for experimental purposes, the amount passing below the lowest point of measurement after the profile has reached field capacity. This assumption will be used in this study so that an estimate of the drainage component can be obtained.

Having determined the other components of the water balance and estimated the drainage component from field capacity data of the profile, the water balance equation can be solved. In this way, evapotranspiration of the crop (or consumptive water use) can be calculated for a given period.

2:3: METHODS OF DETERMINING SOIL MOISTURE

2:3:1: GRAVIMETRIC OR SAMPLING METHOD

The gravimetric or sampling method involves weighing the wet samples, removing the water and reweighing the sample to determine the amount of water removed (Gardener, 1965). Samples are taken from the required depths in the field and immediately transferred into a metal or glass container with a tight fitting lid. The container is sealed immediately to prevent loss of moisture before weighing the samples.

The samples, on reaching the laboratory, are weighed. The lid is removed, the samples are dried to constant weight in an oven at 105 - 110°C, and reweighed. The water content of the sample is then obtained by dividing the difference between wet and dry masses by the mass of the dry soil. When multiplied by a hundred, this becomes the percentage of the water in the sample on a dry weight basis.

To convert this moisture percentage into millimetres of water per soil depth, which is a more useful figure as precipitation and all the components of the water balance have dimensions of length, the percentage is multiplied by the bulk density of that particular depth and then multiplied by the thickness of the sample horizon. Bulk density is the ratio of mass of the dry soil to the volume of the soil sample as from the field (g/cm^3). It has to be determined separately, unless known volume samples are used in the moisture determination, i.e.

$$x = \frac{(\% \; m.c_w \times P_b \times d)}{10} \qquad (2:3)$$

where x = mm moisture per soil depth

$m.c_w$ = moisture content by weight

P_b = bulk density

d = thickness of the sample horizon in cm.

Assuming P_w = 1

The measurement of bulk density in the field is difficult and subject to errors. Even in soils of the same surface texture, great differences in bulk density are to be expected when similar horizon levels are compared. This can be attributed to the soil variability in the field which is caused by soil faunal activity, root activity and the system of crop and soil management which affect the soil structure and organic matter content. The gravimetric method itself, depending as it does on sampling, transporting, and repeated weighings, entails inherent errors. It is laborious and time consuming, since a period of at least twenty-four hours is usually allowed for complete sample drying. The standard method of oven drying is also arbitrary, some clays may still contain appreciable amounts of adsorbed water even at 105 - 110^{o}C. On the other hand, some organic matter may oxidize and decompose at this temperature range so that the weight loss may not be due entirely to water evaporation. The location of sampling points requires careful planning to ensure representative samples for the entire field under investigation (Slatyer, 1966b). This method is also destructive and may disturb an observation or experimental plot sufficiently to disturb the results.

The gravimetric method is the oldest method and is the most accurate if errors are reduced by increasing the sizes and number of samples. Methods such as the neutron scattering and use of electrical resistance blocks require very careful calibration with the soil they are used. They are thus dependent on the gravimetric method to a certain extent for that calibration; and this method remains the simplest, the most widely used and probably the best for determining soil moisture.

2:3:2: NEUTRON SCATTERING METHOD

This method has been recently developed and has some advantages over the gravimetric method. It measures moisture content on the volume basis directly and samples are large and hence constitute a more representative volume of soil, while minimizing sampling errors (since repeated measurements are made at the same site) and avoiding destructive sampling. Moreover, this method provides an immediate answer, thus obviating the need for conveying samples to the laboratory to be weighed and oven dried, a procedure which is time consuming as well as a source of error.

The property that hydrogen nuclei have of scattering and slowing neutrons is exploited in the method for measuring water content. A probe which contains a source of fast neutrons and a detector of slow neutrons is lowered into an access tube inserted vertically into the soil. A scaler or ratemeter monitors the flux of slow neutrons, which is proportional to the soil water content.

The effective volume of soil in which the water content is measured is a sphere which depends on the concentration of the hydrogen nuclei. The sphere in a wet soil is about fifteen centimetres in diameter, but in a relatively dry soil may be as great as fifty centimetres or more (Van Bavel et al., 1961). This low degree of spatial resolution makes the instrument unreliable for detection of water content discontinuities, or for measurement close to the soil surface.

The method requires calibration. Methods of calibration have been described by Holmes (1956) and Holmes and Jenkinson (1959). Field calibration cannot be precise due to inaccuracies arising from the determination of mass-basis water content and bulk density, whose variation can occur over relatively short distances. There is also evidence that the presence of small quantities of good neutron absorbers like boron, lithium, chlorine and iron can affect the calibration curve (Holmes and Jenkinson, 1959). However, if the calibration curve is not considerably in error, water content determinations from the neutron method may be better than those obtained by sampling.

It should be noted that the equipment is expensive and the user risks radiation hazards, if careful handling of the equipment is not observed.

2:3:3: ELECTRICAL RESISTANCE BLOCKS

Electrical resistance blocks moisture measurements depend on the determination of the electrical resistance between two electrodes imbedded in a block of gypsum whose moisture content is in equilibrium with the soil (Kelley *et al.*, 1946). The electrical resistance of a soil volume depends not only on its water content, but also on its composition, texture and soluble salt concentration. Because of this, the blocks need to be calibrated for each individual soil or soil horizon before they can be used. They are calibrated by testing them in soil of known moisture content, using each of the different soils occurring in the field. Calibration also deteriorates with time. This is because the blocks are sensitive to the salt concentration of the soil solution, and also blocks made of gypsum eventually deteriorate in the soil as the gypsum dissolves.

The equilibrium of the porous blocks with the soil moisture may be affected by hysteresis. The hydraulic properties of the blocks may also impede the rapid attainment of equilibrium and cause a time lag between the state of water in the soil and that being measured in the block. Thus the moisture determination using electrical resistance blocks is of limited accuracy. They can also tell one whether the soil is wet or dry. Resistance blocks have the advantage of being able to provide a continuous record of soil moisture changes *in situ* when connected to a recorder.

2:4: WATER USE AND CROP YIELDS

Different crops have varying degrees of drought tolerance in relation to survival and yield reduction. It has been recognised that for crop water use studies to be meaningful, the yield response to the crop to water deficits must be known. Knowledge of the yield and crop water use is needed to predict the level of production that can be achieved by the use of the available water resource.

Assessment of the effects of water supply on agricultural productivity has been carried out using several approaches. Stanhill (1973) recently reviewed four approaches, the first being rainfall either as seasonal total or at particular stages of crop development. Drought indices, based on the absence or deficiency of rain can also be computed and correlated with crop yield. Computed soil water status values have been widely used for assessing the effect of water supply on yield e.g. Smith (1966) correlated meteorological estimates of mean soil water deficit with the yield of copra. Recently, the use of water loss from crop surfaces as an index of crop yield and growth has been made. Climatically computed values of potential evapotranspiration have also been used to assess climatically limited, potential crop yields.

Earlier investigations (Hanks, 1974; Hearn, 1969; Fitzpatrick and Nix, 1969; Laycock, 1964; and Penman, 1962) suggested that for most crops, a linear relationship exists between seasonal water use and dry matter production. The slope of this linear relationship varies with each crop. This relationship is valid only when other growth factors such as fertilizers, temperature, sunshine and soil depth are not limiting and also the management of the crop is good.

For most crops, dry matter production does not determine the actual yield. This depends on the harvested part of the plant. In this study, productivity in terms of seasonal water use is assessed using the harvested or marketable yield.

2:5: HISTORICAL ASPECT OF CROP WATER USE IN EAST AFRICA

A major stimulus for water use studies in East Africa has been the development of irrigation with the extension of crop production to the somewhat drier areas. Irrigation was and is concerned with semi-arid areas of strictly limited water resources and therefore efficient use of water under such conditions requires assessment of the progressive water needs of crops during their growing seasons (Pereira, 1957).

Investigation of water use by annual crops was started in 1954/55 by Pereira and Hosegood at Kongwa in Tanzania and at Muguga in Kenya. Maize, sorghum and groundnuts at Kongwa were found to use less stored soil moisture than was taken by indigenous volunteer herbage or "tumble down fallow". At Muguga oats and beans drew their water from the first one hundred and eighty centimetres only. It was also found that a vigorous crop of oats at Muguga, growing in the cooler part of the year (long rains) drew less water from the soil than that taken by a poorer crop of beans in the hotter short rain season (Pereira _et al._, 1955).

In 1966, a research team led by Dagg at Muguga, found that maize used little water from depths beyond one hundred and thirty five centimetres until after tasselling when depletion was observed to one hundred and ninety five centimetres. Beyond this depth there was some slow water movement out of the profile which was due to drainage (Dagg _et al._, 1966).

Robins and Domingo (1953) working at Serere in Uganda found that water use of maize was influenced markedly by the moisture treatments. A severe water deficit occuring during the fertilisation period lowered water use by reducing the size of plants as well as transpiration during the deficit period. Removal of the available water prior to maturity reduced water use whereas a similar removal following maturity had little effect.

Wangati (1972) showed that water use of maize and bean crops under East African conditions is clearly related to leaf area and hence ground cover.

He also found that the total water use during the season and the ratio of actual evapotranspiration to open water evaporation is affected by the frequency of wetting of the canopy by rain. Rain water interception by the crop canopies could have a significant effect on E_t/E_o ratios by keeping the canopy wet over long periods. The duration of free water on the leaves after rain is governed by the evaporative demand and the quantity of water retained by the canopy. A maximum E_t/E_o ratio of 1.3 to 1.4 was recorded for the bean crop which was grown in the long rainy season. A ratio of 1.6 was recorded for the first maize crop at the tasselling-silking stage in a period of heavy rainfall. In the second maize crop grown in the dry season with sprinkler irrigation, a maximum ratio of 1.2 was recorded at the onset of heavy rain during crop senescence.

Kowal and Andrews (1973) working at Samaru (Nigeria) also found out that for a maize crop, forty days after sowing, E_t/E_o increased from 0.39 to 0.98. Initially the E_t/E_o ratio was small because of the small crop cover and rapid drying of the surface soil after rainstorms. Fifty days later the E_t/E_o was between 0.86 and 1.16. They (Kowal and Andrews, 1973) found out that the ratio of actual evapotranspiration to open water evaporation is primarily dependent on the stage of crop development, the nature of the crop, the degree of crop cover and also to a lesser extent on the frequency of wetting.

CHAPTER III

3. MATERIALS AND METHODS

The experiment was carried out at Kabete Field Station (1^{o} 15'S, 36^{o} 44'E, 1815m), Faculty of Agriculture farm, University of Nairobi in Kenya, over the short rainy season of 1978 and the long rainy season of 1979.

3:1: CLIMATE

Kabete has two rainy seasons per year. Long rains begin at the end of March, continue until the end of May and are followed by a cool cloudy dry period. Short rains begin in late October, continue until the end of the year, occasionally, and are followed by a warm, bright dry season. Both seasons are highly unreliable, both in quantity of rain and its duration.

Figure 3:1 shows the rainfall pattern. The data used are the mean monthly figures for a seven year period (1972 - 1978) from the Field Station Agrometeorological station. The months of April and

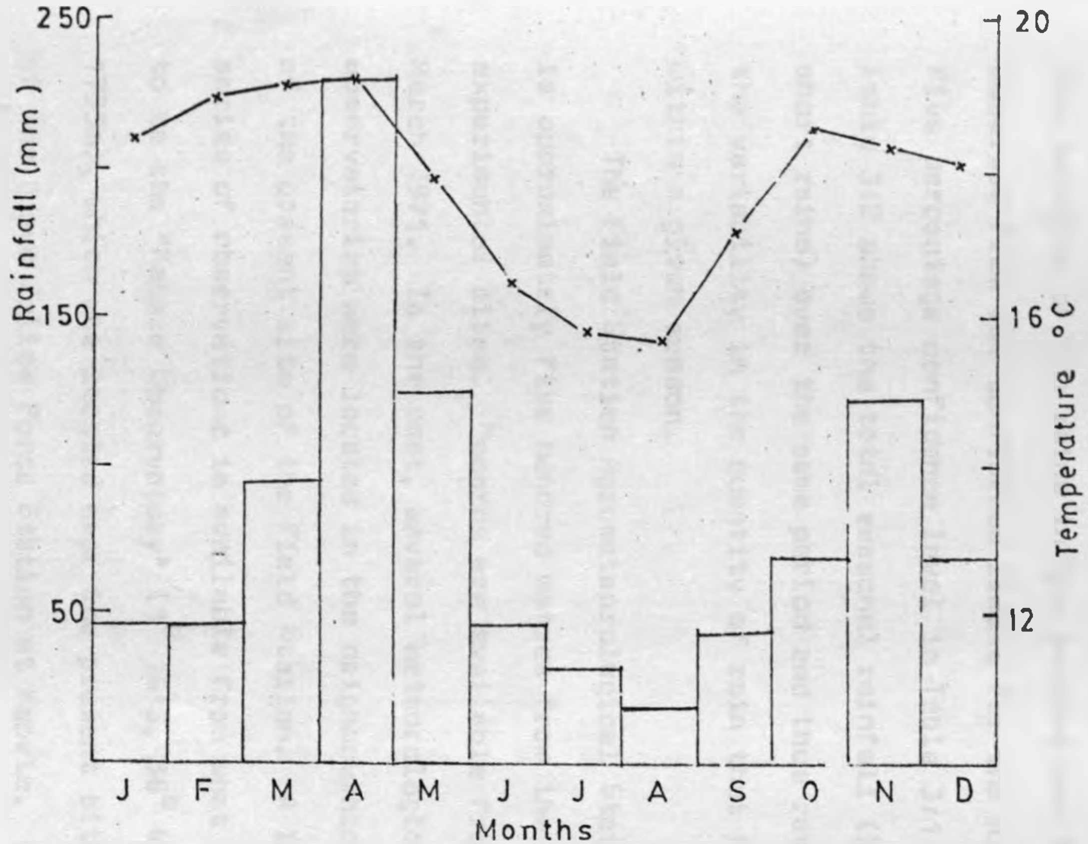


Fig. 3:1

The average rainfall (bar gragh) and average temperature (line gragh) for a 7 year (1972–1978) period at Kabete, Field Station (University of Nairobi).

November are the peak rainfall months and the months of August and January/February are the driest months of the long and short rains respectively.

Table 3:1 shows the monthly distribution of rainfall end mean monthly air temperatures for the same period of seven years. The unreliability of the duration of the rains in the seasons can be observed from the confidence limits for the ninety-five percentage confidence level in Table 3:1. Table 3:2 shows the total seasonal rainfall (long and short rains) over the same period and thus reveals the variability in the quantity of rain that falls within a given season.

The Field Station Agrometeorological Station is approximately five hundred metres from the experimental sites. Records are available from March 1971. In the past, several meteorological observatories were located in the neighbourhood of the present site of the Field Station. A long series of observations is available from what used to be the "Kabete Observatory" (1^{0} 16'S, 36^{0} 45'E, 1773m), which was located near the present site of the Kenya Police Force Station at Kabete. It

TABLE 3:1: MEAN MONTHLY DISTRIBUTION OF RAINFALL (mm) AND MEAN AIR TEMPERATURE AT KABETE, FIELD STATION (1° 15'S, 36°44'E, 1815m) FOR THE PERIOD 1972 - 1978

Month / Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1972	20.4	77.6	58.4	26.0	172.6	124.2	15.0	5.7	50.3	179.1	149.9	28.8	908.0
1973	123.7	61.5	6.4	216.4	46.7	41.8	2.0	6.2	64.3	13.0	88.3	32.5	702.8
1974	2.5	5.1	129.1	285.2	72.5	-	107.9	35.1	40.3	54.7	92.1	55.3	879.8
1975	9.2	2.6	24.6	226.9	144.2	11.9	18.7	5.0	83.0	54.6	84.1	46.5	711.3
1976	10.7	47.2	32.8	147.1	118.8	33.4	12.2	2.0	44.5	12.3	113.4	90.3	664.7
1977	50.1	87.7	82.0	414.8	273.9	49.5	43.7	53.6	16.8	53.1	233.9	89.7	1448.8
1978	107.9	39.0	326.0	286.8	47.3	16.3	24.2	23.7	6.8	104.8	105.5	129.7	1218.0
MEAN	46.4	45.8	94.2	229.0	125.1	46.2	32.0	18.8	43.7	67.4	123.9	67.5	933.3
95% confidence limits (upper and lower)	0.0 to 96.5	12.7 to 78.9	0.0 to 204.3	107.1 to 350.9	43.7 to 206.5	0.0 to 93.3	0.0 to 67.9	0.0 to 38.4	17.5 to 69.9	9.1 to 125.7	70.5 to 177.3	19.2 to 115.8	-
Mean air temperature (°C)	18.4	18.9	19.1	19.2	17.9	16.5	15.8	15.7	17.2	18.5	18.3	18.1	-

TABLE 3 : 2: TOTAL SEASONAL RAINFALL (mm) FOR KABETE FIELD STATION FROM 1972 TO 1978

YEAR / SEASON	Long rains	Short rains
1972	458.8	357.8
1973	311.3	133.8
1974	594.7	202.1
1975	395.7	185.2
1976	345.9	216.0
1977	770.7	376.7
1978	660.1	340.0
Mean	505.3	258.8
95% confidence limits	332.3-678.3	161.9-355.7

was closed down around mid 1960's and was situated approximately three kilometres from the Field Station Agrometeorological Station.

Table 3:3 and Figure 3:2 show the monthly rainfall distribution and rainfall pattern for a period of thirty years (1931 - 1960), from the Kabete observatory. The overall picture of the climate is very similar to that given by the shorter Field Station records.

3:2: SOIL

The experimental sites were on a more or less flat area of Kikuyu friable clay, which is thought to have developed *in situ*, in Tertiary trachytic lava.

3:2:1: GENERAL DESCRIPTION OF KIKUYU FRIABLE CLAYS

The Kikuyu friable clays (formerly known as Kikuyu loams) are known to have a high porosity throughout the profile (Nyandat, 1976) with good moisture holding capacity and availability.

TABLE 3:3: MEAN MONTHLY DISTRIBUTION OF RAINFALL (mm) AT KABETE, "KABETE OBSERVATORY", ($1^{o}16'S$, $36^{o}45'E$, 1773 m) FOR THE PERIOD 1931 - 1960

Year / Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1931	22	49	152	364	129	31	14	37	108	81	104	74	1166
1932	71	35	223	182	154	26	21	17	11	39	63	147	991
1933	122	1	15	60	82	8	16	54	8	55	123	78	621
1934	10	24	41	95	201	57	31	10	1	69	46	63	648
1935	0	161	39	113	99	89	0	33	33	56	145	96	864
1936	129	148	127	198	47	80	4	10	12	90	92	83	1029
1937	9	0	211	311	331	187	6	4	4	149	229	87	1529
1938	24	62	105	119	88	6	9	11	24	43	131	141	765
1939	30	37	142	242	48	7	11	18	19	13	61	6	637
1940	49	78	154	252	230	25	20	14	1	53	88	44	1008
1941	39	105	183	371	149	76	4	15	3	7	90	157	1198
1942	23	67	259	293	214	46	17	35	1	23	30	98	1106
1943	2	66	31	186	47	32	2	29	6	9	67	66	543
1944	15	0	85	154	47	8	21	16	68	66	136	93	708
1945	58	88	61	46	205	63	52	56	41	2	155	39	866
1946	6	5	25	122	102	8	12	77	127	203	74	55	816
1947	88	26	171	314	246	82	39	4	50	7	60	50	1139
1948	0	7	87	222	119	82	3	63	20	59	85	193	941
1949	11	31	14	211	55	6	5	29	17	8	81	107	576
1950	45	13	119	225	67	17	6	48	8	51	95	11	703
1951	4	3	109	328	263	179	33	24	8	97	139	211	1398
1952	2	20	23	393	227	0	10	10	26	25	72	15	824
1953	24	1	47	139	172	26	13	33	34	46	138	32	705
1954	31	97	2	262	373	63	31	9	9	37	133	24	1071
1955	21	76	33	214	135	4	13	16	22	54	54	210	854
1956	172	61	109	177	79	12	11	14	23	39	146	27	870
1957	205	30	42	232	282	75	15	6	42	66	200	84	1379
1958	59	190	42	122	318	48	131	0	4	22	63	72	1072
1959	19	57	158	92	118	0	21	70	18	51	277	58	937
1960	44	3	216	184	73	39	8	10	24	82	75	46	806
MEAN	45	51	101	207	160	46	19	26	26	54	108	82	925

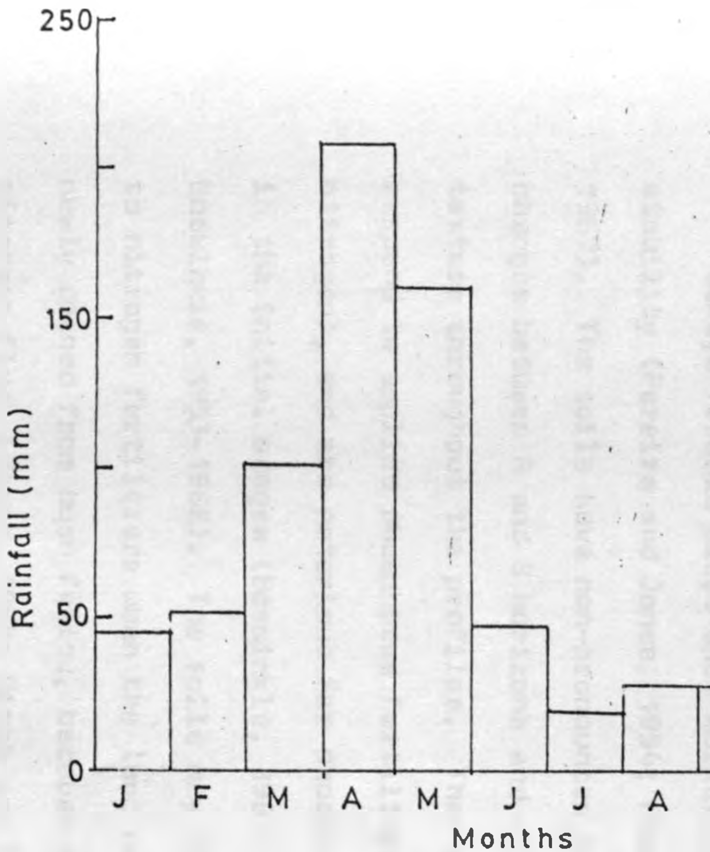


Fig. 3 : 2

The average rainfall for a 30-year (193
at Kabete observatory.

1 - 1960) period

Typical profiles are very deep and can be over fifteen metres in thickness (Nyandat and Michieka, 1970). The deep profiles, good moisture holding capacity and availability features result in favourable moisture relationship for plant growth. Pereira (1955) observed that the physical characteristics of the first foot of the top soil vary greatly with its agricultural history while those of the subsoil were markedly constant.

Kikuyu friable clays show marked structural stability (Pereira and Jones, 1954; Pereira et al., 1967). The soils have non-pronounced textural changes between A and B horizons and a clayey texture throughout the profiles. They markedly respond to applied phosphorus fertilizer (and nitrogen), and are notorious for phosphorus fixation in the initial stages (Boswinkle, 1961; Bellis and Boswinkle, 1953-1962). The soils may not respond to nitrogen fertilizers when the land has been newly opened from bush fallow, because of the nitrogen flush (Birch, 1958; Birch and Friend, 1956). They do not usually respond to applied potash and lack of response may be attributed to the high content of potassium feldspar in the parent material which presumably supplies enough potassium for the potassium requirement of the crop.

3:2:2: DESCRIPTION OF THE SOIL PROFILE AND ANALYTICAL DATA FROM THE EXPERIMENTAL SITE OF FIELD 14 OF THE FIELD STATION FARM

Drainage: well drained.

Moisture conditions in profile: moist below 150 cm depth.

Depth of ground water table: unknown, but probably more than fifteen metres and therefore has no influence on the profile.

Presence of surface stones, rock outcrops: none.

Evidence of erosion: none.

Presence of salt or alkali: none.

Human influence: at the time of examination, the land was under a maize crop. The land has also been used for the cultivation of annual crops such as field beans, irish potatoes, sweet potatoes, sunflower, soyabeans, wheat and linseed in the crop sequence trials. Before the land was opened up in 1978 long rains, it had been under grass for over three years. Light fertilizer applications were done during the cultivation of annual crops, namely CAN;

triple or single superphosphates and muriate of potash, according to the crops' requirements.

Brief description of the profile: this soil is a dark reddish brown clay which overlies a dark red clay. It has been derived from the Kabete trachyte and is deep and well drained as the parent rock and groundwater table have not been reached, and there is no evidence of poor drainage. Earthworm channels and rodent holes are a common feature of this soil and evidence of clay skins is present from twenty-four centimetres and continues into the deep subsoil.

HORIZON BY HORIZON PROFILE DESCRIPTION

Horizon		Description
Symbol	Thickness (cm)	
$A_p(A_{11})$	0 - 10	Dusky red (2.5 YR 3/2) moist and dark reddish brown (2.5 YR 2/4) dry, clay, which feels like a loam; weak medium subangular

Horizon		Description
Symbol	Thickness (cm)	
		blocky breaking into moderate fine crumbs; slightly sticky, slightly plastic wet; friable moist; soft dry, many fine pores, abundant fine roots; diffuse smooth boundary, pH 5.4.
A_{12}	10-24	Dusky red (2.5 YR 3/2) moist and dark reddish brown (2.5 YR 2/4) dry, clay, which feels like a loam; weak medium blocky breaking easily into moderate fine crumbs; slightly sticky, slightly plastic wet; friable moist; slightly hard dry; many fine pores, earthworm channels and rodent holes, MnO_2 present,

Horizon		Description
Symbol	Thickness (cm)	
		many coarse and fine roots, diffuse smooth boundary, pH 5.5.
B_{21}	24-71	Dusky red (2.5 YR 3/4) moist and dry, clay; weak coarse and medium angular blocky breaking into very fine angular blocks; sticky, plastic wet; friable moist; slightly hard dry; distinct patchy, moderately thick clay skins are common; many fine pores, earthworm channels and rodent holes; MnO_2 present; many fine roots and some coarse roots; diffuse smooth boundary, pH 6.4.

Horizon		Description
Symbol	Thickness (cm)	
B_{22}	71-150	Dark red (2.5 YR 3/6) moist and red (2.5 YR 4/6) dry, clay; moderate coarse subangular blocky breaking into strong fine subangular blocks; sticky, plastic wet; firm moist; hard dry; common distinct broken to continuous, moderately thick to thick clay skins, many fine pores, earthworm channels, MnO_2 present, occasional fine and coarse roots, diffuse smooth boundary, pH 6.7.
B_{23}	150 ++	Dark red (2.5 YR 3/6) moist, clay; moderate medium angular blocky breaking into weak granular structure; sticky, slightly plastic wet; friable moist; common distinct

Horizon		Description
Symbol	Thickness (cm)	
B_{23}	150 ++	broken to continuous, moderately thick to thick clay skins, many fine pores, few earthworm channels which decrease with depth, MnO_2 present in the form of few fine nodules, very few fine roots in the upper part of the horizon; pH 6.8.

Table 3:4 shows the analytical data of the same profile from the experimental site in field 14 of the Field Station farm. The pH in water and in calcium chloride range from 5.1 to 6.8 and 5.0 to 5.8 respectively. The pH range down the profile in water is 1.4, while that in calcium chloride is 0.6. The pH generally increases with soil depth.

TABLE 3:4: ANALYTICAL DATA OF THE PROFILE FROM THE EXPERIMENTAL SITE IN FIELD 14

Horizon (cm)	PH(1:2 ratio)		% organic matter	Mechanical analysis			cation exchange capacity (CEC) m.e/100g soil			exchangeable cations				total exchangeable bases	% base saturation
	in H_2O	in $CaCl_2$ (0.01M)		% clay	% silt	% sand	CEC	CEC_{om} (approx)	CEC_{clay} (approx)	Ca	Mg	K	Na		
0- 10	5.4	5.2	5.55	64.06	31.21	4.73	26.80	11	15	13.20	2.80	2.75	1.05	19.80	73.88
10- 20	5.5	5.2	4.47	67.29	26.25	6.46	26.40	9	17	11.20	3.80	3.00	1.08	19.08	72.27
20- 30	5.1	5.0	2.69	67.24	26.85	5.51	22.80	5	18	11.20	1.20	2.50	0.85	15.75	69.06
30- 50	6.5	5.5	1.84	72.54	22.59	4.87	22.00	4	18	11.40	1.00	2.50	1.05	15.95	72.50
50- 70	6.4	5.8	1.29	74.70	20.70	4.60	21.60	3	18	8.40	3.20	2.75	0.90	15.25	70.60
70- 90	6.8	5.6	1.19	77.40	18.57	4.03	21.20	2	19	8.00	3.20	2.75	1.00	14.95	70.52
90-120	6.5	5.1	0.55	79.62	16.02	4.36	19.60	1	18	5.00	3.40	4.00	1.00	13.40	68.37
120-150	6.7	5.7	0.41	75.99	20.47	3.54	17.60	1	17	2.80	1.30	5.75	0.78	10.63	60.40
150-180	6.8	5.8	0.38	79.37	17.46	3.17	17.60	1	17	4.00	0.80	6.25	0.80	11.85	67.33
180++	5.9	5.3	0.38	73.56	24.64	1.80	17.60	1	17	3.60	1.60	4.25	0.80	10.25	58.24

Key: $CaCl_2$ - Calcium Chloride; m.e. - milliequivalent; Ca - Calcium; Mg - Magnesium; K - Potassium; Na - Sodium; om - organic matter; approx - approximate; M - molar.

There is a sharp increase in pH in water between 20-30 and 30-50 cm of about 1.4. The pH values in water are higher than those in calcium chloride with a range of 1.4. The soil is well supplied with organic matter as it still contains about 0.38% at 150 ++ cm depth.

The soil is dominated by the clay fraction and has a very low sand fraction when compared with the silt and clay fractions. The sand fraction is generally less than 6% throughout the profile, whereas the silt fraction ranges from about 16% to 30%. Probably the low sand fraction is a result of the parent material, trachytic lava, having little or no quartz or other resistant minerals. The clay content increases in the subsoil and a deep clay bulge can be observed at 90-120 cm depth. The clay content changes from 64% to about 80% in the subsoil, thus the soil has a deep argillic horizon which is confirmed by the presence of clay skins throughout the subsoil.

The cation exchange capacity ranges from 17 to 27 milliequivalents per hundred grams of soil. The cation exchange capacity due to organic matter ranges from 1.0 to 11.0 milliequivalents per hundred grams and decreases with depth, parallel with organic matter content. The cation exchange capacity due to the clay fraction ranges from 14 to 19 milli-equivalents per hundred grams. This indicates that the soil has a mixture of clay minerals, possibly kaolinite, halloysite and illite.

The percentage base saturation is generally over sixty. Between 30-50 to 90-180 cm depths the pH in both water and calcium chloride is generally high and it is at these depths that there is a clay bulge of about 80% and also a percentage base saturation of about 70. Probably the pH in calcium chloride being generally similar throughout the profile can be related to the percentage base saturation which is generally over 60% throughout the profile. There does not seem to be a close relationship between the pH in water and the percentage base saturation.

Because of the deep clay bulge and deep argillic horizon which is confirmed by the presence of clay skins, and over 50 percentage base saturation, the soil falls within the Nitosol unit in the FAO classification (FAO/UNESCO, 1974) and the alfisol order in the American system (USDA soil taxonomy, 1975).

3:3: PLANTINGS

3:3:1: SHORT RAINY SEASON

3:3:1:1: SHORT RAINY SEASON PLANTING - 30TH OCTOBER 1978 TO APRIL 1979

During the short rainy season of 1978/79, eight crops namely: wheat, maize, linseed, sweet potatoes, Irish potatoes, soyabeans, field beans and sunflower, were grown in a randomized block design (RBD) of two blocks (replicates); replicates seven and eight respectively. The eight crops served as the treatments.

In a randomized block design, blocking is done to reduce variability, such that varisbility is only due to treatments in a given block. Each treatment appears an equal number of times in each block and each block contains all the treatments. Thus variability between the two blocks does not affect differences between treatment means.

During the short rainy season experiment, blocking was done due to a slight slope variability, though the experiment was carried out on more or less flat land. Each replicate had the eight crops grown in eight plots and each thus consisted of sixty four plots. The plot size was sixty four square metres (8m x 8m).

The land was disc ploughed, then disc harrowed twice. By 16th October 1978 land preparation and marking of the plots were completed. Randomization of the eight crops for plot allocation in each replicate was done. Access tube installation for monitoring soil moisture changes using the neutron probe method was completed by 23rd October. Figure 3:3 shows the field layout.

Planting began on 30th October and ended on 7th November. The crop type/variety, seed rate, spacing and fertilizer rate used are shown in Table 3:5. Infestation of the crops by pests and diseases was checked by the use of appropriate pesticides and fungicides. The major diseases controlled were potato blight, haloblight and leaf rust of beans where Rogor E and Dithane M45 were used. Pests controlled included the maize stalk borer, using D.D.T. Birds had to be scared off during planting and maturing of the crops. They can cause great damage to sunflower and wheat.

All plots in the two replicates (blocks) were kept free of weeds and normal agricultural practices, such as thinning of maize, sunflower and field beans;

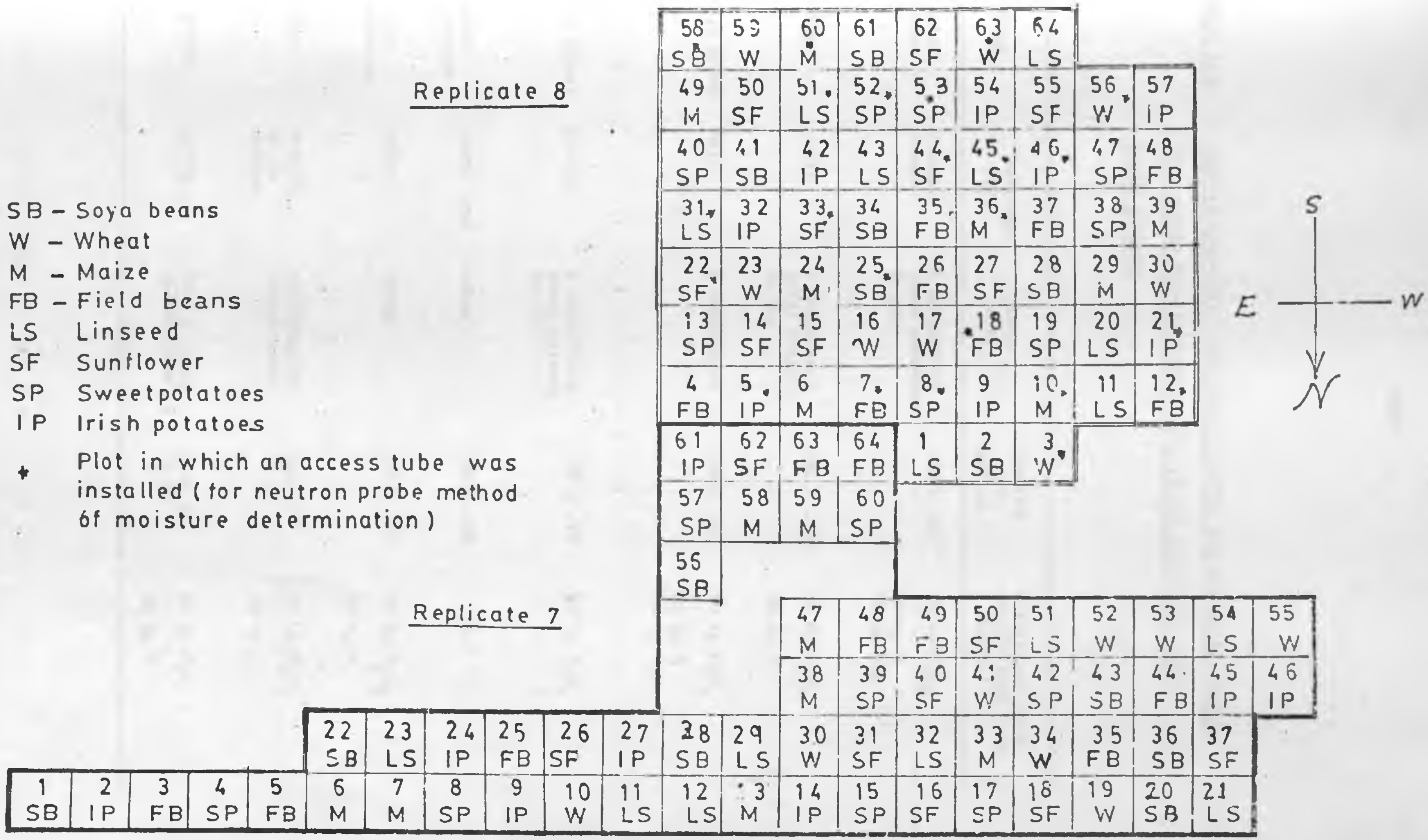


Fig. 3:3

Field layout for the short rainy season (October 1978 to April 1979)

TABLE 3:5: CROP TYPE/VARIETY, SEED RATE, SPACING AND FERTILIZER RATES USED DURING THE EXPERIMENT BOTH IN THE SHORT AND LONG RAINY SEASONS

Crop	Variety/ type	Seed rate	Spacing in metres	Fertilizer rate at planting time (kg/ha)
Field beans	Canadian wonder	2 seeds/hole later thinned to one	.60 x .05	50 kg P_2O_5 20 kg N 40 kg K_2O
Maize	H 511	2 seeds/hole later thinned to one	.60 x .30	60 kg P_2O_5 80 kg N
Soya beans	Hill	2 seeds/hole	.60 x .05	50 kg P_2O_5 20 kg N 40 Kg K_2O
Sun flower	Kensun	2 seeds/hole later thinned to one	.75 x .40	40 kg P_2O_5
Sweet potatoes	local type	vines	.90 x .30	-
Irish potatoes	Anett	1/hole	.75 x .25	60 kg P_2O_5 40 kg N
Wheat	Hybred Kenya Kiboko	broadcasting within rows	rows of 15 cm	40 kg P_2O_5 20 kg N
Linseed	Linda	broadcasting within rows	rows of 15 cm	40 kg P_2O_5 20 kg N

TABLE 3 : 6 : LENGTH OF GROWING SEASON AS CALCULATED FROM PLANTING AND HARVESTING DATES FOR THE SHORT RAINS 1978/79

Crop	Date of planting	Date of harvesting	Length of growing season (days)
Field beans	7/11/78	5/2/79	90
Irish potatoes	7/11/78	6/2/79	91
Wheat	7/11/78	6/2/79	91
Linseed	7/11/78	5/3/79	118
Soyabeans	7/11/78	19/3/79	132
Sunflower	7/11/78	20/3/79	133
Maize	7/11/78	22/3/79	135
Sweet potatoes	7/11/78	19/4/79	163

NB. Planting of the crops began on 30th October and ended on 7th November.
The last day of planting is taken as the date of planting since by then all the crops had been planted.

and ridging of Irish potatoes and sweet potatoes, was carried out throughout the growing season. Crop development and phenological changes were observed and recorded throughout the season.

3:3:1:2: MOISTURE MONITORING DURING THE SHORT RAINS

Two methods were initially employed to monitor soil moisture changes under the eight crops. Readings using the probe were taken twice a week (Mondays and Thursdays) if the weather permitted, and the gravimetric sampling on Mondays. During March and April 1979 after the breakdown of the neutron probe, the gravimetric method only was used, once a week.

Replicate eight of the experimental field was chosen for the soil water studies. Both replicates, however, were used in obtaining yield data. Harvesting of the crops was done as soon as the crop was mature. Table 3:6 shows the dates of planting, dates of harvesting and length of the growing season for the different crops.

3:3:2: LONG RAINY SEASON PLANTING - 9TH APRIL 1979 TO 27TH SEPTEMBER 1979

During the long rainy season, the experiment was modified. The replicates were increased to six and the number of crops was reduced to four. The danger of serious bird damage on wheat and sunflower if the crops are not protected can render these crops rather difficult to manage. Low linseed yields were obtained during the previous plantings which were rather uneconomical. This led to the study being modified to include only the more important food crops for the area, namely maize, field beans, Irish potatoes and sweet potatoes.

The experimental design was similar to that of the short rainy season planting (i.e. RBD); except that the blocks (replicates) were increased from two to six replicates, (replicates one to six). Each replicate had the four crops (treatments) grown in four plots of eight by eight metres, totalling sixteen plots per replicate. Blocking was likewise done due to a slight slope variation of the land. By 31st March 1979, the land preparation (disc ploughing followed by disc harrowing), blocking, and marking of plots had been completed. Randomization of the four crops for plot allocation in each replicate was carried out. Planting began on 9th April and was completed on 11th April. The crop type/variety, seed rate, spacing and fertilizer rate are as shown in Table 3:5. Figure 3:4 shows the layout of the plots for the long rainy season planting. Agricultural crop management practices were similar to those carried out during the short rainy season, as described in section 3:3:1:1.

Replicates two and four were chosen for the soil water studies and all the six replicates were used for obtaining the yield data. The gravimetric method was used to monitor soil moisture changes, and sampling was done on Mondays of every week throughout the growing season. Table 3:7 shows the dates of planting, dates of harvesting and length of the growing season for the crops during the long rainy season.

3:4: METHODS USED IN THE MAIN EXPERIMENTS

3:4:1: GENERAL

In the 1978/79 short rains, two methods were employed to determine water use rate in replicate eight. These were the neutron probe and gravimetric

4 M	3 IP	2 FB	1 M
8 SP	7 IP	6 M	5 SP
12 IP	11 SP	10 FB	9 M
16 FB	15 IP	14 FB	13 SP

REPLICATE 5

4 M	3 IP	2 IP	1 FB
8 SP	7 SP	6 FB	5 FB
12 IP	11 SP	10 M	9 SP
16 FB	15 M	14 M	13 IP

REPLICATE 4

4 SP	3 M	2 M	1 M
8 FB	7 IP	6 IP	5 FB
12 M	11 SP	10 SP	9 FB
16 FB	15 SP	14 IP	13 IP

REPLICATE 1

M – Maize
SP – Sweet potatoes
IP – Irish potatoes
FB – Field beans

4 SP	3 M	2 M	1 IP
8 M	7 IP	6 FB	5 IP
12 SP	11 FB	10 FB	9 SP
16 FB	15 SP	14 M	13 IP

REPLICATE 6

4 SP	3 SP	2 FB	1 IP
8 IP	7 M	6 IP	5 FB
12 FB	11 FB	10 M	9 IP
16 M	15 SP	14 SP	13 M

REPLICATE 3

4 FB	3 M	2 IP	1 SP
8 M	7 FB	6 IP	5 IP
12 SP	11 FB	10 SP	9 M
16 SP	15 FB	14 M	13 IP

REPLICATE 2

Fig. 3:4
Field layout for th long rainy season (April 1979 to September 1979)

18 month sequence

TABLE 3 : 7: LENGTH OF GROWING SEASON AS CALCULATED FROM PLANTING AND HARVESTING DATES FOR THE LONG RAINS, 1979

Crop	Date of planting	Date of harvesting	Length of growing season (days)
Field beans	11/4/79	20/7/79	100
Irish potatoes	11/4/79	10/8/79	121
Maize	11/4/79	24/9/79	166
Sweet potatoes	11/4/79	26/9/79	168

NB. Planting of the crops began on 9th April and ended on 11th April. The last day of planting is taken as the date of planting since by then all the crops had been planted.

methods. The probe broke down in February 1979 and from then on, the gravimetric method was used. During the long rains of 1979, only the gravimetric samplings were done in replicates two and four throughout the growing season.

Monitoring of soil moisture depletion was done to a depth of 180 cm. The normal effective rooting depth for various crops at maturity, grown in homogenous deep soils have been observed by Doorenbos and Pruitt (1977) to be as follows:

TABLE 3:8: NORMAL EFFECTIVE ROOTING DEPTH FOR VARIOUS CROPS AT MATURITY

Crop	Normal effective rooting depth (cm)
Beans	50 - 70
Wheat	100 - 150
Maize	100 - 170
Potatoes	30 - 75
Sweet potatoes	100 - 150
Soyabeans	60 - 130
Sunflower	80 - 150

For the probe method, because of loss of neutrons near the soil surface, soil moisture changes were monitored at the depths of 20, 30, 50, 70, 90, 120, 150, and 180 centimetres. Samples for the gravimetric method were taken at depths of 10, 20, 30, 50, 70, 90, 120, 150 and 180 centimetres.

With the neutron probe, three replicate profiles to 180 cm depth under each of the eight crops were read on each sampling date. For the gravimetric method, two replicate profiles from the beginning of the short rains in 1978 to February 1979 were taken for each of the crops. After February 1979 three replicate profiles were taken for each of the crops. In the 1979 long rains, four replicate profiles to 180 cm depth under each of the crops were taken on each sampling occasion.

3:4:2: NEUTRON PROBE METHOD

For each crop, three plots were randomly selected for the installation of aluminium access tubes for the use of the neutron moderation method of soil moisture determination. The aluminium access tubes were about two metres long and of five centimetre diameter.

A Jarret auger of five centimetre diameter was used for the installation of the tubes. An auger hole of 180 cm depth was made in the centre of a plot. The tube was fitted carefully into the hole after wrapping the bottom end with insulating tape to avoid damaging the tube during the installation. About twenty centimetres of the tube remained projecting above ground level and soil was returned layer by layer starting with the lowest layer, to its correct position in the profile. The mouth of the tube was covered with a polythene sheet which was removable. This kept out water from entering the tube directly.

The taking of readings began on 30th November 1978 using a Troxley probe borrowed from National Agricultural Laboratories (Ministry of Agriculture). Readings were taken twice per week, on Mondays and Thursdays respectively, whenever there was no rain. Prior to taking the readings, the meter was connected to the source and the apparatus was switched on for warming up. Readings taken were counts per half minute. At least four readings were taken at the beginning and end of the work. These served as the initial and final standard counts respectively, and were used for obtaining the count ratio for a sampling depth per crop for that sampling or day of reading. The standard counts were taken in the guard rows, consisting of a maize crop, while the apparatus was intact and resting on the soil. For example on 15th January, the count ratio for a maize crop at 20 cm depth in plot 60 was calculated thus:

TABLE 3:9: EXAMPLE OF PROBE COUNT RATIO CALCULATIONS

	Initial or starting standards (counts/ 30 seconds)	Final or finishing standards (counts/ 30 seconds)
	23773	24683
	23317	24788
	23823	24515
	23717	24328
Mean	23657.5	24579.8
Mean of the two standards	24119	

$$\text{Count ratio for maize in plot 60 at 20 cm depth on 15th January} = \frac{\text{Reading taken}}{\text{Mean standard counts}}$$

$$= \frac{18285}{24119}$$

$$= \underline{\underline{0.758}}$$

The count ratio for each sampling depth and tube was calculated after each sampling occasion as shown above. The time required for readings from the twenty four tubes was at least three and a half hours. One assistant was required during the process for recording, while another operated the machine.

For the count ratios to be meaningful, calibration of the apparatus was necessary. Extra tubes were installed and left in the ground for about two weeks, so that the soil could settle in around the tube. Using a Jarret auger of eleven centimeter diameter, three replicate horizons to a depth of 180 cm were sampled for each soil horizon corresponding to a probe reading. These horizon samples were used for gravimetric moisture determinations. They were taken around the tube at about fifteen centimetres away from the access tube after the readings had been taken. The mean gravimetric moisture content expressed as a percentage of the oven dry weight of the three samples for a given sampling depth was taken to correspond to the reading of that sampling depth.

Eight tubes were used to obtain data for the calibration curve. To convert the percentage moisture by weight obtained gravimetrically into volumetric percentage, the bulk density for each sampling depth was determined.

The calibration curves were obtained by plotting percentage moisture content by volume against the count ratio. The results are shown in section 4:4 of Chapter four.

3:4:3: GRAVIMETRIC METHOD

The gravimetric method involves weighing samples from the field, drying these samples at 105^{o}C for 24 hrs and reweighing them. Results are expressed as the percentage water by weight of the oven-dry soil. These results are then converted into volume weights by the use of the average weight percentage and bulk density of the soil of each sampling depth or horizon.

Soil moisture sampling was carried out by the use of Jarret augers of five centimetre diameter, designed by the Australian soil Survey. Six augers were used for this operation, three short ones used for sampling to a depth of 120 cm and three long ones reaching the desired depth of 180 cm. The stems of the augers were marked in centimetres to indicate the sampling depths. A team of six men was used for augering in the field while another man in the laboratory weighed the samples as soon as they arrived.

Aluminium tins with tightly fitting lids were used for conveying the samples to the laboratory. The tins and lids were numbered. The weight of the tins with their corresponding lids was kept and frequent checking on weight changes with respect to use was done.

Soil samples were obtained from the desired depth by scooping out the bottom soil from the auger head and placing it immediately in the tin whose lid was immediately replaced to prevent losses of moisture to the atmosphere. The containers were then put under shade while sampling was going on. As soon as sampling of the profiles for all the crops had been completed, the samples were transferred to the laboratory.

In the laboratory, the samples were weighed immediately to the nearest .01 gram. The lids from the tins were removed and placed under the tins. The samples were then placed in an oven which had been set at 105^{o}C. They were left for 24 hours or more until there was no further change in weight. After this the samples were removed from the oven, the lids replaced, and weighed immediately to avoid moisture gain from the atmosphere.

The water content of each sample was obtained by dividing the difference between wet and dry weights by the weight of the dry soil. When multiplied by a hundred, this became the percentage of water in the sample on a dry weight basis. To express this moisture content in millimetres of water, the bulk density of the soil was used, the percentage of water on an oven dry basis was converted first into percentage water by volume, and then into millimetres of moisture per soil depth.

In relation to the gravimetric method and hence indirectly to the probe, investigations on bulk density, field capacity and wilting point (to obtain available moisture content) down the 180 cm profile were necessary.

3:4:4: BULK DENSITY DETERMINATION

Bulk density is the ratio of mass of the dry soil to the volume of the sample as taken in the field (g/cm^3). It has to be determined separately unless a known volume of soil sample is used in moisture determinations.

Bulk density values for each sampling depth were obtained by using undisturbed core samples from a pit. Core rings of five centimetre height and diameter were used. The widely used double cylinder hammer-driven core sampler method for obtaining soil samples for bulk density was used. The core ring serving as the sample holder was driven vertically into the soil surface of a given horizon far enough to fill it but not so far as to compress the soil it held. A panga was used to dig out the soil alongside and under the sampler in order to remove the sample without disturbing it.

The sample holder was separated from the sampler and the extending soil beyond each end was trimmed with a straight-edged knife. The soil sample volume was thus the same as the volume of the sample holder core ring (98.125 cm^3). To preserve the soil from sliding out, the ends of the core ring were covered with flat aluminium covers and tied with rubber bands.

On reaching the laboratory, the samples were put onto a tray, placed in an oven at 105^oC for twenty four hours or more and weighed immediately after removing them from the oven. The bulk density was then calculated using the formula:

$$P_b = \frac{M_s}{V_t} \quad (g/cm^3) \qquad (3:1)$$

where P_b = bulk density

M_s = oven dry weight of soil

V_t = volume of sample as taken in the field

Two samples were taken for each sampling depth for bulk density determination. The mean of the two was taken to be the bulk density for the particular sampling depth.

3:4:5: FIELD CAPACITY AND WILTING POINT DETERMINATION

Field capacity and wilting point estimations were carried out at 1/3 and 15 atmospheres respectively using the pressure plate and pressure pot apparatus in the laboratory. Undisturbed soil cores were obtained using the extended double cylinder hammer driven apparatus reaching 180 cm and a Jarret auger of eleven centimetre diameter.

In the field sampling, sites were randomly selected in areas other than the experimental plots from the sites of both the short and long rainy season plantings. The Jarret auger was used to remove the soil from the profile to the desired depth. The sample holder was fitted into the outer sampler and driven in vertically. The samples were obtained as for bulk density determination for each sampling depth. The core rings served as core containers after sampling.

In the laboratory, the bottom end of each core was capped with muslin cloth, then placed in a tray previously lined with polythene to avoid rusting of the samples. The cores were saturated with water at room temperature by raising the water slowly upto three centimetre level from the bottom of the cores.

They were then allowed to stand for at least twenty four hours.

After the samples were saturated, they were placed in a pressure plate apparatus. After placing the cores on a ceramic plate, the pressure plate was closed and adjusted for the desired suction value. When equilibrium was attained, forty eight to seventy two hours after water had ceased to drip from the bottom of the ceramic plate, the air pressure was released from the pressure plate cell. The samples were weighed immediately and oven dried to determine the moisture content at the desired suction; in a manner similar to gravimetric soil moisture content determinations.

The field capacity data used in the study is a mean of ten samples for each sampling depth, whereas the wilting point data is a mean of three samples.

3:4:6: CLIMATIC DATA

During the study climatic data on climatic factors such as rainfall, mean air temperature, mean dew point, wind run, sunshine hours, radiation and evaporation were collected from the field station meteorological observatory, situated about five hundred metres from the site of the experiment.

Rainfall data was necessary for the computation of water loss from the soil profile between two consecutive sampling dates, using the water balance equation. Open pan A evaporation data was required for studying the relationship between open free water evaporation and the actual water use of the crops. The rest of the data collected were used in the computation of evaporation estimate by one of the modified Penman methods, as outlined by McCulloch (1965). His tables for rapid computation as used by the meteorological department at Dagoretti, Kenya, were used. These are the Muguga series of Penman tables as recalculated to incorporate the dependence on altitude and mean air temperature.

Penman's (1948) equation, using the terminology and units is:

$$E_o = \frac{\Delta}{\Delta + \delta}\left(R_A (1 - r)(a + b\frac{n}{N})\right) - \frac{\Delta}{\Delta + \delta}\left((\sigma T_a^4 \; (0.56 - 0.092\sqrt{e_d})(0.10 + 0.90\frac{n}{N})\right) + \frac{\delta}{\Delta + \delta}\left(0.35\,(1 + \frac{u}{100})\,(e_a - e_d)\right) \qquad (3:2)$$

where the three bracketed terms represent respectively the incoming short wave radiation, the outgoing long wave radiation, and a bulk aerodynamic term. The factors $\frac{\Delta}{\Delta+\delta}$ and $\frac{\delta}{\Delta + \delta}$ have been considered as the "weighting factors", which determine the efficiency of conversion of incoming heat into energy of vaporization of water.

The Muguga series of Penman tables were recalculated from the formula:

$$E_o = \frac{\Delta}{\Delta+\delta}\left(R_A\ (1-r)(0.29\ \mathrm{Cos}\ \phi + 0.52\ \frac{n}{N})\right) - \frac{\Delta}{\Delta+\delta}\left(\sigma\ T_a^4\ (0.10 - 0.90\frac{n}{N})\ (0.56 - 0.08\sqrt{e_d})\right) + \frac{\delta}{\Delta+\delta}\left(0.26(1 + \frac{h}{20,000})\ (1 + \frac{u}{100})\ (e_a - e_d)\right) \qquad (3:3)$$

From this formula the series of tables A, B, C, D, E, F, G and H were produced.

In the rapid computation method, the evaporation estimate is estimated by the formula:

$$E_o = ABC - DEF + GHJ \qquad (3:4)$$

(mm of water per day)

where:

$$A = \left(\frac{\Delta}{\Delta + \delta}\right)\left(\frac{1 - r}{L}\right) \quad \text{for } r = 5\%$$

$$B = R_A \; (\text{Cal/cm}^2\text{/day} \times 10^{-3})$$

$$C = 0.29 \; \text{Cos}\,\varphi + 0.52 \frac{n}{N}$$

$$D = \left(\frac{\Delta}{\Delta + \delta}\right)$$

$$E = 0.10 + 0.90 \frac{n}{N}$$

$$F = \sigma T_a^4 \; (0.56 - 0.08 \sqrt{e_d})$$ where e_d is in millibars

$$G = 0.26 \left(1 + \frac{h}{20{,}000}\right)\left(\frac{\delta}{\Delta + \delta}\right) \times 10$$

$$H = (e_a + e_d) \times 10^{-1}$$

$$J = \left(1 + \frac{u}{100}\right)$$ where u is the mean daily wind run (miles/day) at two metres.

Appendices 1 (A - L) show, the daily rainfall; Pan A evaporation data; climatic data used for the computation of the E_o Penman estimate and the calculated E_o Penman estimate; for the period of study (October 1978 - September 1979).

After estimating E_o from the modified Penman method and pan data, the water use to open free water evaporation ratio was determined for each period during the crops' growing season. Using the Pan E_o

data, the ratio gives pan coefficients (k_p) whereas the Penman estimate gives the crop coefficients (K_c) as referred to by Doorenbos and Pruitt (1975). Thus the k_p and K_c coefficients were developed during the water use study.

3:4:7: CROP DEVELOPMENT AND PHENOLOGICAL STAGES

In order to obtain the pan and crop coefficients, planting and harvesting dates were noted so as to determine the length of the growing season. Phenological changes of the crops such as flowering, silking, tasselling, drying of leaves; pods or cobs were also noted.

The crops development at different stages during the growing season was determined visually using the four stages as defined by Doorenbos and Pruitt (1975). They used ground cover percentage of the crop as a criteria for marking the beginning and end of a given stage. They defined these stages as:

a)	Initial stage	=	germination and early growth when the soil surface is not or is hardly covered by the crop.
b)	Crop development stage	=	from the end of the initial stage to attainment of effective full ground cover.
c)	Mid season stage	=	from the attainment of effective full ground cover to time of start of maturity as indicated by discolouring or falling of leaves.
d)	Late season stage	=	from the end of mid-season stage until full maturity or harvest.

Using the above, the approximate lengths of the crop developmental stages for each of the crops grown were determined.

3:4:8: YIELD AND WATER USE EFFICIENCY

For the determination of yields for field beans, maize, Irish potatoes, sweet potatoes, sunflower and soyabeans, two rows of the plants and two plants from the ends of each of the remaining rows were left out as guard rows. The area harvested was thus determined after making allowance for the rows and plants not harvested. Because of the differences in crop spacing, the area harvested thus varied with the crop. In a few cases (namely for wheat and linseed) damage to a crop stand sometimes necessitated harvesting only a part of the normal harvest area, which was carefully weighed, and yields were calculated accordingly.

In order to calculate dry matter content of the freshly harvested sunflower, maize, soyabeans and field beans, the following procedure was adopted. A known sample weight for each crop was taken after mixing the total yield of the whole experimental site. The sample was oven dried at 60^{o}C for twenty four hours and the moisture loss obtained by the difference in weight between the fresh sample and oven dry weight. The percentage moisture loss was obtained by dividing the difference by the fresh sample weight and multiplying by a hundred. The dry matter percentage of the grain was obtained by difference from a hundred.

To obtain yield of maize at 13% mc, sunflower at 14% mc, soyabeans and field beans at 12% mc, the following formula was used:

$$Y_f = \frac{Y_i \times DM_i}{DM_f} \qquad (3:5)$$

where

Y_f	=	final weight yield at desired moisture content for safe storage,
Y_i	=	original weight as from field,
DM_i	=	initial dry matter
DM_f	=	final dry matter.

For example, during the long rains maize was harvested at a moisture content of 27.7%. This meant that the dry matter content of the maize at harvest was 72.3%. Consequent yield figures for maize at 13% moisture content were obtained thus:

$$\text{Yield of maize at 13\% mc} = \frac{Y_i \times (100 - 27.7\%)}{100 - 13\%}$$

$$= \frac{Y_i \times .723}{.870}$$

where

Y_i is the yield as obtained from the field at harvest.

The yield data was analysed to give the total marketable yield per hectare during each season.

Water use efficiency, defined as the ratio of yield in kilogrammes per hectare to seasonal total water use for a given crop, was determined. The marketable yield per millimetre of water used during the season was thus obtained.

3:5: MINOR INVESTIGATIONS

3:5:1: SOIL MOISTURE CHARACTERISTIC CURVES

By determining moisture content at 0.0, 0.1, 0.3, 0.5, 0.7, 1.0, 2.0, 5.0, 7.0, 10.0, 13.0 and 15.0 bars suctions, using the pressure plate and pressure pot apparatus and undisturbed core samples, points were obtained for plotting moisture content against suctions. The curve thus obtained is a P^F curve or soil moisture characteristic curve. The undisturbed core samples at each sampling depth were obtained and treated in a similar manner as for field capacity and wilting point determination, and the moisture content at each suction was obtained.

3:5:2: SATURATED HYDRAULIC CONDUCTIVITY

The cores used for the determination of hydraulic conductivity were obtained in the same way as those used for field capacity and wilting point determinations. The samples were taken from eight replicate profiles at the same sampling depths as for the gravimetric determinations, the rings later serving as the core containers.

In the laboratory, the bottom end of each core sample was capped with muslin cloth, the exposed top was connected with insulating tape to another ring of the same diameter and height, and then placed in an aluminium tray and treated as for field capacity and wilting point.

The cores, after saturating, were carefully mounted vertically and supported on a porous outflow surface. A shallow water level of four centimetre depth was maintained over the soil surface by a siphon tube from a constant head reservoir. The saturation and conductivity tests were conducted using tap water.

The hydraulic conductivity was calculated by using the equation:

$$K = (Q/At)(\Delta L/\Delta H) \qquad (3:6)$$

where

Q = the volume of water passing through the core, after time t

t = time

A = the area of the core

K = the average hydraulic conductivity

ΔL = the soil column length

ΔH = hydraulic head difference

The hydraulic conductivity (K) will be cm/hr if t is expressed in hours, Q in cm^3 and A in cm^2. ΔH and ΔL are both in the same units.

3:5:3: SOIL ANALYSES

The soil analyses were carried out as described by Ahn (1973). Soil samples were obtained from the pit according to the sampling depths for moisture determination, which served as sampling horizons. The samples were air dried, ground and sieved through a two millimetre sieve.

pH was carried out both in water and in M/100 calcium chloride ($CaCl_2$) with a soil/liquid ratio of 1:2. Percentage organic carbon was determined using the Walkley-Black method corrected for 77% recovery and from this the percentage organic carbon was obtained by multiplying by 1.72. Mechanical analysis was determined using the pipette method. Total cation exchange capacity was carried out using the ammonium acetate (pH 7) method and exchangeable cations thereafter using the Versenate titration method for calcium and magnesium, and the flame Photometer method for sodium and potassium.

CHAPTER IV

4. RESULTS AND DISCUSSION

4:1: SATURATED HYDRAULIC CONDUCTIVITY

Hydraulic conductivity at saturation is a characteristic property of a soil toward water flow, and is related to porosity and pore size distribution. Table 4:1 shows the saturated hydraulic conductivity for the soil on which the study was carried out.

The saturated hydraulic conductivity is very variable within a given profile and given soil depth. It varies from 0.004 to 2.977 centimetres per hour (cm/hr). The mean values, however have a much narrower range. For most horizons they are between 0.70 and 0.97 cm/hr, but fall to 0.35 to 0.48 cm/hr in the 10 - 20, 20 - 30 and 30 - 50 cm horizons.

Variability in the conductivity may be due to many factors. Firstly, it may be due to the soil being heterogenous in the field. The fact that the samples used to conduct the experiment were in containers of 98.125 cm^3 volume means that

TABLE 4:1: SATURATED HYDRAULIC CONDUCTIVITY FOR THE SOIL OF THE EXPERIMENTAL AREA (cm/hr)

Soil depth (cm) \ Profile	A	B	C	D	E	F	G	H	MEAN	SE$_{\bar{x}}$
0 - 10	1.204	0.186	0.350	0.218	1.126	1.090	0.864	1.094	0.767	0.155
10 - 20	0.473	0.090	0.004	0.304	0.825	1.072	0.122	0.574	0.433	0.134
20 - 30	0.860	0.144	1.122	0.138	0.354	0.474	0.028	0.778	0.487	0.140
30 - 50	0.206	0.116	0.292	0.466	0.927	0.348	0.176	0.274	0.351	0.019
50 - 70	0.842	0.038	1.557	0.614	0.488	1.274	0.088	0.696	0.700	0.149
70 - 90	2.977	0.392	0.374	0.192	0.301	1.412	0.740	1.392	0.973	0.333
90 - 120	0.866	0.864	0.022	0.318	0.279	1.546	1.804	1.388	0.886	0.230
120 - 150	2.414	0.368	0.118	0.958	0.975	0.338	0.246	1.696	0.889	0.286
150 - 180	1.618	0.802	0.280	0.290	0.609	1.386	0.990	1.698	0.959	0.199

the samples were small and not representative of the field conditions. Secondly, cracks, worm holes and decayed root channels are present in the field and may affect flow in different ways, depending on the directions and conditions of the flow process. The presence of a decayed root channel, worm hole or tiny crack in the core obtained from the field, could have accounted for the high values obtained as they accelerated the flow rate of water.

The area for conductivity in the field is not fixed by any boundaries, but is dependent on the width, continuity, shape and tortuosity of the conducting channels. The pore geometry thus affects the conductivity under field conditions. Lack of continuity of conducting channels caused by the boundary effect of the core containers could have accounted for the very low values. Saturating a soil without trapping some air is difficult. The entrapped air bubbles can block pore passages and this could also have contributed to the low values.

The mean values are more or less similar with a standard error of ($\pm$) 0.079 cm/hr. Little evidence for any marked change in conductivity and porosity between horizons can be deduced.

4:2: SOIL MOISTURE CHARACTERISTIC (P^F) CURVE FOR THE SOIL OF THE EXPERIMENTAL AREA

Figures 4:1 to 4:9 show the P^F curves for the 0 - 10, 10 - 20, 20 - 30, 30 - 50, 50 - 70, 70 - 90, 90 - 120, 120 - 150, and 150 - 180 cm depth for the soil on which the study was done. They are the result of the mean of three samples for each depth and suction. The curves were obtained by plotting the logarithmic scale of the suctions in bars of 0.0, 0.1, 0.3, 0.5, 0.7, 1.0, 2.0, 5.0, 7.0, 10.0, 13.0, 15.0 against their respective percentage moisture content by weight.

Looking at the curves, a point of inflection is observed at log 2.0 (or P^F 2.0) for all depths except for the 0 - 10 cm depth. There is a tendency for the P^F curves to be approximately linear over the range of P^F 2.48 to P^F 4.18, which is the moisture range of importance for crop production because it is the range of available moisture for plant growth. With increase in suction, there is a gradual decrease in moisture content. The slopes of the curves also increase gradually.

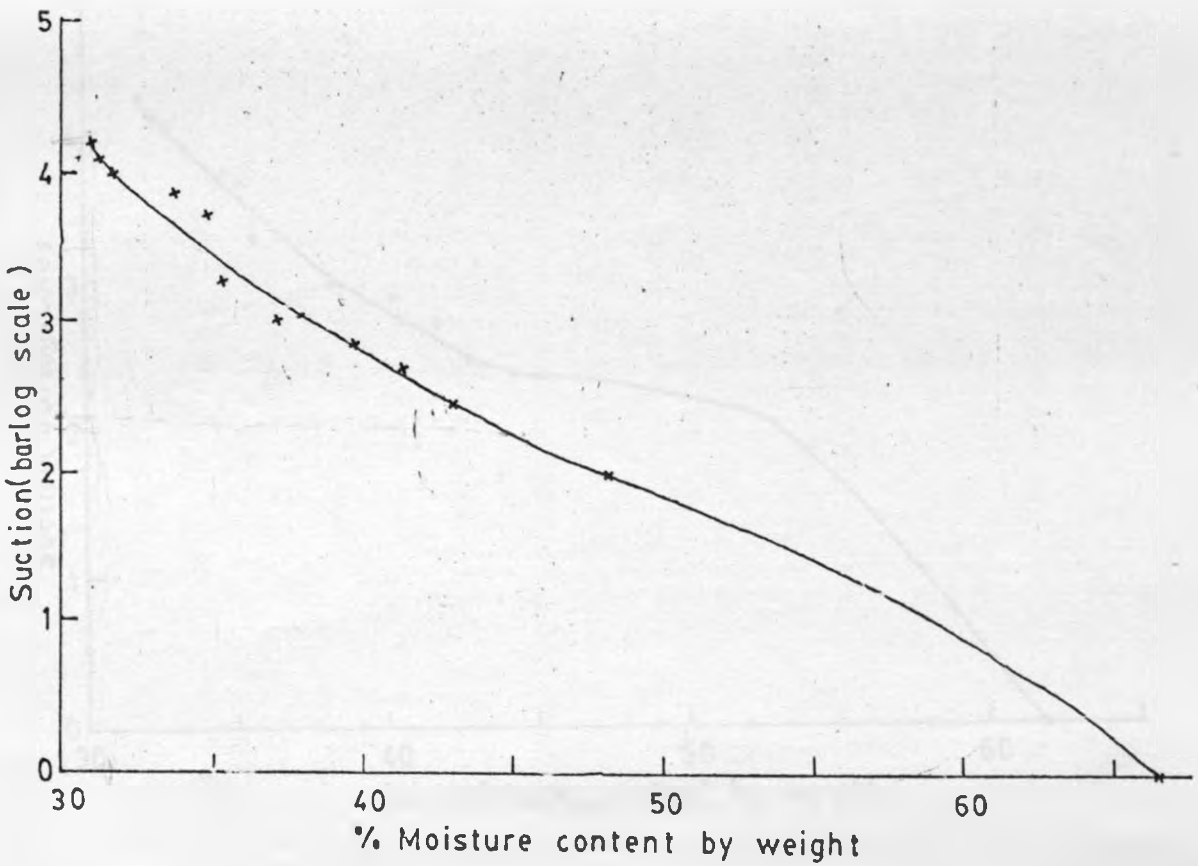


Fig. 4:1

P^F Curve for 0 - 10cm depth for the soil of the experimental area

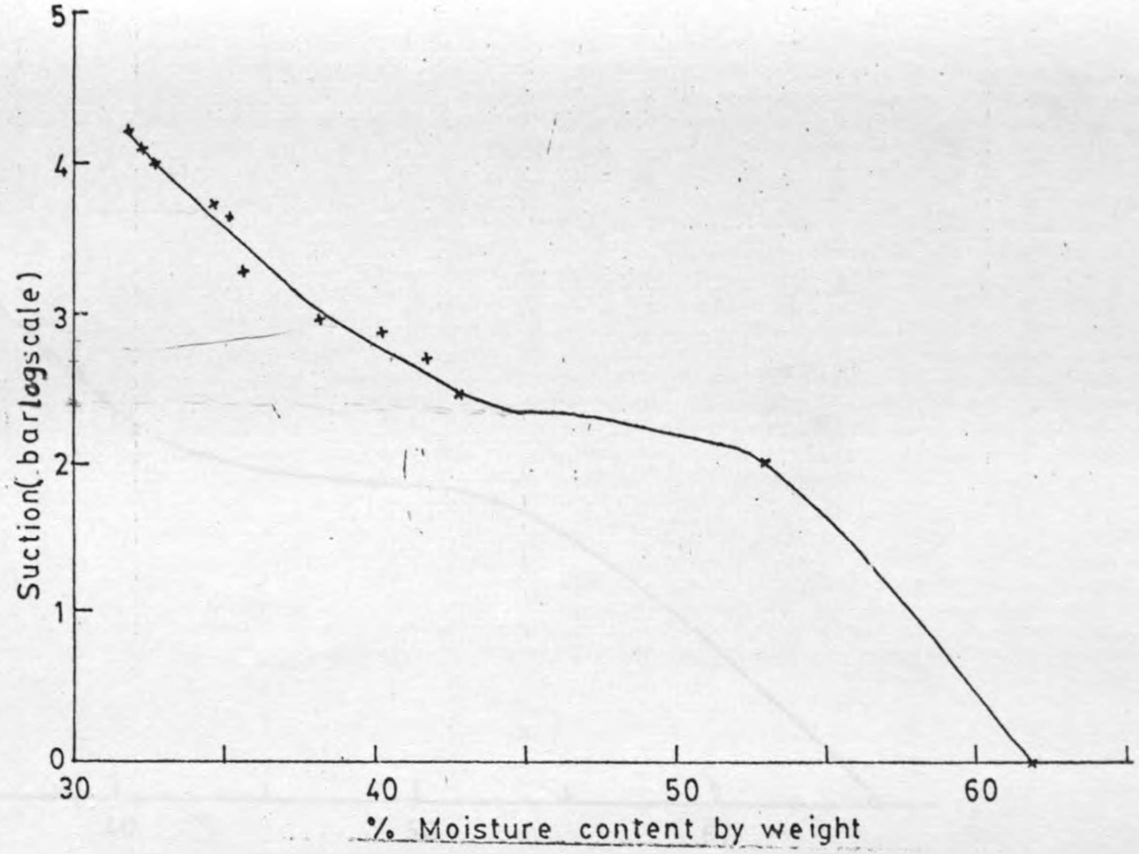


Fig. 4:2

P^F **Curve for 10-20 cm depth for the soil of the experimental area**

Fig. 4:3

PF Curve for 20-30cm depth for the soil of the experimental area

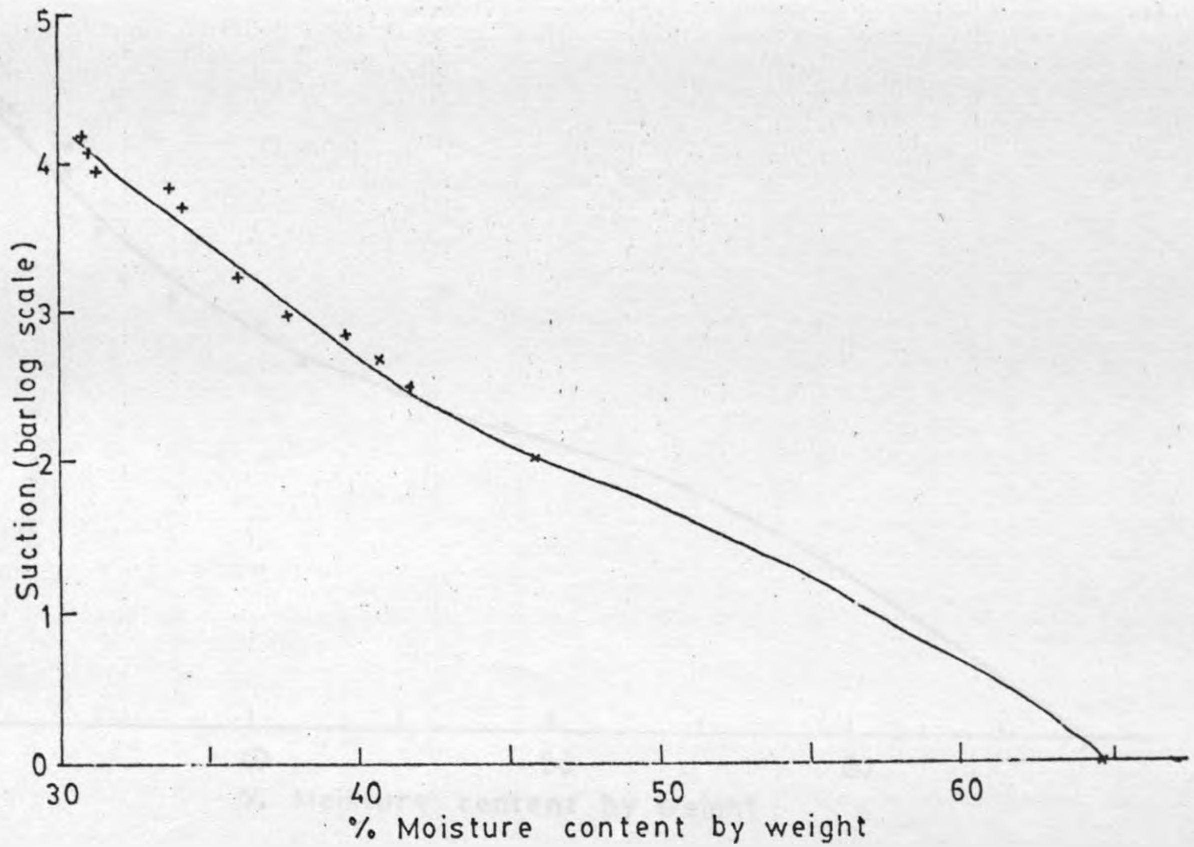


Fig. 4:4

PF Curve for 30-50 cm depth for the soil of the experimental area

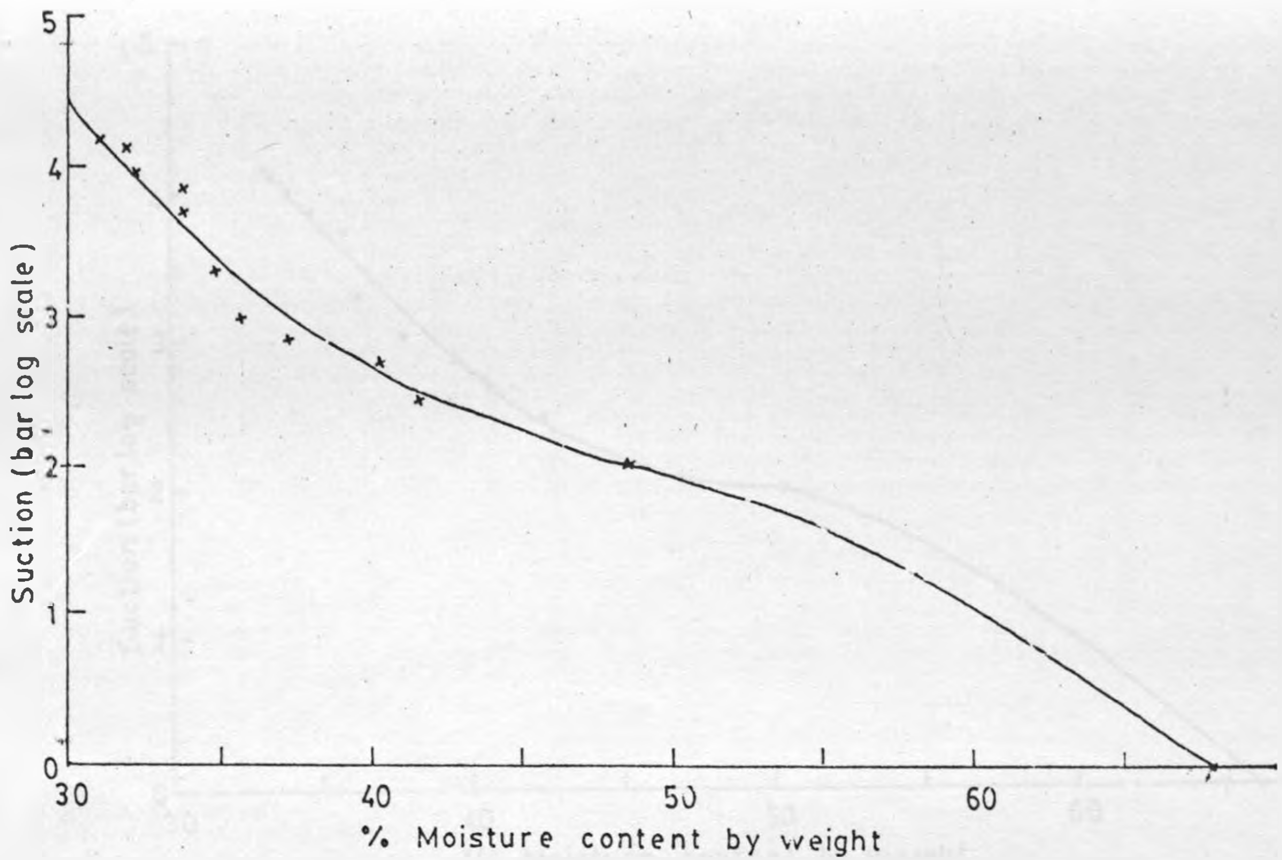


Fig. 4:5

PF Curve for 50-70cm depth for the soil of the experimental area

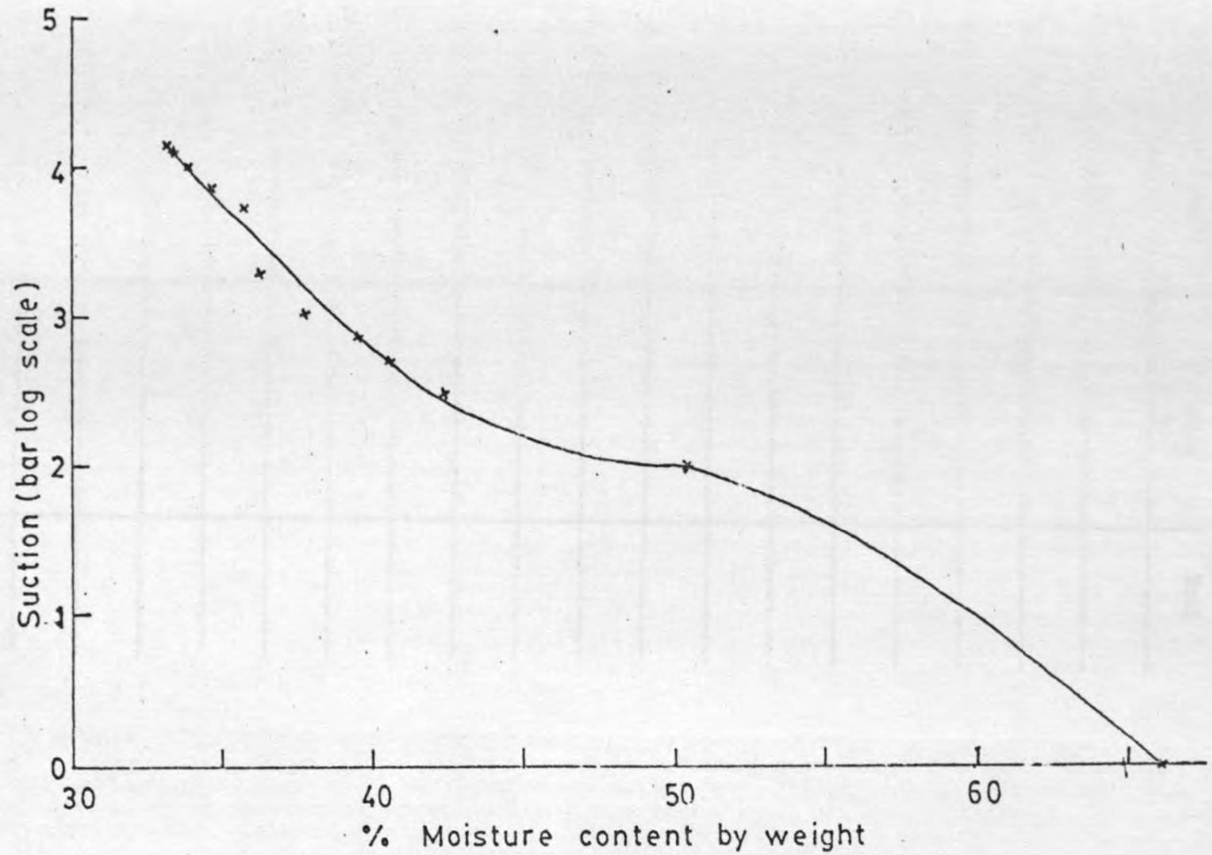


Fig. 4:6

pF Curve for 70-90 cm depth for the soil of the experimental area

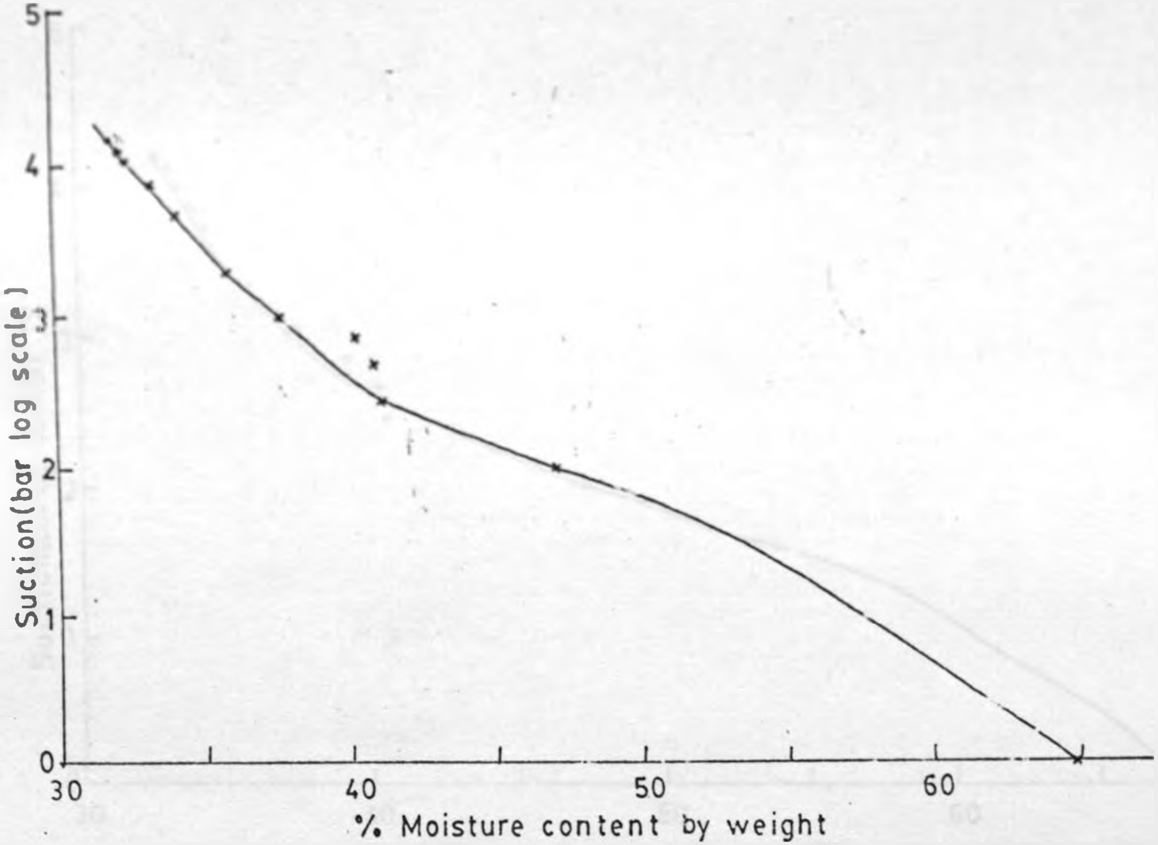


Fig. 4:7

pF Curve for 90 - 120 cm depth for the soil of the experimental area

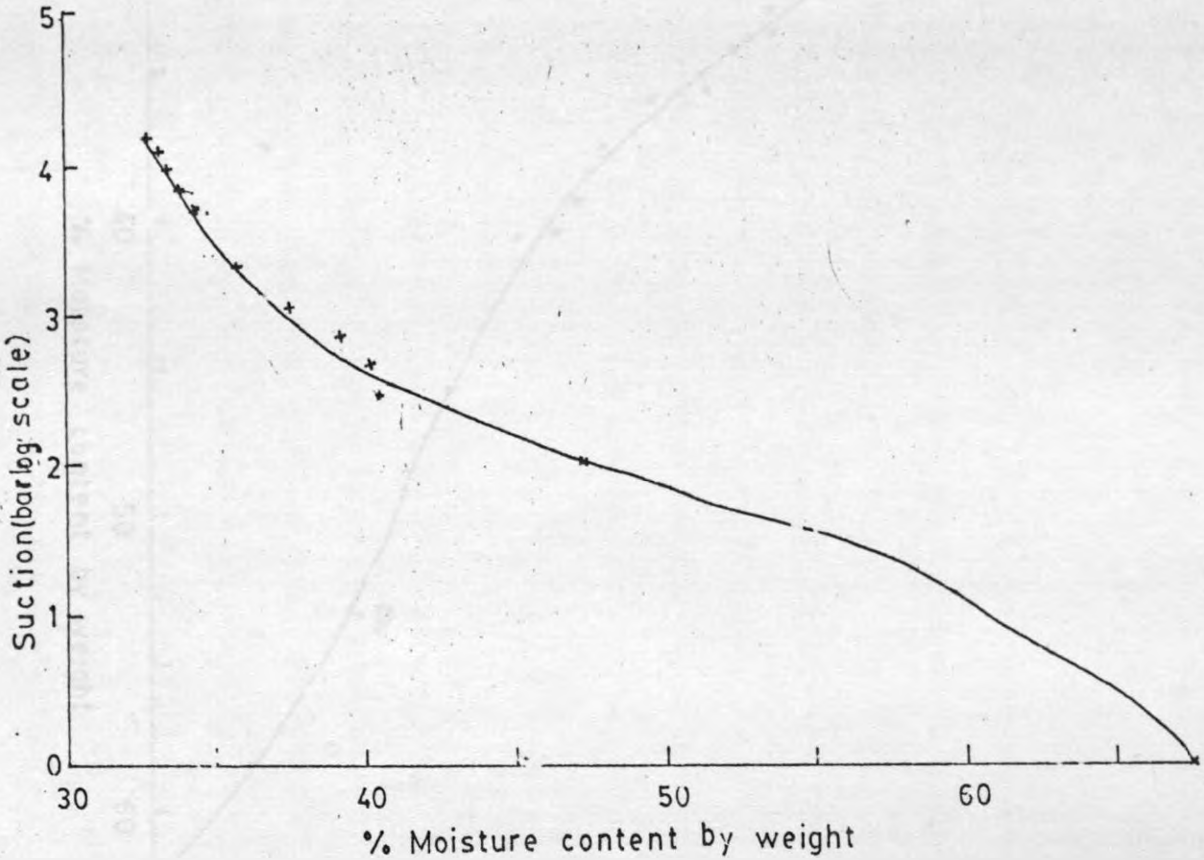


Fig. 4:8

pF Curve for 120 -150 cm depth for the soil of the experimental area

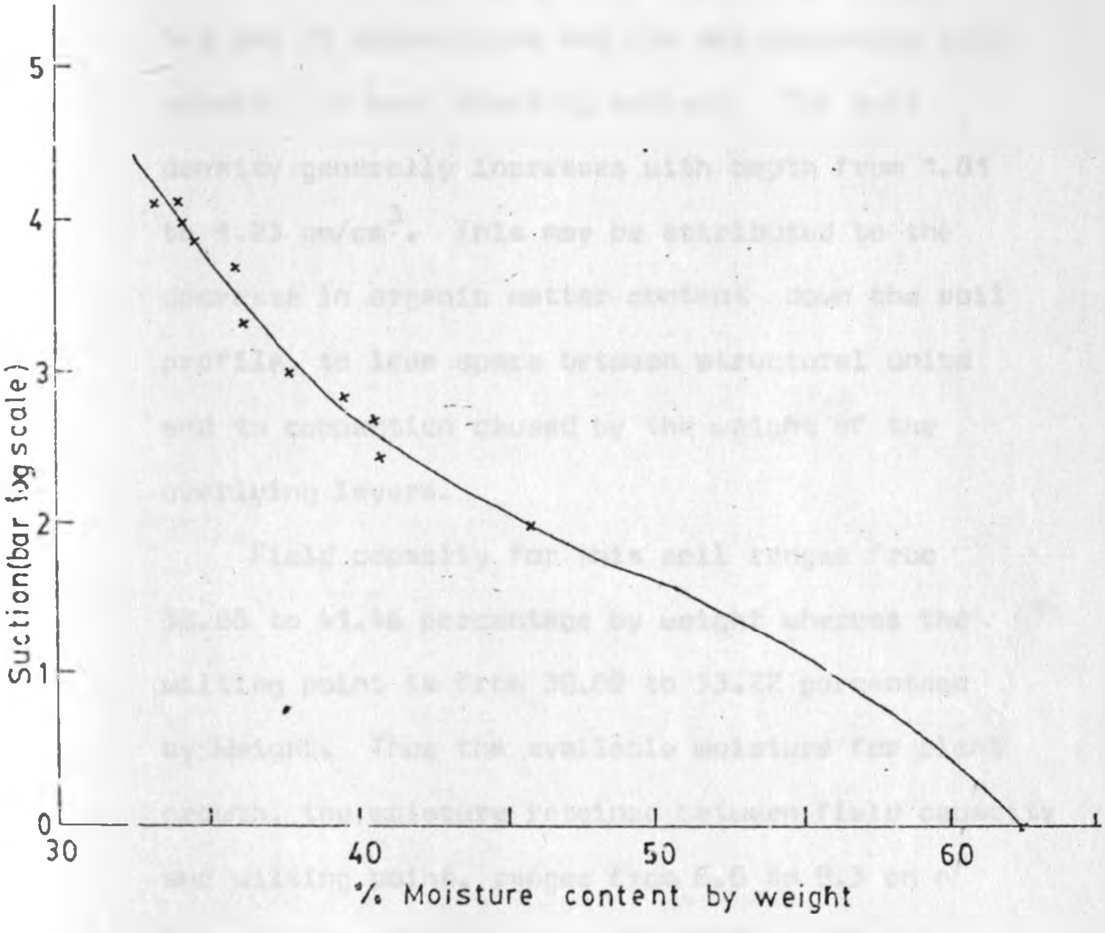


Fig.4:9
pF Curve for 150 – 180 cm depth for the soil of the experimental area

4:3: SOIL MOISTURE STATUS AT 1/3 AND 15 ATMOSPHERES

Table 4:2 shows the soil moisture status at 1/3 and 15 atmospheres and the corresponding bulk density for each sampling horizon. The bulk density generally increases with depth from 1.01 to 1.23 gm/cm^3. This may be attributed to the decrease in organic matter content down the soil profile, to less space between structural units and to compaction caused by the weight of the overlying layers.

Field capacity for this soil ranges from 38.85 to 41.46 percentage by weight whereas the wilting point is from 30.89 to 33.22 percentage by weight. Thus the available moisture for plant growth, the moisture retained between field capacity and wilting point, ranges from 6.6 to 9.3 on a percentage weight basis. The total available moisture for the 180 cm profile is 161.5 millimetres; one centimetre of soil therefore holds an average of about 0.9 millimetres of available moisture.

Pereira (1957), working on a similar soil at Ruiru (Kikuyu red loam soil type), showed that the

TABLE 4:2: SOIL MOISTURE STATUS AT $\frac{1}{3}$ ATMOSPHERES AND 15 ATMOSPHERES OF KABETE FIELD STATION SOIL

Soil depth (cm)	bulk density (g/cm^3)	percentage moisture by weight			amount of water (mm)	
		15 atmospheres	$\frac{1}{3}$ atmospheres	available moisture	15 atmospheres	$\frac{1}{3}$ atmospheres
0 - 10	1.01	31.01	38.85	7.84	31.3	39.2
10 - 20	1.02	32.25	41.25	9.00	32.9	42.1
20 - 30	1.09	32.55	41.46	8.91	35.5	45.2
30 - 50	1.08	30.89	39.82	8.93	66.7	86.0
50 - 70	1.14	30.99	40.28	9.29	70.7	91.8
70 - 90	1.12	33.06	40.59	7.53	74.1	90.9
90 - 120	1.14	32.43	39.82	7.39	110.9	136.2
120 - 150	1.23	32.95	40.54	7.59	121.6	149.6
150 - 180	1.22	33.22	39.84	6.62	121.6	145.8
TOTAL					665.3	826.8

top three hundred centimetres of the Kikuyu red loam holds approximately 1200 millimetres of moisture at field capacity. Of these 1200 millimetres of moisture, three hundred millimetres are available, the permanent wilting point having been reached in all parts of the profile when there are 900 millimetres of moisture present. One centimetre of soil could hold an average of one millimetre of moisture, which is in close agreement with what has been found for the Kabete soil.

4:4: CALIBRATION OF THE NEUTRON PROBE APPARATUS

Figures 4:10 and 4:11 show the calibration curves for the Kabete soil. The curves were obtained by plotting probe count ratio against volumetric moisture content. Because of the large scatter observed during a preliminary plotting of the data, it was decided that separate calibration curves were required for 0-30, 30-90, 90-120, 120-180 cm depths. After separating the curves, it was discovered that for the 90-120 and 120-180 cm depths the points were

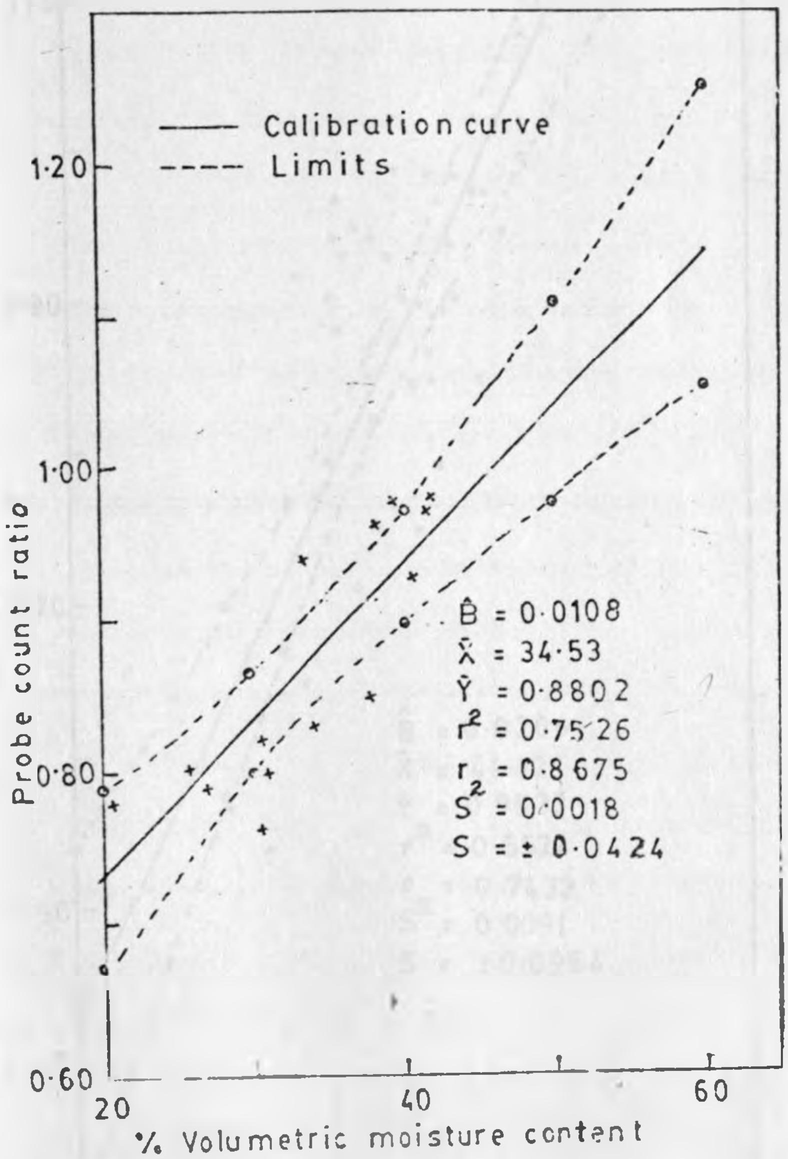


Fig. 4:10
Calibration curve (Neutron probe) for the 0-30 cm depth for the soil of the experimental area

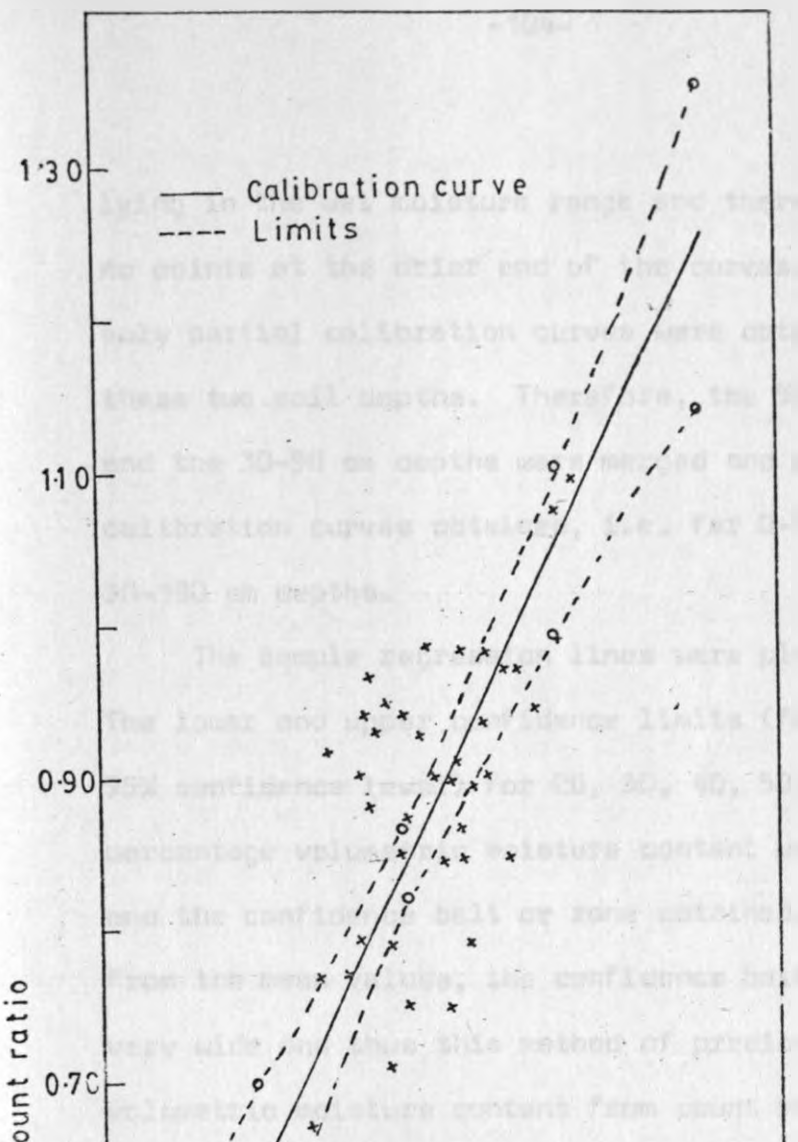


Fig 4:11
Pooled calibration curve (Neutron probe) for 30-180 cm depth for the soil of the experimental area.

lying in the wet moisture range and there were no points at the drier end of the curves. Thus only partial calibration curves were obtained for these two soil depths. Therefore, the 90-180 cm and the 30-90 cm depths were merged and only two calibration curves obtained, i.e. for 0-30 cm and 30-180 cm depths.

The sample regression lines were plotted. The lower and upper confidence limits (for the 95% confidence level) for 20, 30, 40, 50 and 60 percentage volumetric moisture content were plotted and the confidence belt or zone obtained. Away from the mean values, the confidence belts are very wide and thus this method of predicting volumetric moisture content from count ratio is not very accurate for this soil. This is due to lack of precision in making predictions of volumetric percentage moisture content far removed from the mean value. However, the relationship between probe count ratio and volumetric percentage moisture content is highly linear as indicated by the regression coefficients of 0.8675 and 0.7432 for the 0-30 and 30-180 cm depths respectively.

Dagg and Hosegood (1964) found that in the Muguga soils (Kikuyu clay loams), similar to the

Kabete soil, a separate calibration curve was required for each thirty centimetre depth of soil. In 1965, they discovered that the sensitivity of the probe in the Muguga soils fell drastically at volumetric moisture content higher than forty percent. This was believed to be due to the geometry of the radioactive source relative to the detection, and probably the presence of a hydrated halloysite clay type. Quantitative assessment of the situation was difficult because of the relatively large quantities of amorphous alluminium and iron oxides in the soil, which are good neutron absorbers.

Because of the difficulties encountered in the calibration, water use calculations were based on gravimetric samplings.

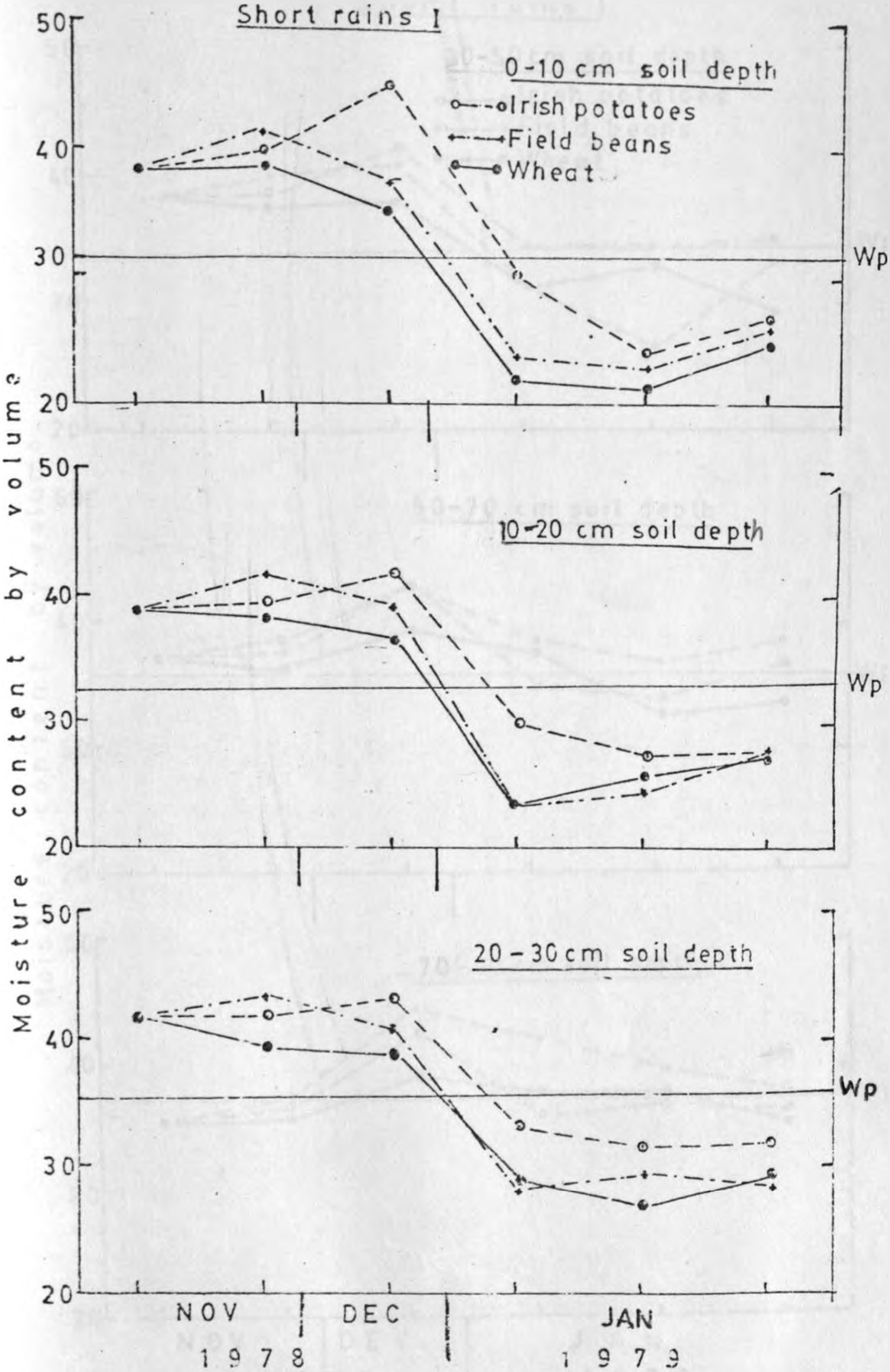
4:5: SEASONAL CHANGES IN SOIL WATER STATUS

The analysis of soil water data was directed towards estimates of plant water use. Volumetric percentage moisture content from gravimetric samplings for each depth under each crop during the short rains (SR) and long rains (LR) and their changes with time are shown in appendices 3 (A - J) and 4 (A - S). The amount of rainfall received between sampling dates during the seasons is shown in appendix 2.

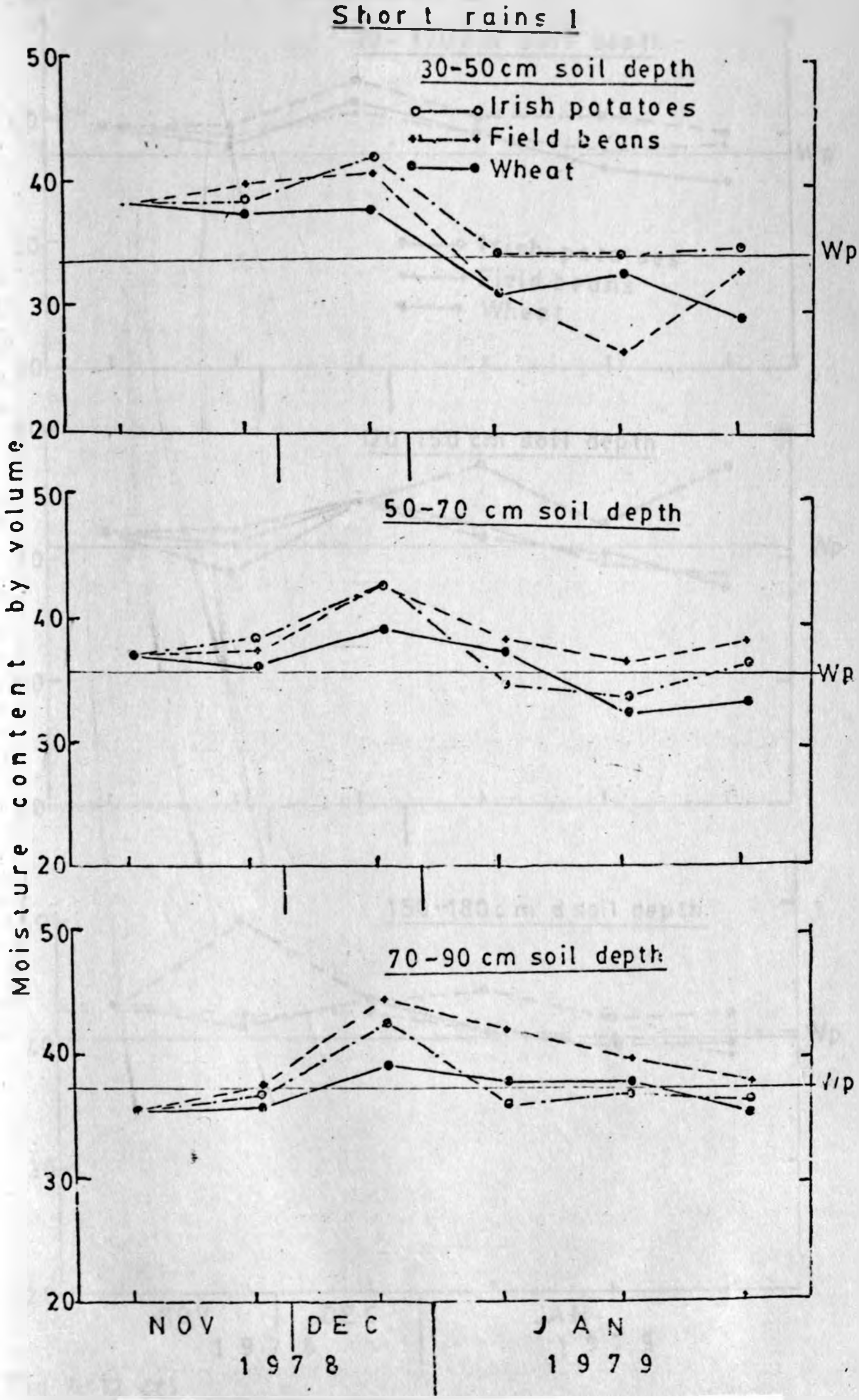
At planting, in both the short rains and long rains, the percentage moisture content by weight was averaged out from selected profiles (five profiles in the short rains and six profiles in the long rains) to give a uniform initial moisture content for each season.

Figures 4:12 (I, II, III) and 4:13 (I, III) show the changes in water content with time for the different sampling depths for the crops both in the short and long rains. The crops are grouped according to the length of the growing season. Field beans (FB), Irish potatoes (IP) and wheat (W) have the shortest length of growing season of about 90 days followed by linseed (LS), soyabeans (SB) and sunflower (SF) which have a growing season of about 130 days. Maize (M) and sweet potatoes (SP) have the longest growing season of about 160 days.

After planting in the short rains, the volumetric moisture content percentage at all depths for all crops either generally remained constant or increased until 18th December when the rains stopped. The percentage later decreased until after 15th January when the rains rewetted the profile.



See Page 109 for the title of these graphs.



See Page 109 for the title of these graphs.

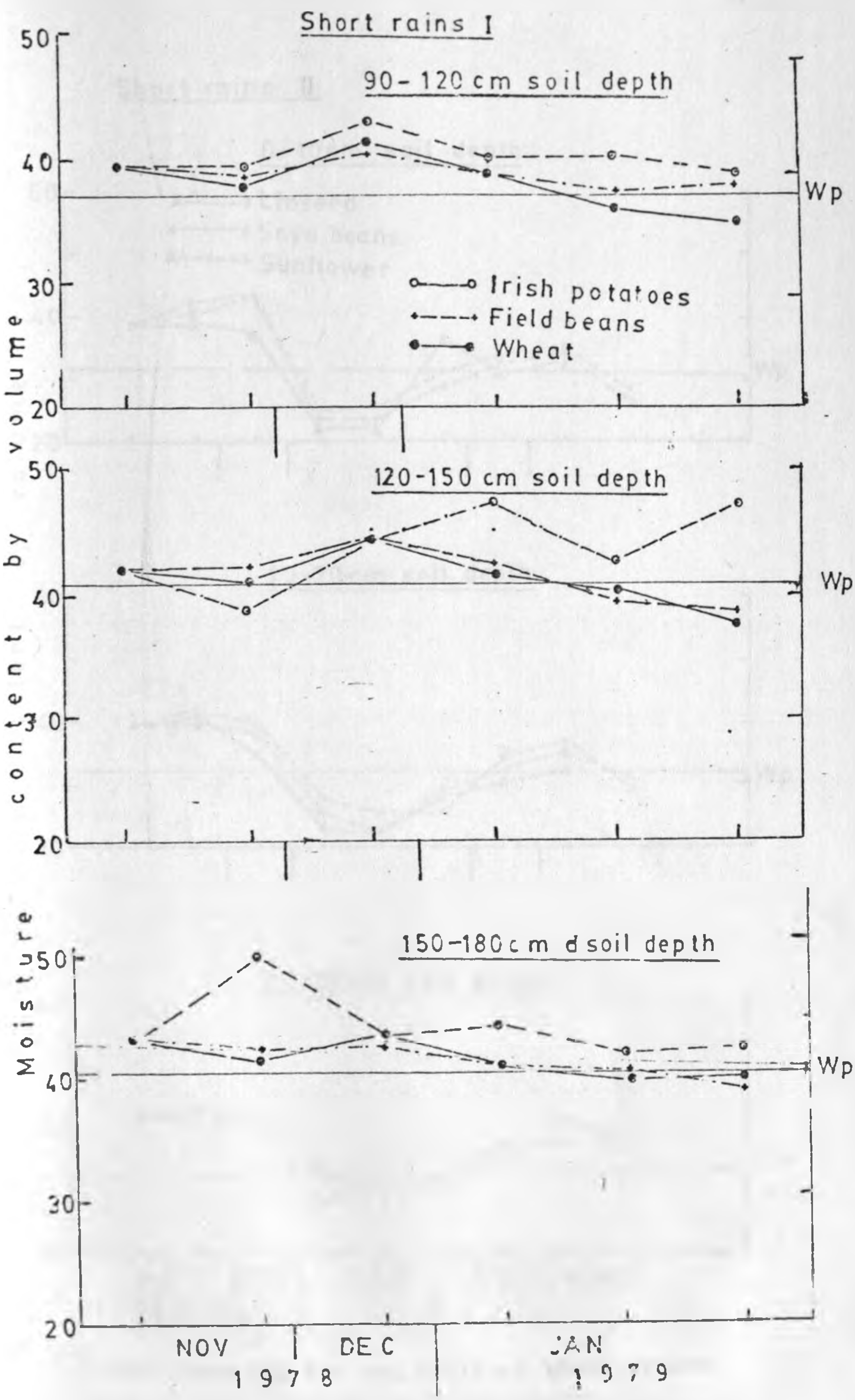
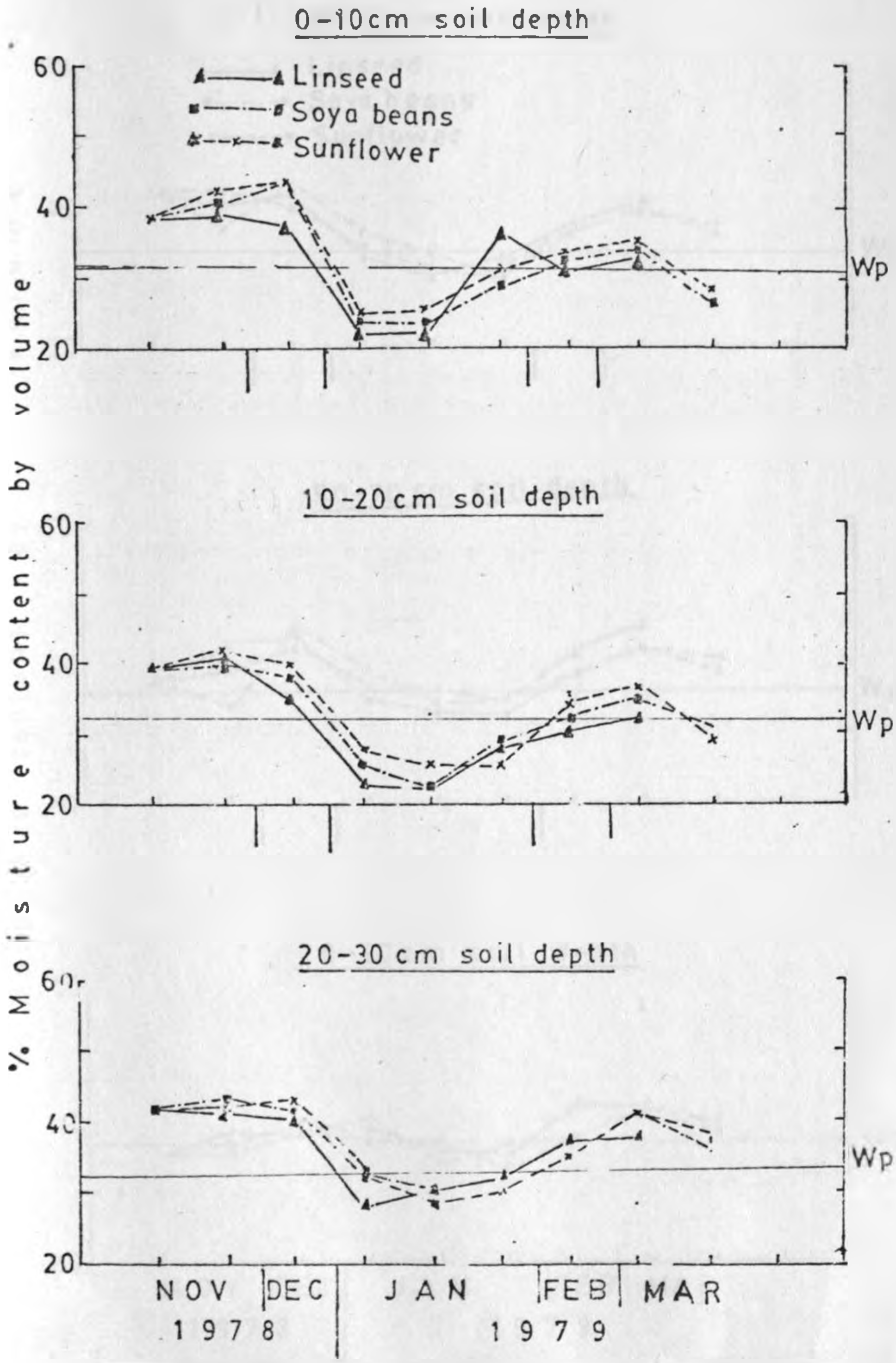


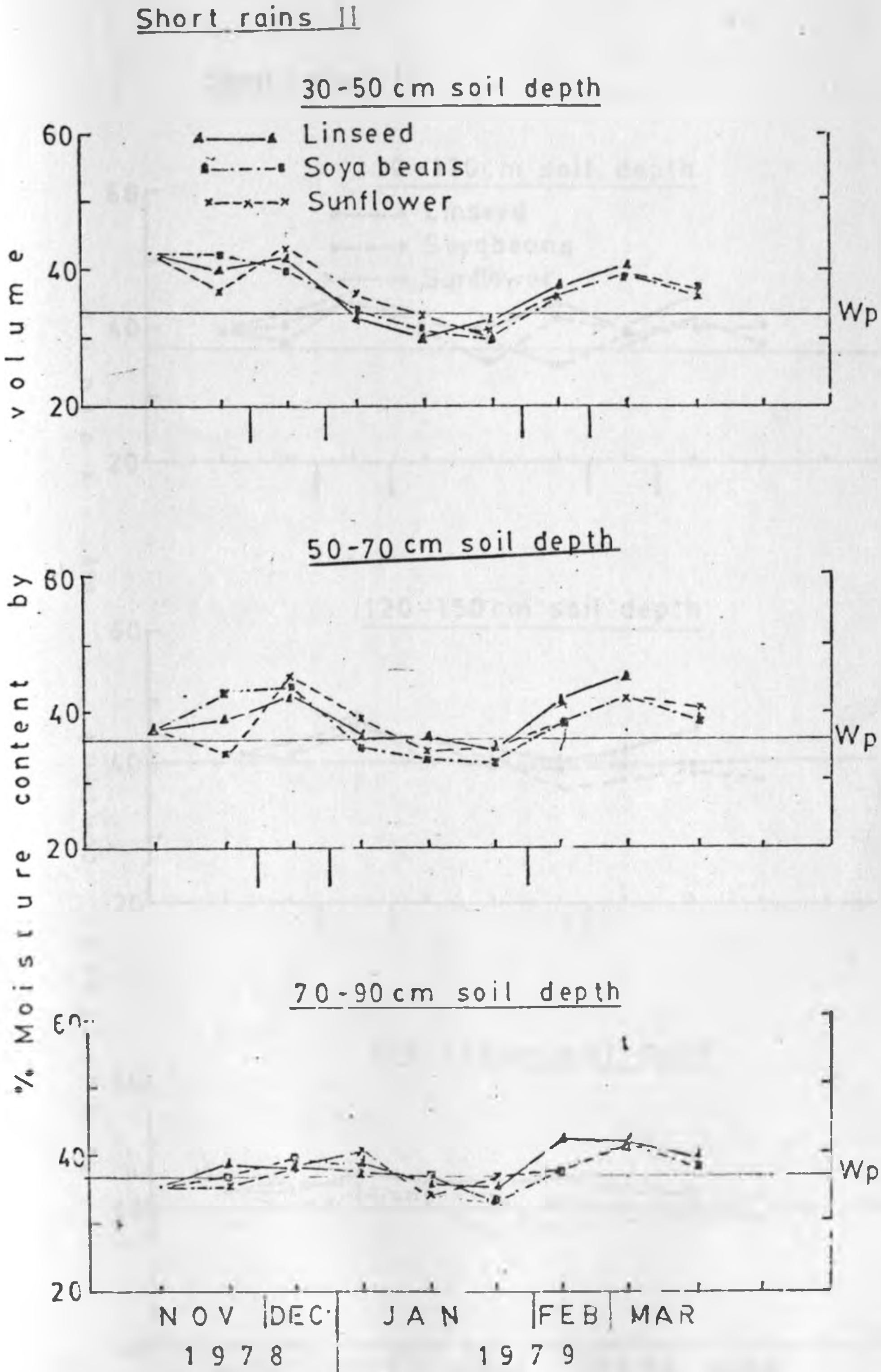
Fig 4:12 (I)

The change in soil water content at each depth measured throughout the growing season with wilting point coefficient drawn in

Short rains II



See Page 112 for the title of these graphs.



See Page 112 for the title of these graphs.

Short rains II

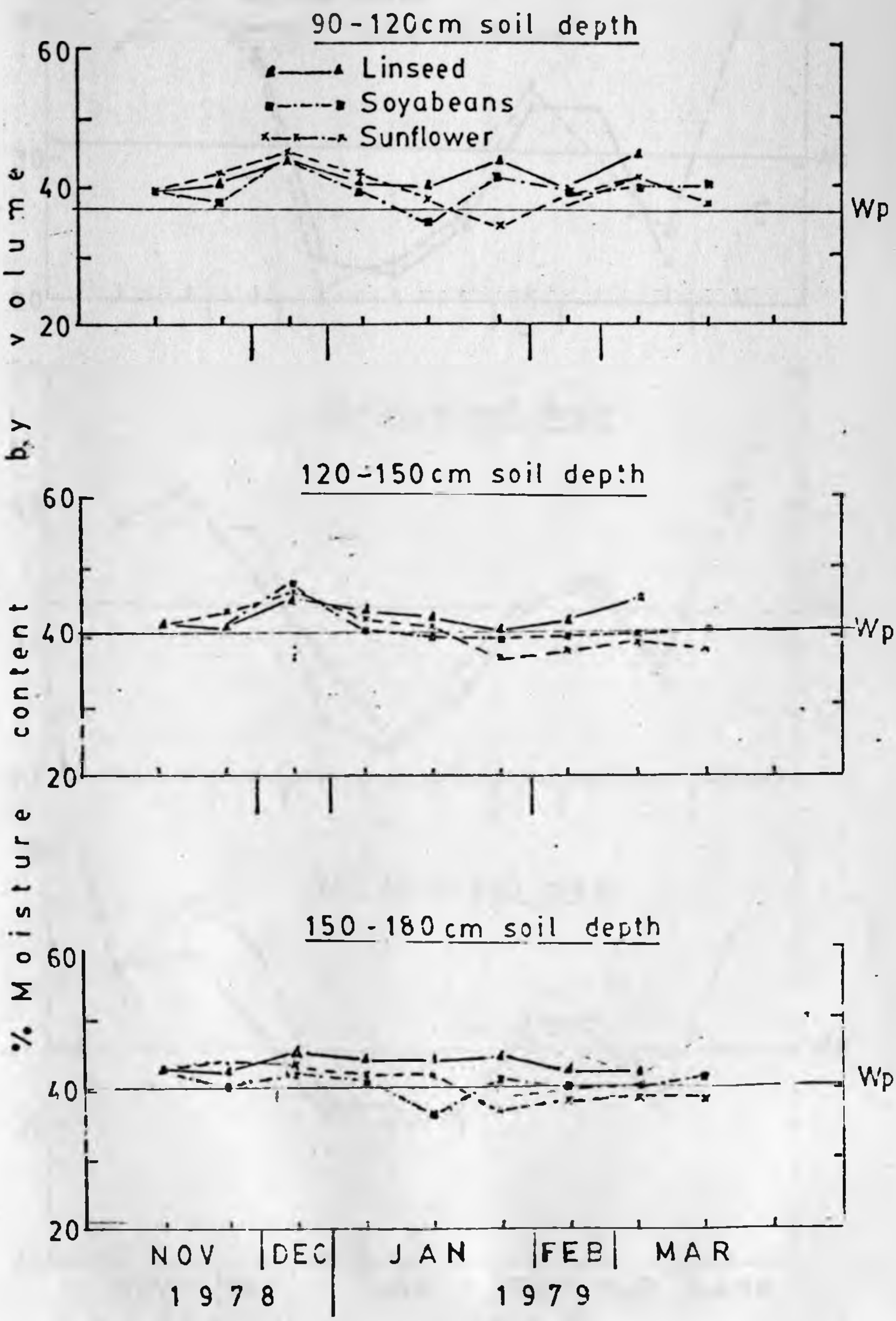
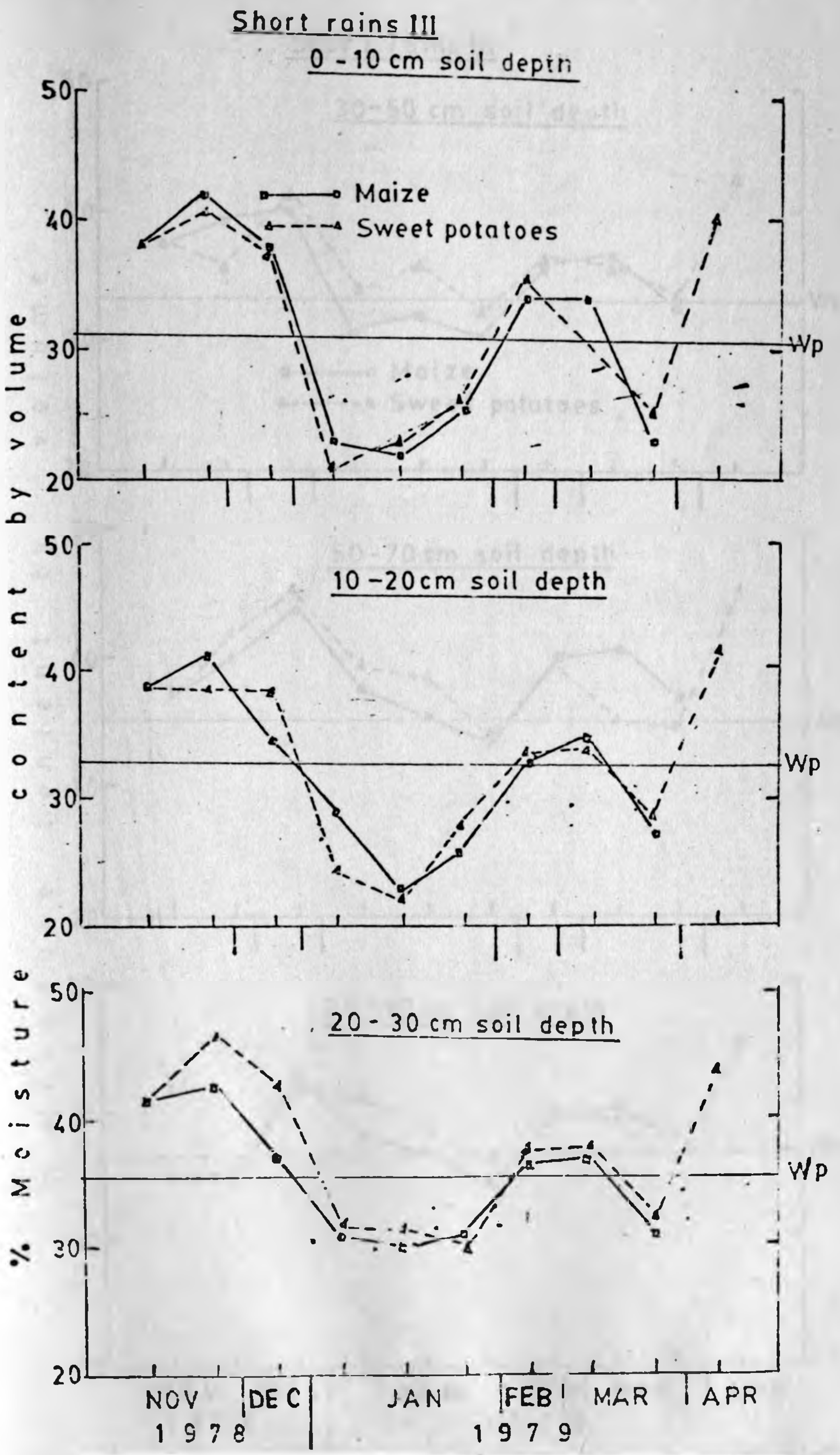
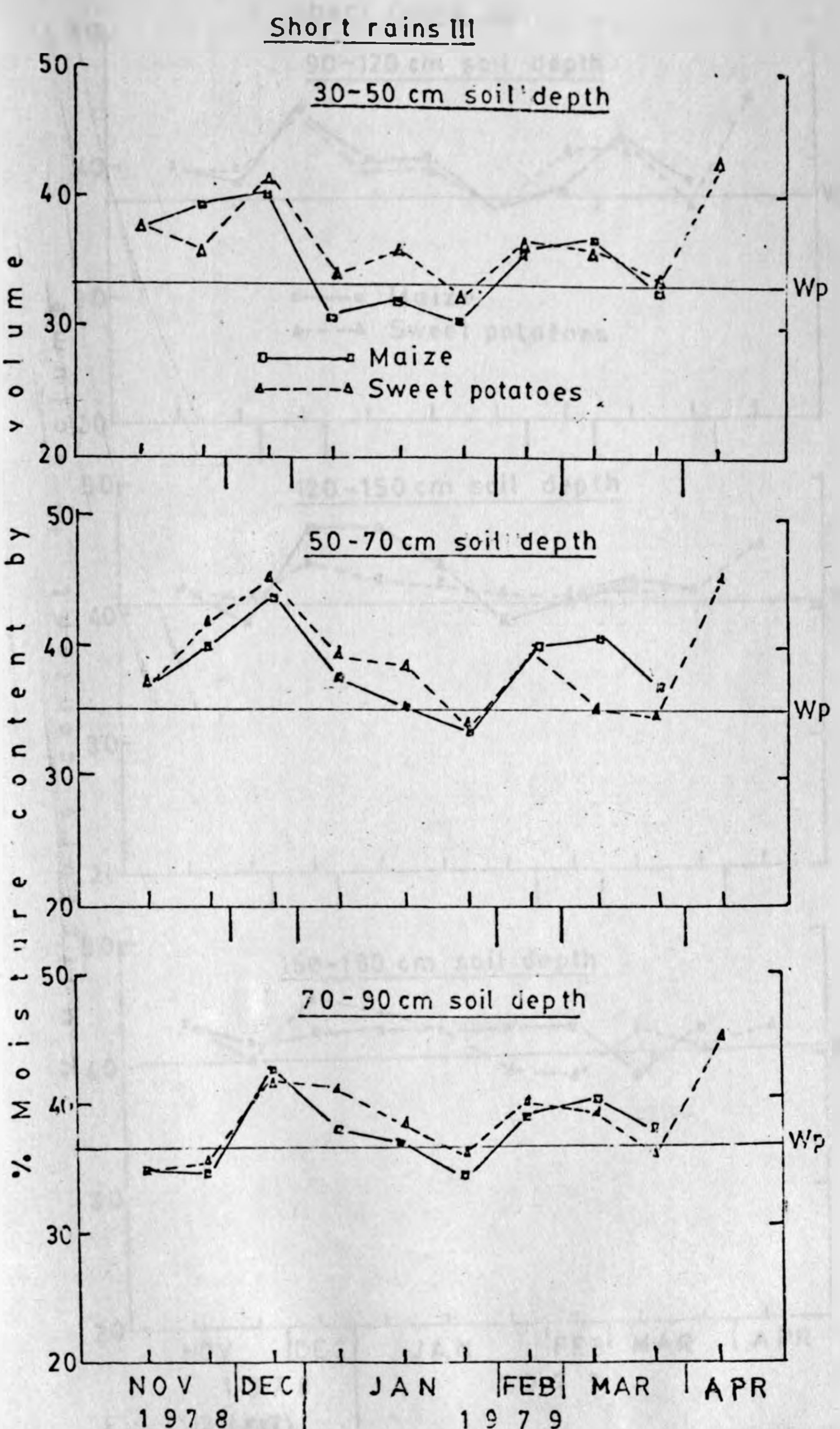


Fig. 4.12 (II)
The change in soil water content at each depth measured throughout the growing season with respective wilting point coefficient drawn in.



See Page 115 for the title of these graphs.



See Page 115 for the title of these graphs.

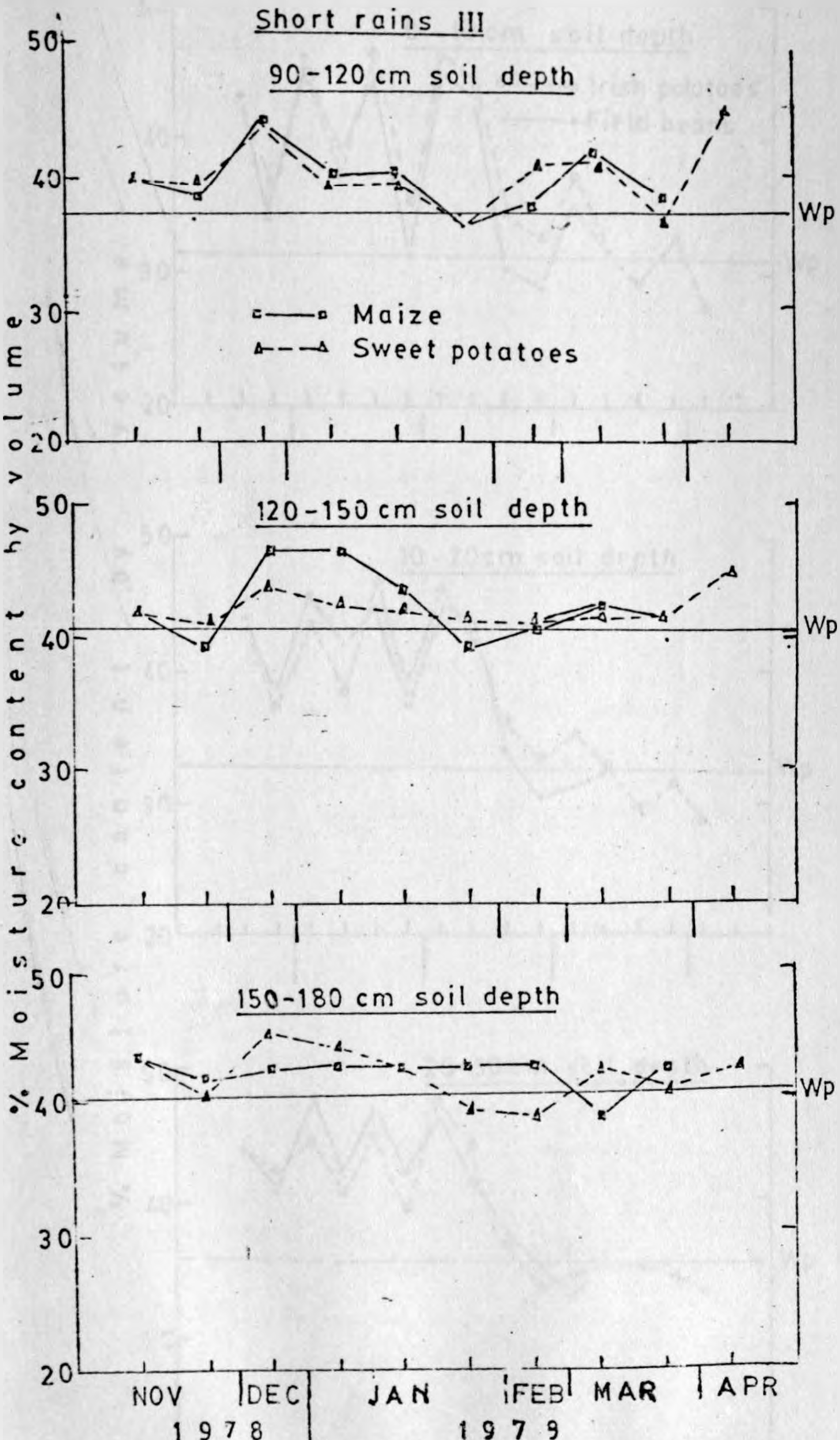
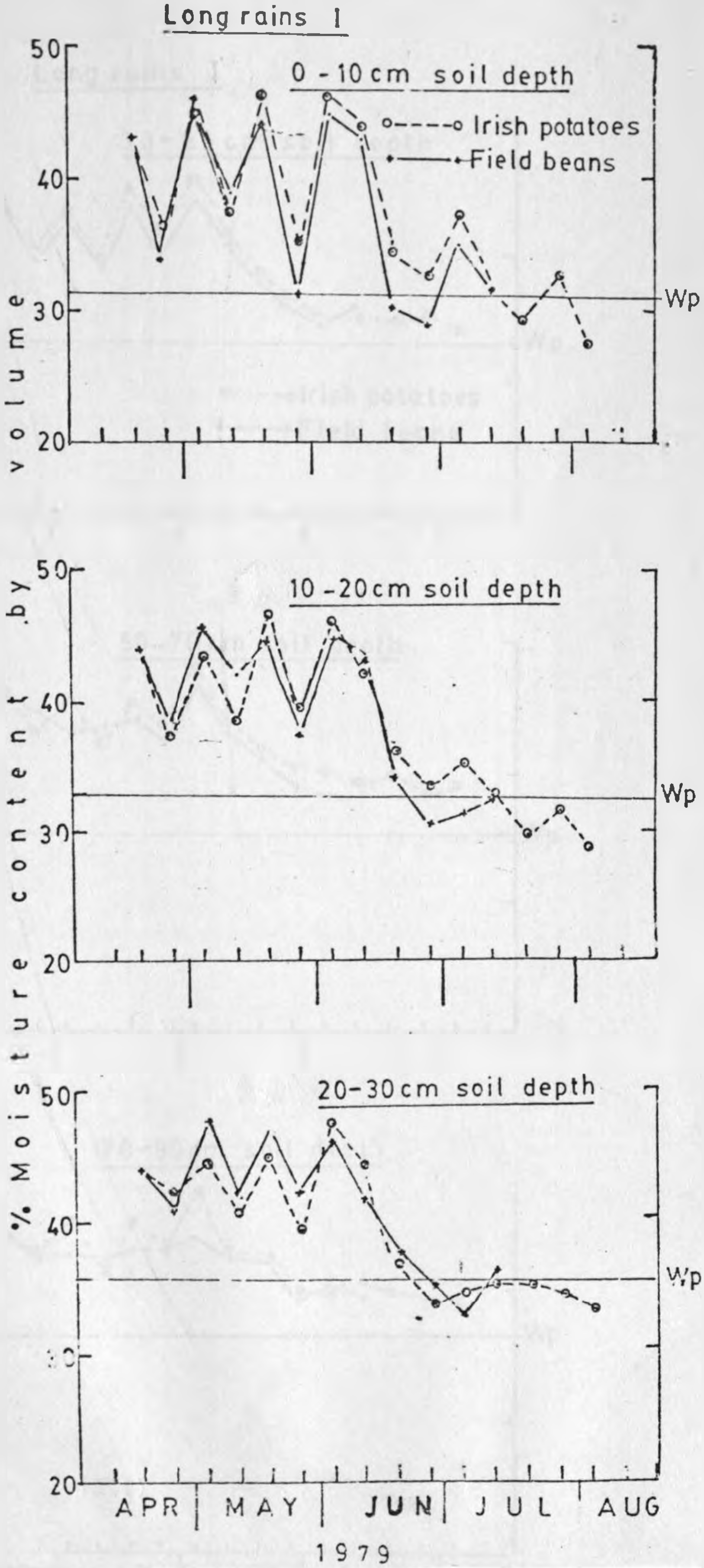
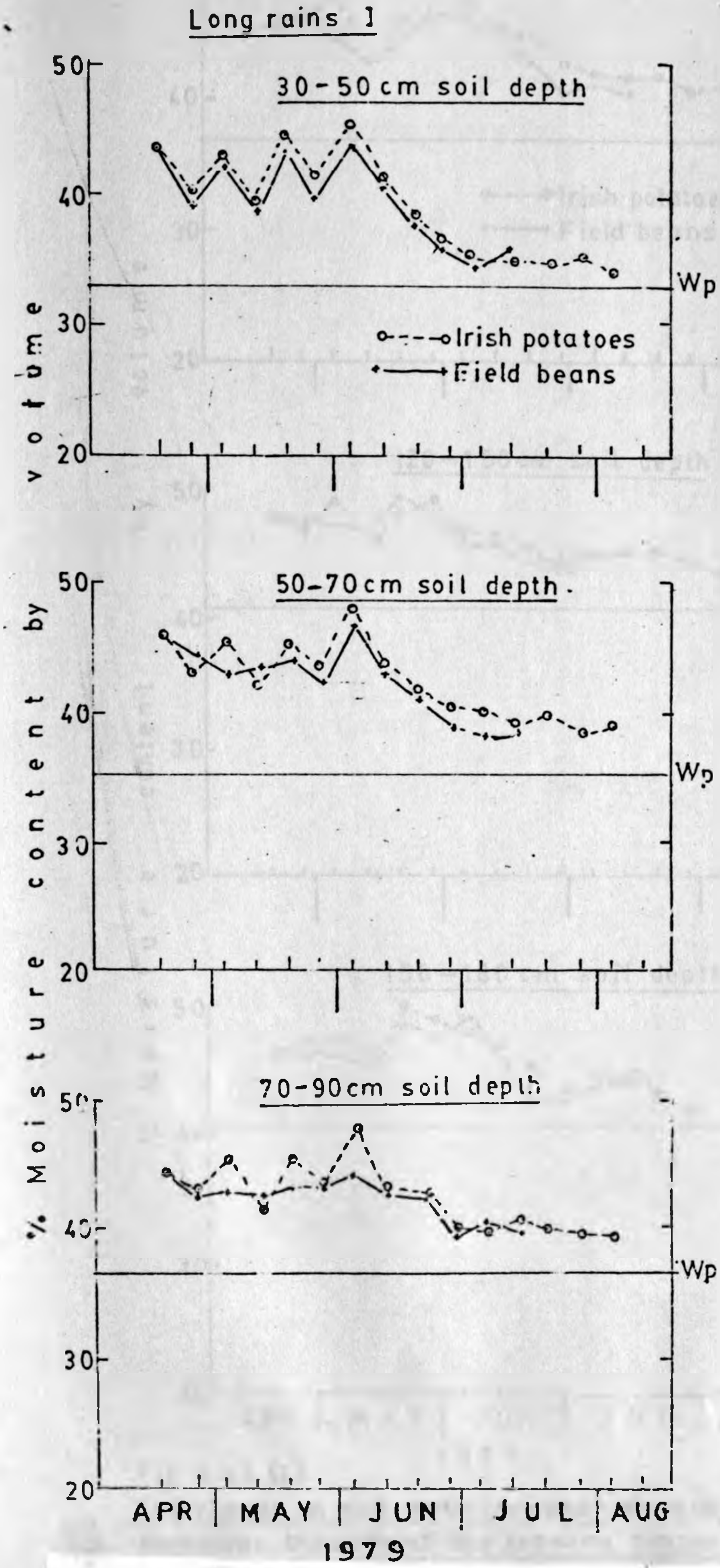


Fig. 4:12 (III)

The change in soil water content at each depth measured throughout the growing season with the wilting point coefficient drawn in



See Page 118 for the title of these graphs.



See Page 118 for the title of these graphs.

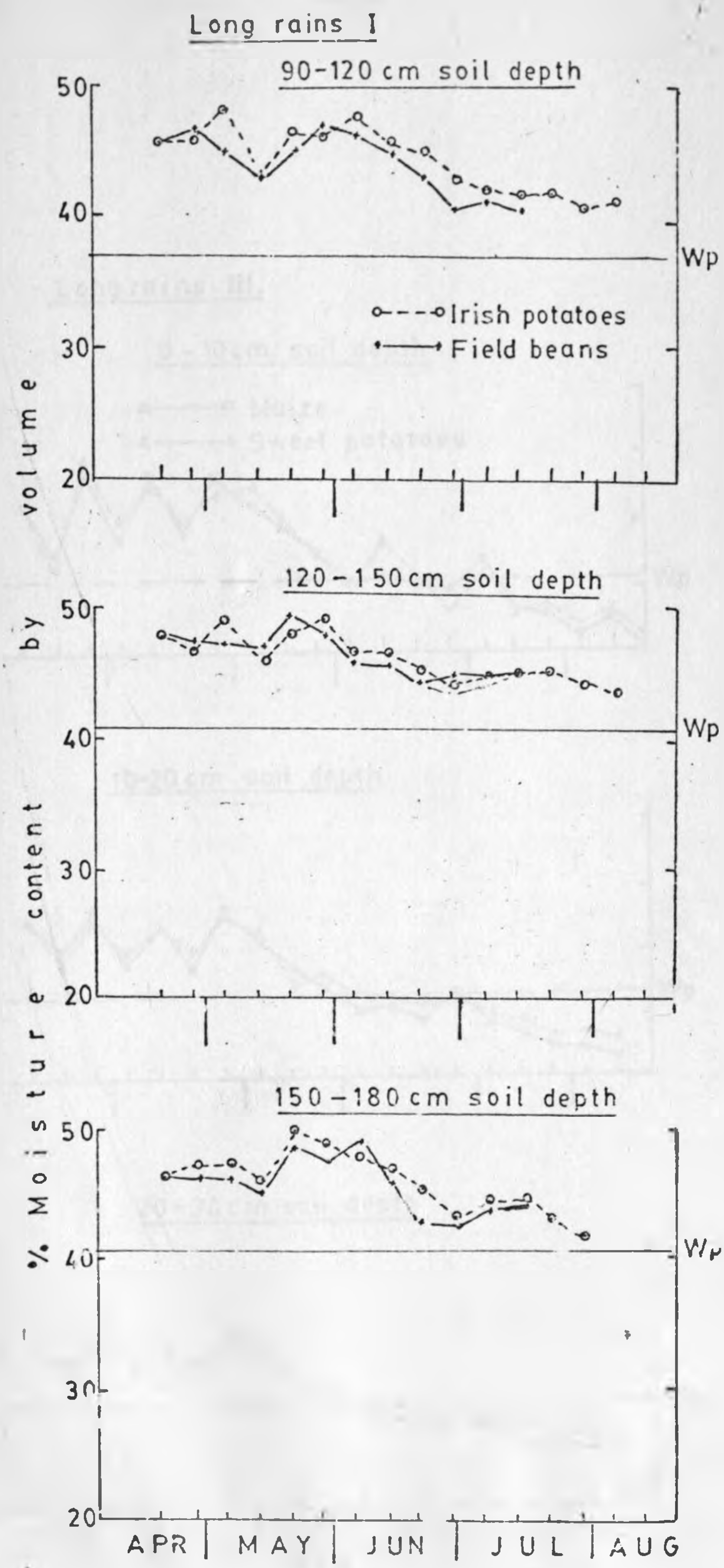
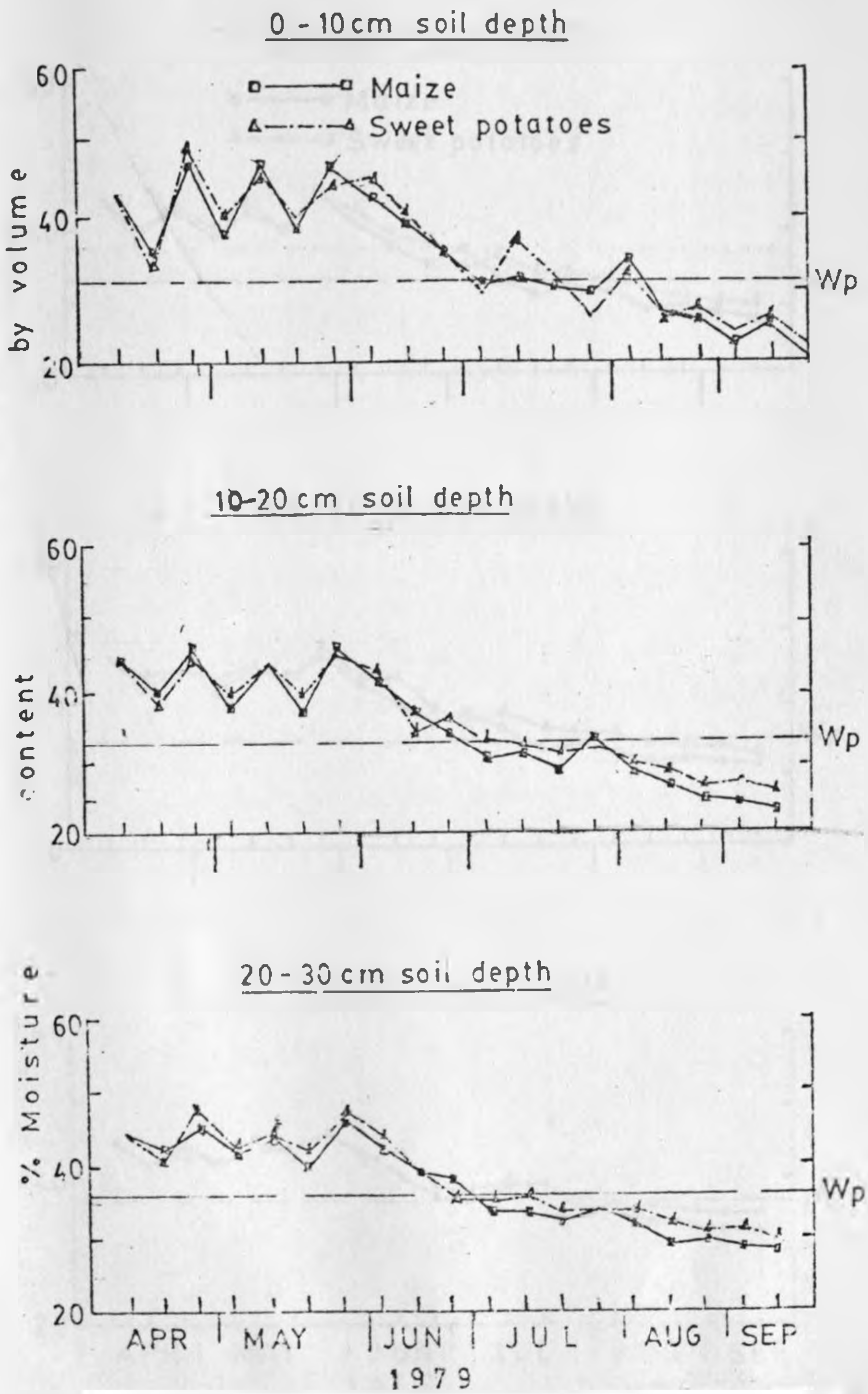


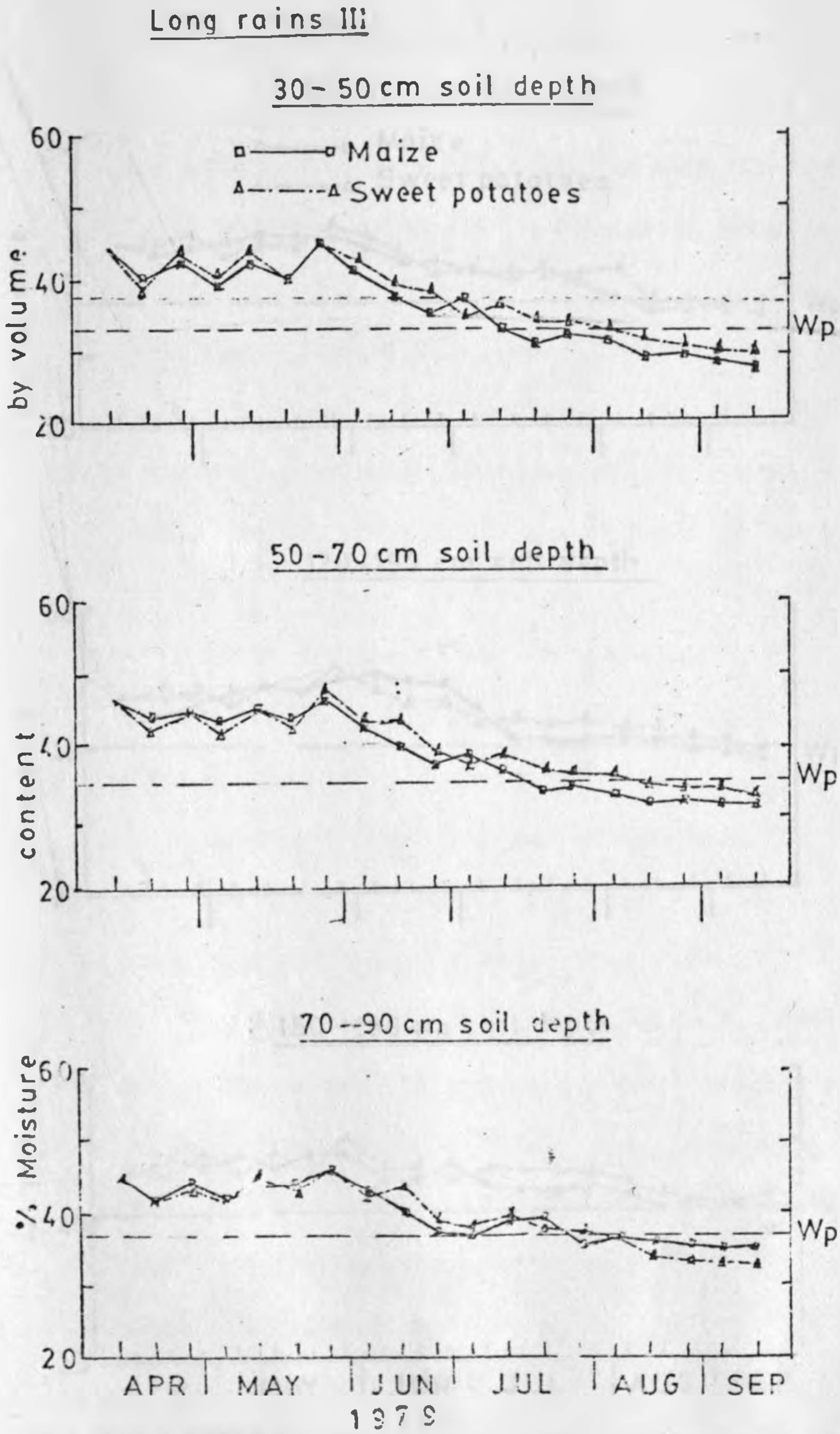
Fig 4:13 (I)

The change in soil water content at each depth measured throughout the growing season with the wilting point coefficient drawn in

Long rains III.



See Page 121 for the title of these graphs.



See Page 121 for the title of these graphs.

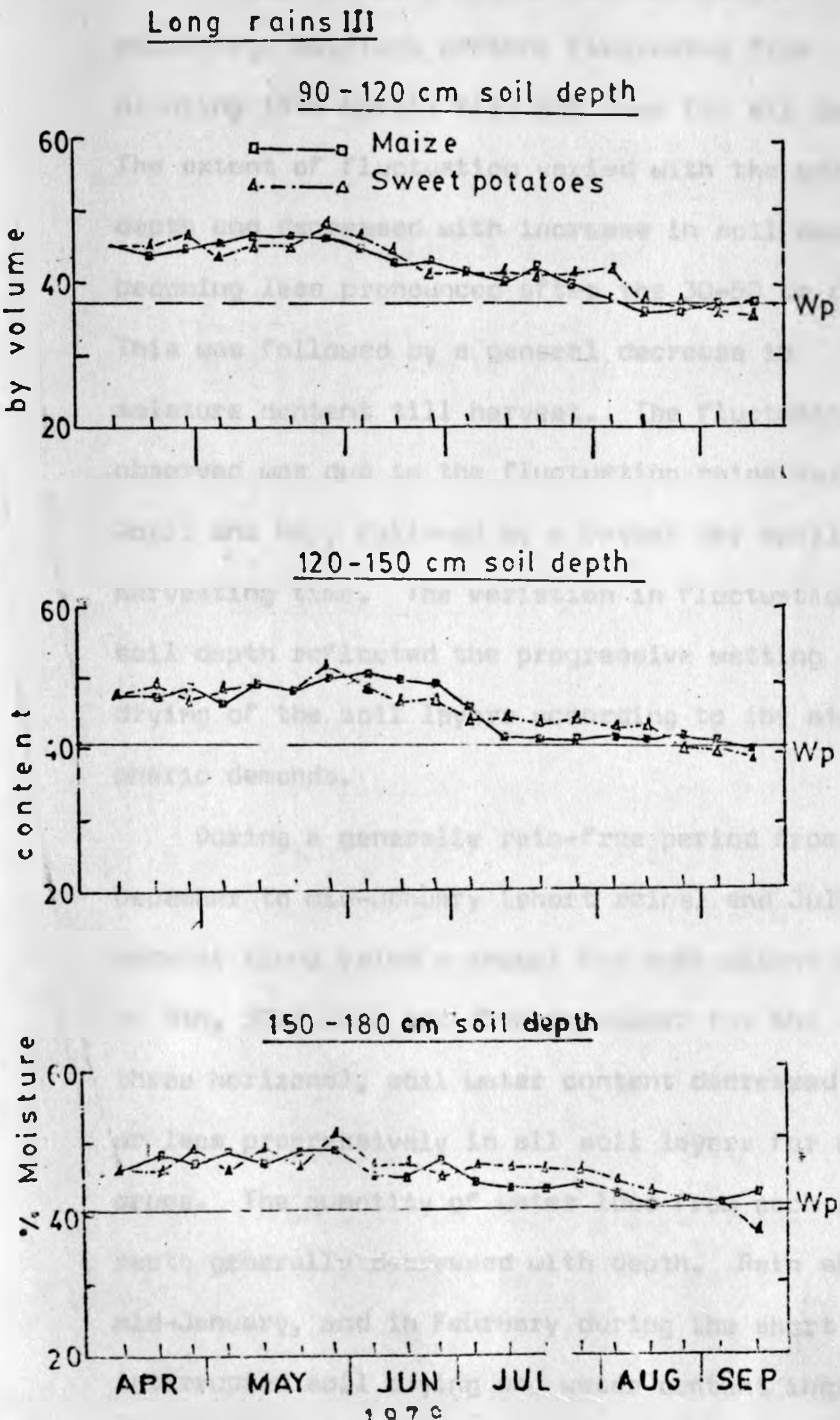


Fig. 4:13 **(III)**

The change in soil water content at each depth measured throughout the growing season with the wilting point coefficient drawn in.

During the long rains, the volumetric percentage moisture content fluctuated from planting (9th April) till 4th June for all crops. The extent of fluctuation varied with the soil depth and decreased with increase in soil depth, becoming less pronounced after the 30-50 cm depth. This was followed by a general decrease in moisture content till harvest. The fluctuation observed was due to the fluctuating rains between April and May, followed by a rather dry spell till harvesting time. The variation in fluctuation with soil depth reflected the progressive wetting and drying of the soil layers according to the atmospheric demands.

During a generally rain-free period from mid-December to mid-January (short rains) and July till harvest (long rains - except for some slight rises on 9th, 30th July and 10th September for the top three horizons), soil water content decreased more or less progressively in all soil layers for all the crops. The quantity of water loss from each soil depth generally decreased with depth. Rain after mid-January, and in February during the short rains interrupted soil drying and water content increased for the medium season crops to a depth of 150 cm for linseed and to 120 cm for soyabeans and sunflower. For the long season crops, maize and sweet potatoes, water content increased to a depth of 150 cm.

4:6: SEASONAL CHANGES IN RELATION TO DEPTH OF ROOT WATER EXTRACTION

Changes in soil water content with time for individual soil depths illustrate some characteristic patterns. These are:

(i) water content of the soil is initially almost constant (short rains) or fluctuating (long rains), followed by a period of rapid loss and then a gradual loss of moisture (this pattern was observed in the 0-10, 10-20, 20-30, 30-50 cm depths in both the long and short rains); and

(ii) water content remaining more or less constant or decreasing continuously at a similar rate throughout (this was observed in the long rains at the 70-90, 90-120, 120-150, 150-180 cm depths).

These observations may be explained as follows. When a soil layer drains or loses water by evaporation; its water content gradually decreases unless rewetting of the layer by rain occurs. The rate of water loss from that layer also decreases. When crop water extraction begins from a layer, the rate of water loss suddenly increases and results in fluctuations in the water content against time curve. The identification of these fluctuations provides a means of determining effective rooting depth and a simple method of separating horizons of soil undergoing through drainage from those subject to evapotranspiration.

The effective rooting depths were determined from the gravimetric samplings and the wilting point coefficient (WP) percentage by volume plotted against time for each depth and crop, (Figures 4:12 (I, II, III) and 4:13 (I, III)). It was assumed that where the percentage volumetric moisture content against time for a given depth was above wilting point and the water content remained more or less constant throughout, the effective roots did not pass beyond this depth. This means that the soil water storage remained more or less constant below this depth and the soil moisture changes were negligible.

The effective rooting depths for the eight crops and four crops grown in the short and long rains respectively were as shown below:

TABLE 4:3: EFFECTIVE ROOTING DEPTHS FOR THE EIGHT AND FOUR CROPS GROWN DURING THE SHORT AND LONG RAINS RESPECTIVELY

Crop	Effective rooting depth (cm)	
	Short rains	Long rains
Field beans (FB)	90 - 120	50 - 70
Irish potatoes (IP)	50 - 70	50 - 70
Maize (M)	150 - 180	150 - 180
Sweet potatoes (SP)	150 - 180	150 - 180
Wheat (W)	150 - 180	
Linseed (LS)	90 - 120	
Soyabeans (SB)	150 - 180	
Sunflower (SF)	150 - 180	

The differences observed between short and long rains in the effective rooting depth for field beans may probably be due to the fact that the water needs of the beans in the long rains could be supplied from a shallower depth without recourse to the lower layers. The roots went deeper into the soil during the short rains looking for moisture. Because of the dry period observed from July to harvest, maize and sweet potatoes started extracting moisture from lower depths from the end of July onwards. Thus the maize and sweet potatoes during the long rains sent their roots as deep as during the short rains. These effective rooting depths for the different crops during the two seasons more or less agree with what was found by Doorenbos and Pruitt (1977).

It is possible for roots to be present in a soil depth without extracting much water, or for water to move upwards through the soil before being taken up by the plant. An effective rooting depth, therefore, indicates only the maximum identifiable depth of net water extraction, but not necessarily the presence of roots.

4:7: CROP WATER USE

4:7:1: PERIODIC CROP WATER USE

The water depletion observed in relation to seasonal changes in soil water status (section 4:5) is a result of evapotranspiration (water use) and drainage. Before crop water use can be calculated, these two components must be seperated.

A water budget was carried out using equation 2:2 for the crops during the two seasons. Because the experiment was carried out under rainfed conditions, the term irrigation (I) was eliminated. Surface runoff (S) was assumed to be negligible as the soil is well drained, and no evidence of erosion was observed in addition to the fact that the experiment was carried out on fairly flat land where the slope was less than two percent. The equation thus reduced to:

$$\int E\,dt = P - \Delta w - \mu \qquad (4:1)$$

where,

E	=	evapotranspiration
dt	=	time
P	=	precipitation (rainfall)
Δw	=	change in soil moisture storage
μ	=	drainage

The drainage component was estimated by assuming that it was the amount of water passing below the 180 cm soil depth, after the profile had reached field capacity. The change in soil water storage between two consecutive samplings, taking into account any rainfall received provided an estimate of water use for that period using the water balance equation. Appendices 5 (A - D) and 6 (A - B) show the water budget for the different crops during the short and long rains respectively.

Table 4:4 and Table 4:5 show the amount of water (millimetres) in the 180 cm profile for the crops at each sampling date during the short and long rains respectively. Tables 4:6 and 4:7 show the amount of water used between consecutive sampling dates for the different crops during the same two growing seasons.

From tables 4:4 and 4:5, it is observed that on 8/1/79, 15/1/79 and 29/1/79 (short rains - table 4:4) and 28/5/79 and 30/7/79 (long rains - table 4:5) the total moisture in the 180 cm profiles for some of the crops was either too high or too low from the previous value, and the rainfall received could not account for the great gains or losses in moisture observed.

Tables 4:8 and 4:9 show the daily rates of moisture use for all crops in the two seasons (short and long rains respectively).

TABLE 4: 4 : TOTAL AMOUNT OF WATER (mm) IN 180 cm SOIL PROFILE FOR THE EIGHT CROPS, AT EACH SAMPLING DATE DURING THE SHORT RAINS (SR) OF 1978/79

Date	FB	IP	W	LS	SB	SF	M	SP
7/11/78	712.5	712.5	712.5	712.5	712.5	712.5	712.5	712.5
27/11/78	720.4	728.5	684.8	727.3	694.2	751.3	706.7	710.7
18/12/78	750.3	779.9	727.2	771.9	793.9	779.9	780.9	709.2
8/ 1/79	641.5	700.2	646.5	673.0	681.6	675.2	693.1	680.2
15/ 1/79	617.9	673.1	623.0	657.1	608.9	647.1	661.7	670.0
29/ 1/79	637.8	671.2	612.5	678.0	656.2	604.3	633.4	631.9
19/ 2/79				712.6	686.8	670.1	699.6	704.1
5/ 3/79				776.7	730.2	717.6	717.0	699.2
12/ 3/79					698.4	660.7	658.7	644.0
17/ 4/79								702.1

Key: FB - Field beans; IP - Irish potatoes; W - Wheat; LS - Linseed; SB - Soyabeans; M - Maize; SP - Sweet potatoes.

TABLE 4:5: TOTAL AMOUNT OF WATER (mm) IN 180 cm SOIL PROFILE FOR THE FOUR CROPS AT EACH SAMPLING DATE DURING THE LONG RAINS (LR) 1979

Date	FB	IP	M	SP
9/ 4/79	819.2	819.2	819.2	819.2
23/ 4/79	782.3	787.6	783.3	780.0
30/ 4/79	807.7	841.9	824.8	834.2
7/ 5/79	772.4	768.1	778.8	784.1
14/ 5/79	828.6	839.8	827.8	829.7
21/ 5/79	783.2	805.0	795.3	792.8
28/ 5/79	841.3	855.9	850.6	860.7
4/ 6/79	792.9	801.1	794.6	805.1
18/ 6/79	742.0	768.9	750.4	770.7
25/ 6/79	706.8	734.7	712.7	720.3
9/ 7/79	717.1	727.9	717.0	717.1
16/ 7/79	718.0	721.6	707.0	711.6
23/ 7/79		712.4	674.6	698.2
30/ 7/79		708.9	683.6	692.6
6/ 8/79		693.7	657.9	683.0
20/ 8/79			628.5	661.1
27/ 8/79			625.2	642.1
10/ 9/79			620.2	634.5
17/ 9/79			607.8	600.1

Key: FB - Field beans; IP - Irish potatoes; M - Maize; SP - Sweet potatoes.

TABLE 4:6: CROP WATER USE (mm) FOR THE DIFFERENT CROPS DURING THE SHORT RAINS (SR), 1978/79

Period	Days	FB	IP	W	LS	SB	SF	M	SP
7/11 - 27/11	20	52.2	44.1	87.8	45.3	78.4	21.3	65.9	61.9
27/11 - 18/12	21	90.8	69.3	78.3	76.1	21.0	92.1	46.5	62.2
18/12 - 8/ 1	21	127.2	98.1	99.1	117.3	130.7	123.1	106.2	107.4
8/ 1 - 15/ 1	7	26.7	30.2	26.6	19.0	}51.0	31.2	34.5	}73.9
15/ 1 - 29/ 1	14	2.6	24.4	33.0	}105.6		65.3	50.8	
29/ 1 - 19/ 2	21					108.0	72.8	72.4	66.4
19/ 2 - 5/ 3	14				36.8	57.5	53.4	83.5	105.8
5/ 3 - 12/ 3	7					32.2	57.3	58.7	55.6
12/ 3 - 17/ 4	36								96.1
TOTAL		299.5	266.1	324.8	400.1	478.8	516.6	518.4	629.3

Key: FB - Field beans; IP - Irish potatoes; W - Wheat; LS - Linseed; SB - Soyabeans; M - Maize; SP - Sweet potatoes; SF - Sunflower.

TABLE 4 : 7 : CROP WATER USE (mm) FOR THE DIFFERENT CROPS DURING THE LONG RAINS 1979

PERIOD	DAYS	FB	IP	M	SP
9/4 - 23/4	14	118.5	113.2	117.5	120.8
23/4 - 30/4	7	41.3	12.4	25.2	12.5
30/4 - 7/5	7	47.3	70.7	58.0	54.7
7/5 - 14/5	7	44.0	28.5	51.2	54.6
14/5 - 21/5	7	45.1	23.3	33.0	35.5
21/5 - 28/5	7	14.3	21.5	17.1	78.1
28/5 - 4/6	7	51.9	43.7	50.2	
4/6 - 18/6	14	63.2	44.5	56.5	46.1
18/6 - 25/6	7	37.1	36.1	39.6	52.3
25/6 - 9/7	14	15.2	32.3	21.2	28.7
9/7 - 16/7	7	1.0	8.2	11.9	7.4
16/7 - 23/7	7		10.7	33.9	14.9
23/7 - 30/7	7		17.2	30.4	19.3
30/7 - 6/8	7		15.2		9.6
6/8 - 20/8	14			40.9	33.4
20/8 - 27/8	7			4.5	20.2
27/8 - 10/9	14			14.8	17.4
10/9 - 17/9	4			13.3	35.3
TOTAL		478.9	477.5	619.2	641.4

Key: FB - field beans; IP - Irish potatoes; M - maize; SP - sweet potatoes

TABLE 4:8: AVERAGE DAILY RAINFALL, E_o (PAN AND PENMAN) AND CROP WATER USE DURING THE SHORT RAINS, 1978/79

Period	(days)	Average daily rainfall (mm)	Average daily E_o		Average daily crop water consumption (mm)								
			(a) Pan A	(b) Penman	FB	IP	W	LS	SB	SF	M	SP	Average for all crops
7/11 - 27/11	20	3.0	3.81	4.58	2.61	2.20	4.39	2.26	3.92	1.06	3.29	3.09	2.85
27/11 - 18/12	21	5.7	3.25	4.49	4.32	3.30	3.73	3.62	1.00	4.39	2.21	2.96	3.19
18/12 - 8/1	21	0.9	3.95	4.72	6.06	4.67	4.72	5.59	6.22	5.86	5.06	5.11	5.41
8/1 - 15/1	7	0.4	3.59	4.56	3.81	4.31	3.80	2.71)	2.43	4.46	4.93)	3.52	3.75
15/1 - 29/1	14	1.6	3.43	4.59	0.19	1.74	2.36)	3.02		4.66	3.63)		2.69
29/1 - 19/2	21	6.6	3.82	4.87					5.14	3.47	3.45	3.16	3.65
19/2 - 5/3	14	7.2	4.59	5.55				2.63	4.11	3.81	5.97	7.56	4.82
5/3 - 12/3	7	0.1	5.34	6.41					4.60	8.19	8.39	7.94	7.28
12/3 - 17/4	36	6.5	4.41	4.92								2.67	2.67

Key: FB - Field beans; IP - Irish potatoes; W - Wheat; LS - Linseed; SB - Soya beans; SF - Sunflower; M - Maize; SP - Sweet potatoes

TABLE 4.9 : AVERAGE DAILY RAINFALL, E_o (PAN A AND PENMAN) AND CROP WATER USE DURING THE LONG RAINS, 1979

Period	(days)	Average daily rainfall (mm)	Average daily E_o		Average daily crop water consumption (mm)				
			(a) Pan A	(b) Penman	FB	IP	M	SP	Average for all crops
9/4 - 23/4	14	5.8	3.76	4.69	8.46	8.09	8.39	8.63	8.39
23/4 - 30/4	7	9.5	3.87	4.76	5.90	1.77	3.60	1.79	3.27
30/4 - 7/5	7	1.7	3.29	4.53	6.76	10.10	8.29	7.81	8.24
7/5 - 14/5	7	14.3	4.24	4.56	6.29	4.07	7.31	7.80	6.37
14/5 - 21/5	7	0.2	3.43	4.36	6.44	3.33	4.71	5.07	4.89
21/5 - 28/5	7	10.3	2.27	3.00	2.04	3.07	2.44 }	5.58	3.28
28/5 - 4/6	7	2.6	2.36	3.14	7.41	6.24	7.17 }		6.60
4/6 - 18/6	14	0.9	2.99	4.24	4.51	3.18	4.04	3.29	3.76
18/6 - 25/6	7	0.3	2.41	3.54	5.30	5.16	5.66	7.47	5.90
25/6 - 9/7	14	1.8	1.86	2.79	1.09	2.31	1.51	2.05	1.74
9/7 - 16/7	7	0.3	2.56	2.93	0.14	1.17	1.70	1.06	1.02
16/7 - 23/7	7	0.2	2.64	4.00		1.53	4.84	2.13	2.83
23/7 - 30/7	7	2.0	2.53	3.43		2.46 }	2.17	2.76	2.46
30/7 - 6/8	7	0.0	2.71	3.79		2.17 }		1.37	1.90
6/8 - 20/8	14	0.8	2.01	3.09			2.92	2.39	2.66
20/8 - 27/8	7	0.2	3.74	4.80			0.64	2.89	1.77
27/8 - 10/9	14	0.7	3.56	4.79			1.06	1.24	1.15
10/9 - 17/9	7	0.1	3.91	5.21			1.90	5.04	3.47

Key: FB - Field beans; IP - Irish potatoes; M - Maize; SP - Sweet potatoes

Field beans - during the short rains the crop water loss for field beans was low initially. This early low water loss was due to the incomplete canopy cover of the crop. This gradually increased till the maximum rate of 6.1 mm/day was obtained in mid-December. Drying off of the leaves and pods, from mid-January onwards, in the later stage of crop growth led to the decrease in the rate of water loss.

Irish potatoes and linseed - the water loss trends for Irish potatoes and linseed were similar to that for field beans. Maximum water loss rate of 4.7 mm/day was obtained for Irish potatoes after the maximum ground cover of the canopy had developed in late December. As the crop matured (shown by leaf yellowing and fall), the water loss rate decreased. The maximum rate for linseed was 5.6 mm/day. Increase in water use rate for linseed after 15th January was due to rain rewetting the soil in late January to February. The rain thus interrupted the water use trend for linseed.

Wheat - initial water loss for wheat was high probably due to the close spacing of this crop combined with its quick growth rate, thereby developing a complete cover on the soil at a fast rate. By 10/11/78 the wheat crop had germinated and by 20/11/78 it had more or less covered the ground. The highest rate of water loss of 4.7 mm/day was obtained when anthesis was taking place (22/12/78).

Soyabeans - water loss for soyabeans was initially high due to a low germination rate and slow rate of canopy development. The wet soil surface thus lost most of the moisture by direct evaporation. The high water loss rate then decreased, followed by an incfease to 6.2 mm/day, which was the maximum.

Sunflower, maize and sweet potatoes - the initial water loss rates for maize and sweet potatoes were high compared to that of sunflower. This was probably due to the fast rate of development of the maize and sweet potatoes compared to that of the sunflower. There was an increase during the 18/12/78 - 8/1/79 period followed by a general decrease till after 19/2/79; when the maximum rate of water loss for sunflower, maize and sweet potatoes were 8.2, 8.4, and 7.9 mm/day respectively. These rates were quite close and were obtained later in the growing season when the crops had reached full maturity.

During the long rains (table 4:9), the water loss rate for all the crops was initially very high, compared with those in corresponding stages during the short rains; about 8.0 mm/day. This later fluctuated but the fluctuations became less pronounced after 25th June, after which there was a general decrease. Maximum rates of water loss for the crops cannot be easily identified due to the great initial losses during the months of April, May and early June. Relatively low water losses are observed during the later part of the growing season for all the crops.

The above observations can be explained as follows: Evapotranspiration (or water use in this case) can be limited either by the supply of water to be evaporated or by the supply of energy for vaporization; the latter is determined mainly by climatic factors such as net radiation, temperature, humidity and wind velocity. When the supply of water is plentiful, the net radiation determines water use. Thus frequent wetting of the soil by rain can lead to high rates of water loss, even if there is no through drainage, because evaporation of water from the soil surface is added to the transpiration of the crop. This could have accounted for the high water loss rates obtained at the beginning of the rains and after rainy periods.

The drier the soil, the lower is the rate at which the roots can supply water to the foliage.

The wilting point coefficient, defined as the soil wetness below which soil water extraction by a given plant is insufficient to balance the transpiration rate demanded by the atmosphere, can be a measure of soil dryness. During the short rains, field beans and wheat dried out the soil below wilting point to 90 cm by 8/1/79 and the soil remained below this till harvest. Linseed dried out the soil below wilting point to 50 cm by 15/1/79 but the profile regained moisture after the rains. Maize, soyabeans, sunflower and sweet potatoes had dried out the soil to below wilting point to 50 cm, 90 cm, 90 cm and 30 cm respectively by 15/1/79 and the soil remained below this till 29/1/79.

During the long rains, maize dried out the soil to below wilting point to 150 cm by 6/8/79 whereas under sweet potatoes the soil reached wilting point to 180 cm by 20/8/79. The soil remained below the wilting point till harvest. This and the fact that the crops had started maturing could account for the low water loss rates obtained during the later stages of the growing season.

4:7:2: SEASONAL TOTAL CROP WATER USE

Tables 4:6 and 4:7 also show the total seasonal water use by the different crops during the short and long rains. During the short rains, field beans, wheat and Irish potatoes had a more or less similar length of growing period over which the water use calculations were done. During this period of eighty three days, Irish potatoes used the least amount of water (266.1 mm) followed by field beans (299.5mm) and wheat (324.8mm) respectively.

To be able to compare the seasonal water use of the remaining five crops, linseed, soyabeans, sunflower, maize and sweet potatoes, the water use was calculated for a period of 118 days. Within this period, linseed had used 400.1 mm, soyabeans 446.6 mm, sunflower 456.6 mm, maize 459.7 mm and sweet potatoes 477.6 mm. During this period of 118 days, therefore, linseed had used the least amount of water followed by soyabeans, sunflower, maize and sweet potatoes respectively.

During the long rains, field beans and Irish potatoes water use calculations done upto 16/7/79 show that Irish potatoes used the least amount of water during the period of 98 days (434.4 mm, cf 478.9mm for field beans). Over the period of 161 days, maize had used 619.2 mm and sweet potatoes 641.4 mm. Comparatively, the long growing season crops used more than the short growing season crops both in the short and long rains.

The high values obtained for field beans and Irish potatoes in the long rains compared with the short rains could have resulted from the more frequent rains experienced during April and May which kept the soil surface wet, thereby increasing the amount of water available and also the rate of evaporation which is added to the water use of the crop. Because the consumption of water by the field beans and Irish potatoes was not very different in April and May from that of maize and sweet potatoes, the high values as discussed above could also have resulted from the high initial soil moisture content in the 180 cm profile (819.2 mm) at planting during long rains compared to the 712.5 mm at planting during the short rains. The former value is nearer to that of field capacity (826.8 mm) than the latter (with reference to table 4:2). Thus more water was available at planting time during the long rains than during the short rains.

The high total value obtained for maize in the long rains as compared with the short rains is due to the longer growing season since the crop was left to dry in the field as compared to the short rain crop which was harvested at soft dough stage. The values for sweet potatoes in the short and long rains are similar. This could be due to the fact that the length of the growing season was the same, a period of 161 days. Also, there was an overlap in the seasons as the short rains sweet potatoes crop was harvested in April after the long rains had started; therefore the sweet potatoes had an extra amount of water for use which in the real sense came from the long rainy season.

Differences in water use by the crop is a result of differences in depth of rooting, length of the growing season, morphology of the crop canopy and probably the degree of stomatal control over transpiration.

4:8: RELATIVE EVAPOTRANSPIRATION (E_t/E_o) AND CROP GROWTH

Evaporation from an open free water surface (E_o) calculated according to Penman's estimate and as measured by the Pan A, and the relative evapotranspiration (E_t/E_o) are shown in table 4:10 for the short rains and table 4:11 for the long rains. Tables 4:8 and 4:9 show the average daily rainfall, average daily E_o (Pan A and Penman estimate), average daily water consumption for each crop and for all the crops during the short and long rains respectively.

TABLE 4:10. CALCULATED PAN A AND PENMAN OPEN WATER EVAPORATION (E_o) AND RELATIVE EVAPOTRANSPIRATION (Et/E_o) FOR THE CROPS DURING THE SHORT RAINS, 1978/79

Period	Days	E_o Pan A	E_o Penman	Relative Evapotranspiration (Et/E_o): Et/E_o Pan A FB	IP	W	LS	SB	SF	M	SP	Average for all crops	Et/E_o Penman FB	IP	W	LS	SB	SF	M	SP	Average for all crops
7/11 - 27/11	20	76.2	91.6	0.69	0.58	1.15	0.59	1.03	0.28	0.86	0.81	0.75	0.57	0.48	0.96	0.49	0.86	0.23	0.72	0.68	0.62
27/11 - 18/12	21	68.2	94.3	1.33	1.02	1.15	1.12	0.31	1.35	0.68	0.91	0.98	0.96	0.73	0.83	0.81	0.22	0.98	0.49	0.66	0.71
18/12 - 8/ 1	21	83.0	99.2	1.53	1.18	1.19	1.41	1.57	1.48	1.28	1.29	1.37	1.28	0.99	1.00	1.18	1.32	1.24	1.07	1.08	1.15
8/ 1 - 15/ 1	7	25.1	31.9	1.06	1.20	1.06	0.76	0.70	1.24	1.37	1.01	1.05	0.84	0.95	0.83	0.60	0.53	0.98	1.08	0.77	0.62
15/ 1 - 29/1	14	48.0	64.3	0.05	0.51	0.69	0.82		1.36	1.06		0.78	0.04	0.38	0.51	0.63		1.02	0.79		0.59
29/1 - 19/ 2	21	80.2	102.2					1.35	0.91	0.90	0.83	0.96					1.06	0.71	0.71	0.65	0.75
19/ 2 - 5/ 3	14	64.3	77.7				0.57	0.89	0.83	1.30	1.65	1.05				0.47	0.74	0.69	1.08	1.36	0.87
5/ 3 - 12/ 3	7	37.4	44.9					0.86	1.53	1.57	1.49	1.36					0.72	1.28	1.31	1.24	1.14
12/ 3 - 17/ 4	36	158.6	177.1								0.61	0.61								0.54	0.54

Key: FB - Field beans; IP - Irish potatoes; W - Wheat; LS - Linseed; SB - Soya beans; M - Maize; SP - Sweet potatoes; SF - Sunflower.

TABLE 4:11 CALCULATED PAN A AND PENMAN OPEN WATER EVAPORATION (E_o), AND RELATIVE EVAPOTRANSPIRATION (Et/E_o) FOR THE CROPS DURING THE LONG RAINS, 1979

Period	Days	E_o		Relative evapotranspiration (Et/E_o)									
				Et/E_o Pan A					Et/E_o Penman				
		Pan A	Penman	FB	IP	M	SP	Average for all crops	FB	IP	M	SP	Average for all crops
9/4 - 23/4	14	52.6	65.7	2.25	2.15	2.23	2.30	2.23	1.80	1.72	1.79	1.84	1.79
23/4 - 30/4	7	27.1	33.3	1.52	0.46	0.93	0.46	0.84	1.24	0.37	0.76	0.38	0.69
30/4 - 7/5	7	23.0	31.7	2.06	3.07	2.52	2.38	2.51	1.49	2.23	1.83	1.73	1.82
7/5 - 14/5	7	29.7	31.9	1.48	0.96	1.72	1.84	1.50	1.38	0.89	1.61	1.71	1.40
14/5 - 21/5	7	24.0	30.5	1.88	0.97	1.38	1.48	1.43	1.48	0.76	1.08	1.16	1.12
21/5 - 28/5	7	15.9	21.0	0.90	1.35	1.08)	2.41	1.44	0.68	1.02	0.81)	1.82	1.08
28/5 - 4/6	7	16.5	22.0	3.15	2.65	3.04)		2.81	2.36	1.99	2.28)		2.11
4/6 - 18/6	14	41.8	59.4	1.51	1.06	1.35	1.12	1.26	1.06	0.75	0.95	0.79	0.89
18/6 - 25/6	7	16.9	24.8	2.20	2.14	2.34	3.09	2.44	1.50	1.46	1.60	2.11	1.67
25/6 - 9/7	14	26.0	39.1	0.58	1.24	0.82	1.10	0.94	0.39	0.83	0.54	0.73	0.62
9/7 - 16/7	7	17.9	20.5	0.06	0.46	0.66	0.41	0.40	0.05	0.40	0.58	0.36	0.35
16/7 - 23/7	7	18.5	28.0		0.58	1.83	0.81	1.07		0.38	1.21	0.53	0.71
23/7 - 30/7	7	17.7	24.0		0.97)	0.83	1.09	0.96		0.72)	0.60	0.80	0.71
30/7 - 6/8	7	19.0	26.5		0.80)		0.51	0.71		0.57)		0.36	0.51
6/8 - 20/8	14	28.2	43.2			1.45	1.18	1.32			0.95	0.77	0.86
20/8 - 27/8	7	26.2	33.6			0.17	0.77	0.47			0.13	0.60	0.37
27/8 - 10/9	14	49.8	67.0			0.30	0.35	0.33			0.22	0.26	0.24
10/9 - 17/9	7	27.4	36.5			0.49	1.29	0.89			0.36	0.97	0.67

Key: FB - Field beans; IP - Irish potatoes; M - Maize; SP - Sweet potatoes;

The Pan A open free water evaporation values are lower than those from the Penman estimate. This led to the E_t/E_o values calculated using Pan A data being higher than those calculated from the Penman estimate. Both E_o calculated and E_o Pan A remain reasonably constant throughout the growing seasons but tend to rise towards the end of the seasons as rainfall and cloud cover get less.

Figures 4:14 and 4:15 show the general relationship between daily water use, E_t/E_o and rainfall (average for all crops) during the short and long rains respectively. From the figures, it is observed that E_t/E_o ratio is obviously due to the fact that while consumption varies widely, the E_o Penman and the E_o Pan A both remain fairly constant. The water consumption curves are not as expected and may be due to the rainfall distribution during the seasons as the experiment was carried out under natural rainfall conditions, where at times water became limiting. Because of the close relationship between E_t/E_o ratio and water consumption, comments on the way this ratio goes up and down to a considerable extent resemble comments given earlier on the reasons for consumption having gone up and down.

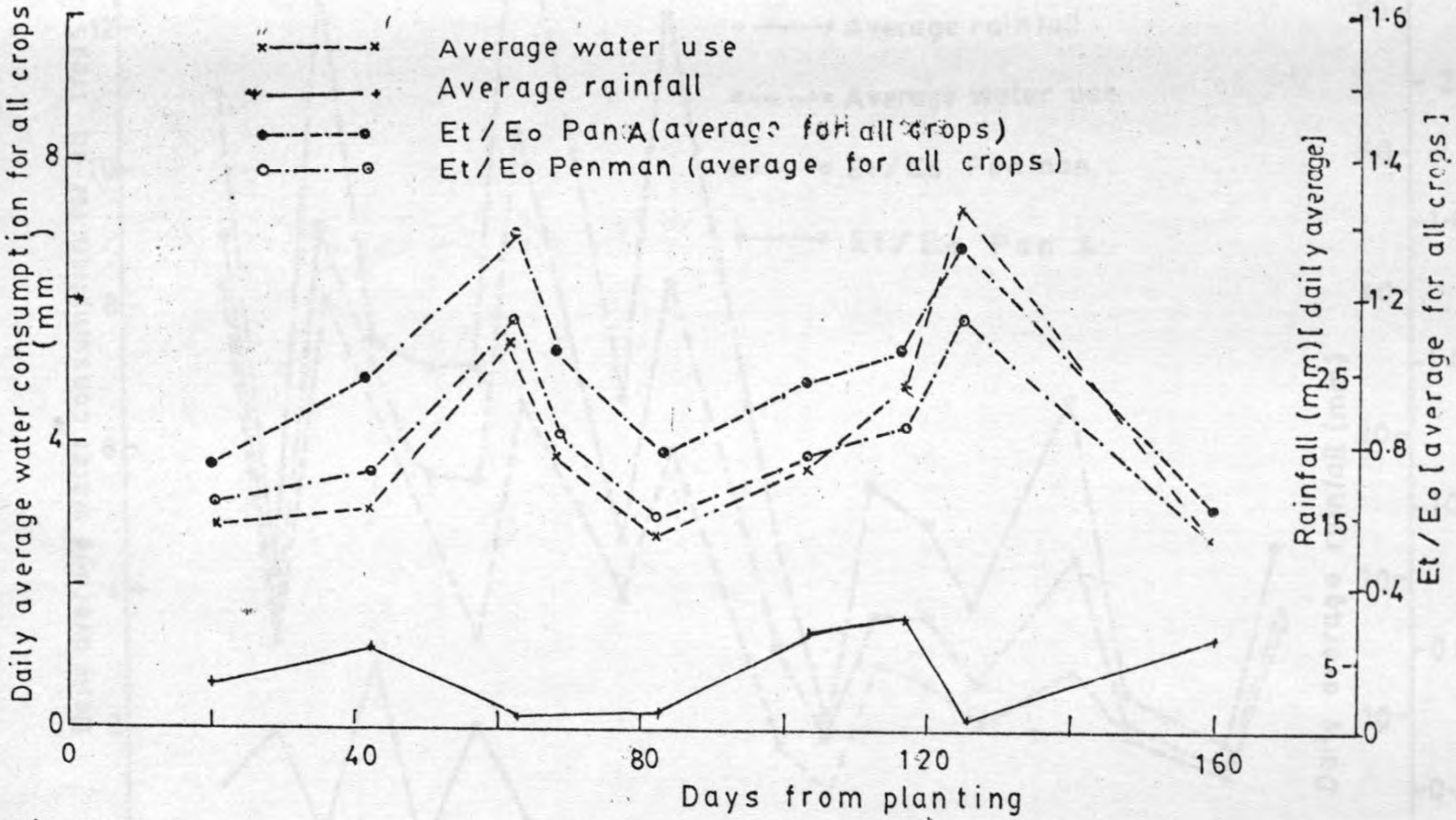


Fig. 4:14

Relationship between (periodic average for all crops) daily water use, Et / Eo Pan A, Et / Eo Penman and rainfall during the short rains 1978 / 79

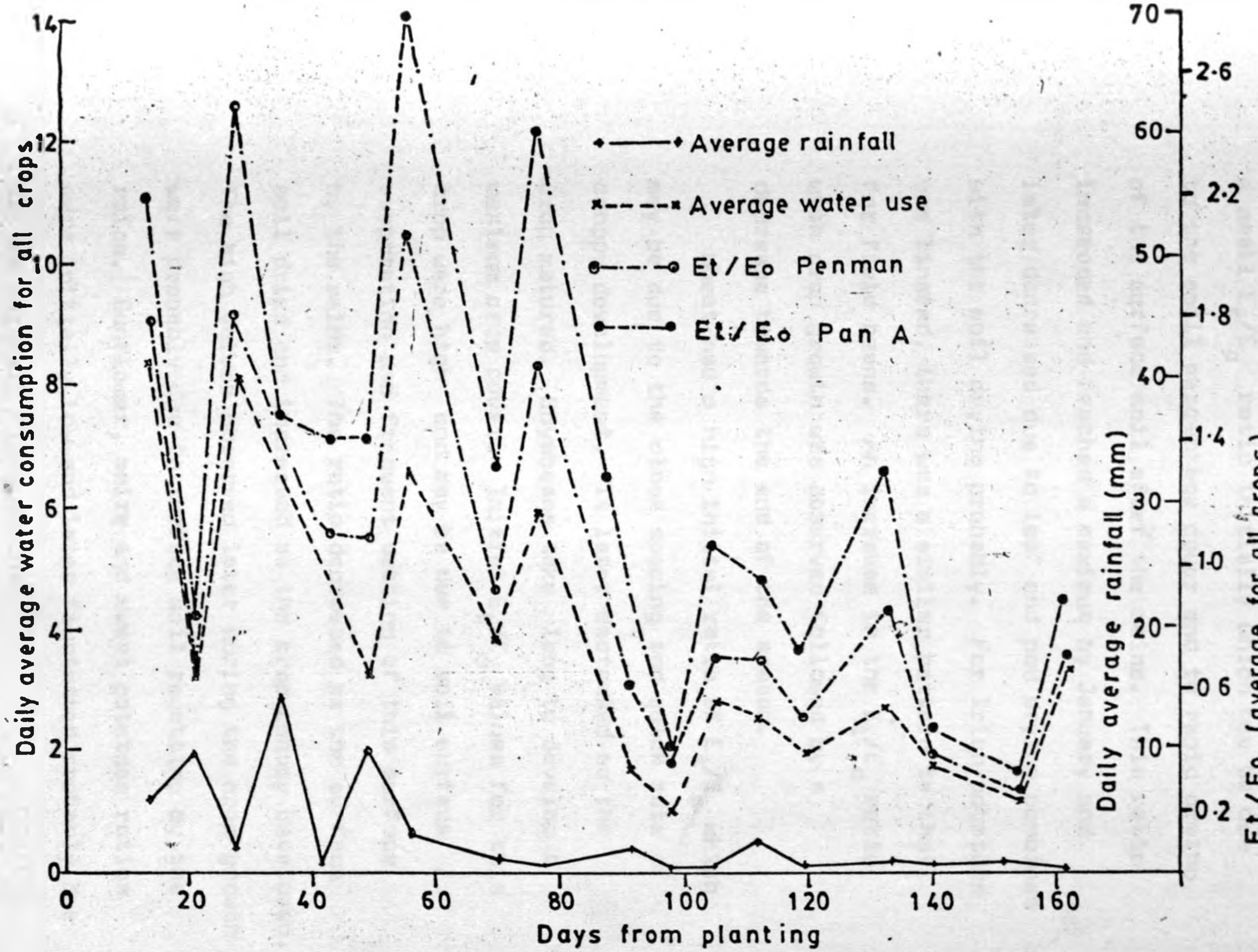


Fig. 4:15
Relationship between (periodic average for all crops) daily water use. Et / Eo Pan A.

During the short rains, field beans had a small E_t/E_o ratio initially which may be due to the small percentage cover and to rapid drying of the surface soil after the rains. This ratio increased and reached a maximum by January and later decreased due to leaf and pod drying combined with the soil drying probably. For Irish potatoes and linseed, there was a similar pattern to that for field beans. An increase in the E_t/E_o ratio with crop growth was observed followed by a decrease towards the end of the season.

Wheat had a high initial ratio of E_t/E_o which may be due to the close spacing and quick rate of canopy development. It later decreased as the crop matured. Soyabeans take long to develop a maximum crop cover. Initial E_t/E_o values for this crop were high and may be due to soil surface evaporation and frequent wetting of this surface by the rains. The ratio decreased as the surface soil dried and increased as the crop canopy developed. The high values observed later during the crop growth were probably due to surface soil rewetting by the rains. Sunflower, maize and sweet potatoes ratios were initially low and later fluctuated probably due to the rainfall fluctuations.

During the long rains, very high values of E_t/E_o were obtained for all crops on 9/4 - 23/4, 30/4 - 7/5, 28/5 - 4/6 and 18/6 - 25/6. The cause for the high values is rather difficult to explain. Probably it is due to the large losses of surface moisture by evaporation during 9/4 - 23/4 and 30/4 - 7/5 periods. It could be due to the deep drainage that took place after 30/4 as the soil profile had passed field capacity by 30/4. The deep drainage and surface evaporation probably accounted for the greater water loss between 28/5 - 4/6. The greater water loss between 18/6 - 25/6 could be attributed by the evaporation and the fact that the rooting systems of the crops were rapidly developing during this time.

Values of E_t/E_o at any stage for any of the crops depended on the degree of crop cover, nature of the crop and frequency of wetting of the soil. The pattern of E_t/E_o ratios for the crops during the seasons were variable and could be accounted for by the complex interaction of the soil factors (mainly moisture availability), plant factors such as age and morphology, and meteorological factors such as air temperature, rainfall, humidity and wind velocity which determine the evaporative demand of the atmosphere.

4:9: WATER USE EFFICIENCIES AND YIELDS

Water use efficiency, defined as the crop yield (marketable) in kg/ha/mm of water used was calculated for the different crops in each season. Table 4:12 shows the water use efficiency data.

In both seasons, Irish potatoes were more efficient than the rest of the crops. Water use efficiencies of 36.42 kg/ha/mm and 20.50 kg/ha/mm of water used for Irish potatoes were realised in the short and long rains respectively. The next most efficient crop was maize, followed by sweet potatoes, field beans, wheat, sunflower, soyabeans and linseed respectively. Water use efficiency in the long rains was lower than in the short rains for maize, sweet potatoes and Irish potatoes. Water use efficiency for field beans was higher during the long rains than during the short rains.

Water use efficiency is dependent on total yields and thus factors affecting the latter will affect the former. Total yields are generally affected by nutrient availability, moisture availability, pests and diseases and the management of the crop. During the experiment, nutrient

TABLE 4:12. TOTAL CROP WATER USE, MEAN MARKETABLE YIELD AT HARVEST, AND WATER USE EFFICIENCY (WUE) FOR THE CROPS DURING THE SHORT (SR) AND LONG RAINS (LR)

Crop	SR			LR		
	Total water use (mm)	Yield (kg/ha)	WUE (kg/ha/mm)	Total water use (mm)	Yield (kg/ha)	WUE (kg/ha/mm)
FB	299.5	725.9 ± 54.1	2.42	478.9	1340.6 ± 36.0	2.80
IP	266.1	9692.3 ± 1064.2	36.42	477.5	9789.8 ± 478.6	20.50
M	518.4	4927.7 ± 228.9	9.50	619.2	4472.8 ± 118.0	7.22
SP	629.3	4362.5 ± 394.1	6.93	641.4	3291.4 ± 249.4	5.13
LS	400.1	91.9 ± 18.7	0.23			
W	324.8	683.6 ± 97.4	2.10			
SB	478.8	491.3 ± 51.5	1.03			
SF	516.6	638.8 ± 91.7	1.24			

Key: FB - Field beans; IP - Irish potatoes; M - Maize; SP - Sweet potatoes; LS - Linseed; W - Wheat; SB - Soya beans; SF - Sunflower.

NB. (a) FB yield at 12% moisture; (b) M yield at 13% moisture; (c) W yield at field dryness; (d) LS yield at field dryness; (e) SB yield at 12% moisture; (f) SF yield at 14.0% moisture.

availability was thought not to be seriously limiting, as fertilizers were applied (section 3:3). The management of the crops both in the short and long rains was the same. Thus any differences in total yields which is reflected in the water use efficiency, could be due to either moisture availability; other climatic parameters such as sunshine hours and air temperature; or to pests and diseases.

Water used in the long rains was higher than in the short rains for the four crops (Field beans, Irish potatoes, maize and sweet potatoes). This was partly due to the differences in the initial moisture at planting time and the frequency of wetting of the soil surface during the short and long rains respectively. During the short rains the crops were planted in plots which had had one of the eight crops previously. Residual soil moisture and the rainfall received was thus lower than that observed during the long rains; where the land had been opened from grass.

Greater yields were obtained for field beans during the long rains, but because of the higher water use, water use efficiency values for the short and long rains were similar (2.42 and 2.80 kg/ha/mm respectively). Despite the higher water use in the long rains, Irish potato yields were more or less similar to those of the short rains. This could have been due to the blight which affected the crop and although spraying was done, the rains frequently washed this away and it was not as effective as during the short rains.

The differences in maize yields and sweet potatoes during the two seasons is due to insufficient soil moisture during the long rains for a longer period compared to the short rains. Grain filling of maize occurred in the month of August when the soil had reached below wilting point. During mid August, sweet potato tubers were forming and it was around the same time that the soil reached below wilting point. Moisture limitation during these critical periods appears to have resulted in the lower yields than those realised in the short rains.

The amount of water left in the 180 cm profiles under different crops at harvest during the short and long rains is shown in table 4:13 (with reference to tables 4:4 and 4:5).

TABLE 4:13: TOTAL AMOUNT OF WATER LEFT IN THE 180CM PROFILES UNDER THE DIFFERENT CROPS AT HARVEST DURING THE SHORT AND LONG RAINS

Crop	Amount of water in 180cm profile (mm)	
	Short rains	Long rains
Field beans	637.8 (29/1/79)	718.0 (16/7/79)
Irish potatoes	671.2 (29/1/79)	693.7 (6/8/79)
Maize	717.0 (12/3/79)	607.8 (17/9/79)
Sweet potatoes	782.1 (17/4/79)	600.1 (17/9/79)
Wheat	612.5 (29/1/79)	
Linseed	776.7 (19/2/79)	
Soyabeans	730.2 (12/3/79)	
Sunflower	717.6 (12/3/79)	

The first crops to be harvested were field beans, Irish potatoes and wheat followed by linseed, soyabeans sunflower, maize and sweet potatoes during the short rains. During the long rains field beans were harvested first followed by Irish potatoes, maize and sweet potatoes respectively. Moisture monitoring under field beans, Irish potatoes and wheat stopped at the same time. Also, under soyabeans, sunflower and maize, soil moisture monitoring stopped at the same time.

It was observed that wheat extracted moisture from the soil most, followed by field beans and Irish potatoes respectively, for the short growing season crops during the short rains. Maize extracted moisture from the soil most, followed by sunflower and soyabeans respectively, for the remaining crops during the same season. The amount of water left in the profile after 29/1/79 was higher than in the earlier crop profiles (field beans, Irish potatoes and wheat) due to moisture rewetting the profiles during February, March and April. During the long rains, because of the dry spell observed after July, the longer the crop stayed in the ground the less the amount of moisture left in the profile at harvest. Comparing maize and sweet potatoes, however, sweet potatoes dried the soil more than maize.

The amount of water left in the 180 cm profile under different crops at harvest was dependent on the length of the growing season of the crop, frequency of rainfall and amount prior to harvesting,in addition to the type of crop.

CHAPTER V

5. CONCLUSIONS

From the study, the following conclusions may be made:

(1) the fact that the pores of the soil are progressive in size and are well distributed throughout the soil profile (180 cm - Kabete soil profile) is shown by the mean saturated hydraulic conductivity values and P^F curves. The mean saturated hydraulic conductivity values for the depths are more or less similar throughout the 180 cm profile, with a standard error of 0.079 cm/hr, and there is a gradual decrease in moisture content with increase in suction and at suctions above P^F 2.0 the percentage moisture content retained progressively decreases in an almost constant rate.

(2) the available moisture for the Kabete soil in a profile of 180 cm is about 161.5 millimetres which is in close agreement with what Pereira

(1957) found for similar soils (Kikuyu red clay loams).

(3) the calibration of the moisture probe showed that this method may not be very accurate for predicting volumetric moisture content in the Kabete soil, due to lack of precision at the higher moisture range (above 37%) and at greater soil depths (90 + cm depth) due to the high clay content. However, it was shown that volumetric moisture content and probe count ratio are linearly related (r = 0.8675 for 0 - 30 cm depth and r = 0.7432 for 30 - 180 cm depth).

(4) periodic and seasonal total water use by crops is found to be affected by the length of the crop's growing season, amount and frequency of the rainfall, soil water availability and crop development stage. The following table 5:1 shows the total seasonal water use for the different crops during the short and long rains.

TABLE 5:1: TOTAL SEASONAL WATER USE FOR THE DIFFERENT CROPS DURING THE SHORT AND LONG RAINS

Crop	Total seasonal water use (mm)	
	short rains	long rains
Field beans	299.5 (83 days)	478.9 (98 days)
Irish potatoes	266.1 (83 days)	477.5 (119 days)
Maize	518.4 (125 days)	619.2 (161 days)
Sweet potatoes	629.3 (161 days)	641.4 (161 days)
Wheat	324.8 (83 days)	
Linseed	400.1 (118 days)	
Soyabeans	478.8 (125 days)	
Sunflower	516.6 (125 days)	

Irish potatoes used the least amount of water. These were followed by field beans, wheat, linseed, soyabeans, sunflower, maize and sweet potatoes; both in the short and long rains respectively.

(5) Irish potatoes and field beans have a short effective rooting depth range of 50 - 70 cm, followed by linseed which has 90 - 120 cm range of effective rooting depth. Wheat, maize, sweet potatoes, soyabeans and sunflower have an effective rooting depth range of 150 - 180 cm. Thus the crops utilize their water from varying soil depths under the same environment.

(6) the crop coefficients (E_t/E_o Penman) are consistently lower than the pan coefficients (E_t/E_o Pan A) because of the E_o (Penman and Pan A) values being fairly constant throughout the seasons and the Penman values being higher than the Pan A values. The E_t/E_o ratios are closely related to the water consumption values, and in addition to being influenced by the crop's development and phenology, these coefficients are also influenced by the frequency of wetting, as found by Kowal and Andrews (1973) and Wangati (1972).

(7) Water use efficiency is dependent on total yields and is thus affected by nutrient

availability, moisture availability, pests and diseases and general crop management. On the assumption that nutrient availability and crop management were adequate and constant during the experiment, the water use efficiencies of the different crops were affected mainly by moisture availability and pests and diseases. Bearing this in mind, it was found out that Irish potatoes were the most efficient crop. The next most efficient crop was maize followed by sweet potatoes, field beans, wheat, sunflower, soyabeans and linseed during the short and long rains respectively. Table 5:2 shows the water use efficiency values ralized by the different crops during the two seasons.

TABLE 5:2: WATER USE EFFICIENCIES FOR THE DIFFERENT CROPS DURING THE SHORT AND LONG RAINS

Crop	Water use efficiency (kg/ha/mm)	
	Short rains	Long rains
Field beans	2.42	2.80
Irish potatoes	36.42	20.50
Maize	9.50	7.22
Sweet potatoes	6.93	5.13
Wheat	2.10	
Linseed	0.23	
Soyabeans	1.03	
Sunflower	1.24	

REFERENCES

1. Acland, J. D. (1971). East African Crops. Longman, London.

2. Ahn, P. M. (1973). Analytical methods used in the Department of Soil Science: I. Laboratory practicals currently carried out by second year students. Technical Communication No. I; University of Nairobi, Faculty of Agriculture, Department of Soil Science.

3. Barrada, Y. (1972). Crop water requirements. Irrigation and drainage paper No. 13, FAO, Rome.

4. Bellis, E. and Boswinkle, E. (1953-1962). Fertilizer trials. Department of Agriculture. Ann. Report Part II; Kenya.

5. Birch, H. F. (1958). The effect of soil drying on humus composition and Nitrogen availability. Plant and Soil 10:9-31.

6. Birch, H. F., and Friend, M. T. (1956). The organic matter and Nitrogen status of East African soils. J. Soil Sci. 7:156-167.

7. Black, T. A., Thurtell, G. W. and Tanner, C. B. (1968). Hydraulic load-cell lysimeter, construction, calibration and tests. Soil Sci. Soc. Amer. Proc. 32:623-629.

8. Blaney, H. F. and Criddle, W. D. (1950). Transpiration from short grass. U.S. Soil Cons. Serv. Scs. Tp. 96.

9. Blore, T. W. D. (1966). Further studies of water use by irrigated and unirrigated arabica coffee in Kenya. J. Agric. Sci. 67:145-154.

10. Boswinkle, E. (1961). Residual effect of phosphorus fertilizer in Kenya. Empire. J. Exp. Agric. 29:136-142.

11. Brady, N. C. (1974). The nature and properties of soils. 8th Ed. MacMillan.

12. Carry, J. W. (1968). An instrument for *in situ* measurement of soil moisture flow and function. Soil Sci. Soc. Amer. Proc. 32:3-5.

13. Dagg, M. (1972). Water requirements of crops. *In* Morgan, W. T. W. (ed.). "East Africa: its peoples and resources". London, Oxford. UP. pp 119-125.

14. Dagg, M. (1970). A study of water use of Tea in East Africa using a hydraulic lysimeter. Agric. Met. 7:303-320.

15. Dagg, M. (1969). Factors affecting the use of evaporation pan data in East Africa. E. Afric. Agric. For. J. 35:205-210.

16. Dagg, M., Blackie, J. R., Wangati, F. J. and Ngugi, P. (1966). Crop water use. E. Afric. Agric. For. Res. J. Org. Annual Report 1966.

17. Dagg, M. (1965). A rational approach to the selection of crops for areas of marginal rainfall in East Africa. E. Afric. Agric. For. J. 30:296-300.

18. Dagg, M., Hosegood, P. H., Kinyali, S. M. and Mudianga, J. (1964/65). Calibration of neutron probe for soil moisture measurements. E. Afric. Agric. For. J. Org. Annual Report 1964/1965.

19. Dagg, M., Hosegood, P. H., Kinyali, S. M., and Mudianga, J. (1961/62). Irrigation and crop water use trials. E. Afric. Agric. For. J. Org. Annual Report 1961/1962.

20. Dastane, N. G. (1974). Effective rainfall and its significance. Irrigation and Drainage Paper No. 25, FAO, Rome.

/21. Doorenbos, J. and Pruitt, W. O. (1977). Guidelines for predicting crop water requirements. Irrigation and Drainage Paper No. 24, FAO, Rome (REVISED).

22. Doorenbos, J. and Pruitt, W. O. (1975). Guidelines for predicting crop water requirements. Irrigation and Drainage Paper No. 24, FAO, Rome.

23. FAO/UNESCO (1974). The soil map of the world.

24. Fitzpatrick, E. A. and Nix, H. A. (1969). A model for simulating soil water regime in alternate fallow-crop systems. Agric. Met. 6:303-319.

25. Gardener, W. R., Hillel, D. and Benyamini, Y. (1970). Post irrigation measurement of soil water. I: Redistribution. Water Resources Res. 6:1148-1153.

26. Gardener, W. R. (1970). Field measurement of soil water diffusivity. Soil Sci. Soc. Amer. Proc. 34:832-833.

27. Gardener, W. H. (1965). Water content. In "Methods of soil analysis" Part I. (Ed. Black, C. A.) Amer. Soc. of Agron. No. 9. Agronomy; Madison, Wisconsin, U.S.A. pp. 82-127.

28. Glover,J. and Forsgate, J. (1964). Transpiration from short grass Q. J. R. Met. Soc. 90:320-324.

29. Griffiths, J. F. (1972). Climate. In Morgan, W. T. (Ed.) "East Africa: its peoples and resources". London, Oxford, U.P. pp. 107-118.

30. Hanks, R. J. (1974). Model for predicting plant yields as influenced by water use. Agron. J. 66:660-664.

31. Hearn, A. B. (1969). Growth and performance in a desert environment. III: Crop performance. J. Agric. Sci. 73:87-97.

32. Hillel, D. (1972). Optimizing the soil physical environment toward greater crop yields. Academic press. New York and London.

33. Hillel, D. and Guron, Y. (1970). The use of radiation techniques in water use efficiency studies. Res. Rep. submitted to International Atomic Energy Agency. The Hebrews University of Jerusalem, Israel.

34. Hillel, D., Gairon, S., Falkenflug, V., and Rawitz, E. (1969). New design of a low cost hydraulic lysimeter for field measurements of evapotranspiration. Israel J. Agric. Res. 19:57-63.

35. Hills, A. G. (1947). Oil plants in East Africa. E. Afric. Agric. J. 12:140-152.

36. Holmes, J. W., Taylor, S. A. and Richards, S. J. (1967). Measurement of soil water. In "Irrigation of Agricultural lands". Agronomy 11. Amer. Soc. Agron. Madison, Wisc. pp 275-306.

37. Holmes, J. W. and Jenkinson, A. F. (1959). Techniques for using the neutron moisture meter. J. Agric. Eng. Res. 4: 100-109.

38. Holmes, J. W. (1956). Calibration of field use of the neutron scattering method of measuring soil water content. Aust. J. applied Sci. 7:45-58.

39. Jensen, M. E., (1968). Water consumption by agricultural plants. In "Water deficits and plant growth", Vol. 2. (Ed. Kozlowski, T. T.) pp. 1-22.

40. Kelly, O. J., Hunter, A. S., Haise, H. R. and Hobbs, C. H. (1946). A comparison of methods of measuring soil moisture under field conditions. J. Amer. Soc. of Agron. 38:(9) 759-784.

41. Kenworthy, J. M. (1964). Rainfall and water resources of East Africa. In "Geographers and the tropics": Liverpool essays. (Ed.

Steel, R. W. and Mansell, R. P.) London: Longmans. pp. 111-137.

42. Kowal, J. and Andrews, D. J. (1973). The pattern of water availability and water requirement for grain sorghum production at Samaru, Nigeria. Trop. Agric. 50: 89-100.

43. Kramer, P. J. (1949). Plant and soil water relationships. McGraw-Hill; New York, Toronto and London.

44. Laycock, D. H. (1964). An emperical correlation between weather and yearly tea yields in Malawi. Trop. Agric. Trin. 41: (4) 277-291.

45. McCulloch, J. S. G. (1965). Tables for the rapid computation for the Penman estimate of evaporation. E. Afric. Agric. For. J. 30:286-295.

46. Monteith, J. L. (1973). Principles of environmental physics. Edward Arnold, London.

47. Nyandat, N. N. (1976). Nitosols and ferralsols in Kenya. Morphological and chemical properties, use and management. Ministry of Agriculture, National Agricultural Laboratories. Kenya Soil Survey. Miscellaneous soil paper M9.

48. Nyandat, N. N. and Michieka, D. O. (1970). Soils of Kirima Kimwe Faculty of Agriculture Farm. Ministry of Agriculture, National Agricultural Laboratories. Soil Survey Unit.

49. Pelton, W. L. (1961). The use of lysimeter methods to measure evapotranspiration. Proc. Hydrol. Symp. 2:106-134.

50. Penman, H. L. (1962). Woburn Irrigation 1951-59 II. Results for grass. III. Results for rotation crops. J. Agric. Sci. 58:349-364.

51. Penman, H. L. (1948). Natural evaporation from open water, bare soil and grass. Proc. Royal Soc; London (A) 193:120-145.

52. Pereira, H. C., Hosegood, P. H. and Dagg, M. (1967). Effect of tied-ridges, terraces and grass leys on lateritic soil in Kenya. Exp. Agric. 3:89-98.

53. Pereira, H. C. and Hosegood, P. H. (1962). Comparative water use of softwood plantations and bamboo forest. J. Soil Sci. 13:299-313.

54. Pereira, H. C. (1957). Field measurements of water use for irrigation control in Kenya coffee. J. Agric. Sci. 49:459-466.

55. Pereira, H. C. and Jones, P. A. (1954). A tillage study in Kenya coffee. Empire. J. Exp. Agric. 22:231-240.

56. Pereira, H. C. and Hosegood, P. H. (1954/55). Water use by crops and leys in rotations. E. Afric. Agric. For. Res. J. Org. Annual Report 1954/55.

57. Pinto, F. F. and Hurd, E. (1970). Seventy years with wheat in Kenya. E. Afric. Agric. For. J. 36: Special issue (December).

58. Pruitt, W. O. and Angus, D. E. (1960). Large weighing lysimeter for measuring evapotranspiration. Tran. Amer. Soc. Agric. Eng. 3:3-15, 18.

59. Richards, L. A. and Weaver, L. R. (1943). Fifteen-atmosphere percentage as related to the permanent wilting percentage. Soil Sci. 56:331-339.

60. Rijtema, P. E. (1966). An analysis of actual evapotranspiration. Agricultural Research Report No. 659 (1965).

61. Robins, J. S. and Domingo, C. E. (1953). Some effects on Serere soil moisture deficits at specific growth stages in corn. Agron. J. 45:618-621.

62. Rose, C. W. and Stern, W. R. (1967a). Determination of withdrawal of water from soil by crop roots as a function of depth and time. Aust. J. Soil Res. 5:11-19.

63. Rose, C. W. and Stern, W. R. (1967b). The drainage component of the water balance equation. Aust. J. Soil Res. 3:95-100.

64. Rosenberg, N. J. (1974). Microclimate: The biological environment. John Wiley and Sons, New York. London. Sydney. Toronto.

65. Russell, E. W. (1973). Water and crop growth In "Soil conditions and plant growth". 10th Ed. Longmans. pp. 448-477.

66. Sarraf, S. (1972). Crop water requirements. Irrigation and drainage. Paper No. 13, FAO, Rome.

67. Salter, P. J. and Goode, J. E. (1967). Crop responses to water at different stages of growth. Research Review No. 2 (CAB)

68. Slatyer, R. O. (1966a). The use of soil water balance relationships in agroclimatology. pp. 73-86. UNESCO Symposium on "Methods in agroclimatology". University of Reading. Agroclimatological methods.

69. Slatyer, R. O. (1966b). The future trends in agroclimatology. pp. 367-369. UNESCO Symposium on "Methods in agroclimatology". University of Reading. Agroclimatological methods.

70. Smith, G. W. (1966). The relation between rainfall, soil water and the yield of copra on a coconut estate in Trinidad. J. appl. Ecol. 3:117-125.

71. Stanhill, G. (1973). Simplified agroclimatic procedures for assessing the effect of water supply. In "Plant response to climatic factors"(Ed. Slatyer, R. O.). UNESCO. Paris. pp. 461-476.

72. Tanner, C. B. (1968). Evaporation of water from plants and soil. In "Water deficits and plant growth." (Ed. Kozlowski, T. T.); Vol. I. Academic press, New York. pp. 73-105.

73. Thom, A. S. (1975). Momentum, Mass and Heat Exchange. In "Vegetation and the atmosphere". (Ed. Monteith, J. L.); Vol. I. pp. 57-109. Academic press, London, New York, San Francisco.

74. Thornthwaite, C. W. (1948). An approach toward a rational classification of climate. Geogr. Rev. 38:55-94.

75. U.S.D.A. Soil Taxonomy (1975). Soil Taxonomy.

76. Van Bavel, C. H. M., Stirk, G. B. and Brust, K. J. (1968a). Hydraulic properties of a clay loam soil and the field measurements of water uptake by roots. I. Interpretation of water content and pressure profiles. Soil Sci. Soc. Amer. Proc. 32:310-317.

77. Van Bavel, C. H. M., Brust, K. J. and Stirk, G. B. (1968b). Hydraulic properties of a clay loam soil and the field measurements of water uptake by roots. II. The water balance of the root zone. Soil Sci. Soc. Amer. Proc. 32:317-321.

78. Van Bavel, C. H. M. and Myers, L. E. (1962). An automatic weighing lysimeter. Agric. Eng. 43:580-583.

79. Van Bavel, C. H. M., Nielsen, D. R. and Davidson, J. M. (1961). Calibration and characteristics of two neutron moisture probes. Soil Sci. Soc. Amer. Proc. 25:329-334.

80. Veihmeyer, F. J. and Hendrickson, A. H. (1931). The moisture equivalent as a measure of the field capacity of soils. Soil Sci. 32:181-194.

81. Wallis, J. A. N. (1963). Water use by irrigated arabica coffee in Kenya. J. Agric. Sci. 60:381-388.

82. Wangati, F. J. (1972). Lysimeter study of water use of maize and beans in East Africa. E. Afric. Agric. For. J. 38: 141-156.

83. Watson, K. K. (1966). An instantaneous profile method for determining the hydraulic conductivity of unsaturated porous materials. Water Resources Res. 2:709-715.

APPENDIX 1:A: DAILY WEATHER SUMMARY FOR THE MONTH OF OCTOBER 1978

Date	Mean air temperature °C	Mean dew point °C	Wind run miles/day	Sunshine hours (n)	Radiation (Langleys)	Evaporation (Pan A) (mm)	Calculated Penman estimate of evaporation (mm)	Rain (mm)
1	17.8	12.6	24.9	2.2	383	2.2	4.3	1.2
2	15.6	13.5	13.6	0.9	235	1.0	2.4	0.0
3	18.4	12.4	32.1	4.8	453	3.5	4.7	0.0
4	18.2	11.6	29.3	10.0	575	3.0	5.1	0.0
5	17.7	11.7	30.6	10.1	642	6.5	5.8	0.0
6	18.5	11.9	32.4	8.9	648	4.5	6.2	0.5
7	19.2	13.2	35.1	8.4	611	5.5	6.0	0.0
8	16.1	12.2	33.3	6.0	450	4.0	4.1	0.0
9	18.5	12.9	37.1	7.9	527	4.5	5.0	0.0
10	18.7	11.3	37.1	9.5	578	5.0	5.4	0.0
11	18.6	12.0	40.4	7.9	572	5.0	5.6	0.0
12	18.0	13.0	41.4	4.9	438	3.3	4.5	0.3
13	18.0	13.2	47.8	4.1	408	3.0	4.3	4.5
14	17.4	13.0	51.4	7.9	456	4.5	4.1	0.0
15	18.1	9.4	37.6	9.1	675	5.0	6.5	0.0
16	19.3	11.6	36.9	8.0	654	5.0	6.7	0.0
17	18.5	12.7	33.5	9.0	560	6.0	5.2	0.0
18	18.9	12.3	28.5	10.6	649	5.0	5.9	0.0
19	18.0	10.1	25.5	7.4	629	4.5	6.2	0.0
20	19.9	12.9	29.4	5.8	505	5.2	5.3	9.2
21	17.9	14.2	38.5	2.4	325	1.8	3.5	36.8
22	18.0	12.5	20.8	7.2	496	3.8	4.6	0.2
23	18.7	12.3	23.8	8.2	569	4.0	5.4	0.0
24	18.9	12.4	45.3	9.0	626	4.5	6.1	TR
25	18.9	14.4	28.2	3.6	392	5.6	4.2	28.1
26	12.5	13.5	18.7	3.7	335	2.4	2.7	8.6
27	17.4	14.7	17.0	4.8	335	6.5	3.0	0.0
28	19.0	9.8	27.8	8.7	645	5.5	6.3	TR
29	18.4	12.5	29.4	6.2	566	3.8	5.7	2.3
30	18.8	15.2	21.8	0.0	155	1.2	2.0	15.7
31	17.7	12.3	30.4	7.7	496	3.5	4.6	0.0

(TR = Trace which is less than 0.05 mm)

APPENDIX 1:8: DAILY WEATHER SUMMARY FOR THE MONTH OF NOVEMBER 1978

Date	Mean air temperature °C	Mean dew point °C	Wind run miles/day	Sunshine hours (n)	Radiation (Langleys)	Evaporation (Pan A) (mm)	Calculated Penman estimate of evaporation (mm)	Rain (mm)
1	18.2	14.2	34.4	5.2	411	3.0	4.1	1.0
2	18.1	13.1	49.1	8.5	590	3.5	5.6	4.5
3	17.7	14.6	41.4	2.0	341	3.5	3.7	1.0
4	18.0	14.7	52.6	3.0	338	2.9	3.6	29.9
5	18.3	14.8	54.0	3.9	345	3.9	3.6	0.9
6	17.4	12.8	67.4	5.4	456	3.9	4.6	0.4
7	18.2	13.3	56.4	6.9	550	3.6	5.5	1.1
8	17.8	12.1	42.2	9.0	566	4.2	5.2	0.7
9	18.7	12.2	28.1	10.2	575	2.5	5.1	0.0
10	18.3	12.3	24.7	9.7	672	5.5	6.2	TR
11	18.6	13.2	25.9	10.2	608	4.5	5.4	0.0
12	19.1	13.1	21.4	8.7	681	5.0	6.6	0.0
13	19.7	13.0	38.5	7.4	524	6.0	5.3	0.0
14	19.6	12.8	52.4	9.1	572	4.3	5.6	8.8
15	17.6	15.0	31.3	7.1	398	3.0	3.4	15.0
16	18.0	13.5	41.6	9.1	620	4.5	5.7	0.0
17	18.7	13.8	35.2	8.4	572	3.7	5.4	5.2
18	16.9	14.6	29.1	3.9	335	3.0	3.1	0.0
19	17.4	15.0	49.6	6.4	395	3.5	3.5	2.5
20	17.4	13.6	58.9	6.9	374	2.7	3.3	4.7
21	17.3	14.9	45.9	4.1	316	1.8	3.0	6.3
22	17.4	13.2	43.2	8.8	521	4.5	4.6	TR
23	17.9	12.8	51.8	11.1	542	4.0	4.6	0.0
24	17.2	13.7	53.3	8.1	508	2.9	4.5	4.4
25	16.2	15.5	70.1	3.6	268	3.5	2.5	11.0
26	17.3	14.8	59.5	7.4	368	3.5	3.1	0.0
27	17.0	11.2	50.2	10.0	629	5.0	5.6	0.0
28	16.7	10.5	46.3	10.6	645	3.0	5.6	0.0
29	17.5	12.4	47.8	8.7	514	5.0	4.6	0.0
30	16.1	13.7	62.1	2.9	310	0.6	3.1	8.1

APPENDIX 1:C: DAILY WEATHER SUMMARY FOR THE MONTH OF DECEMBER 1978

Date	Mean air temperature °C	Mean dew point °C	Wind run miles/day	Sunshine hours (n)	Radiation (Langleys)	Evaporation (Pan A) (mm)	Calculated Penman estimate of evaporation (mm)	Rain (mm)
1	15.8	13.9	31.3	1.8	347	2.2	3.5	3.7
2	16.9	14.4	79.9	5.3	432	0.9	4.1	28.9
3	16.2	15.3	15.9	1.3	256	0.8	2.5	13.1
4	17.6	15.0	37.6	5.3	383	4.0	3.5	2.0
5	16.1	15.0	55.9	3.0	246	1.6	2.2	11.1
6	17.2	11.7	59.9	8.4	462	3.5	4.1	0.0
7	17.3	12.2	59.5	8.4	657	4.5	6.3	0.0
8	18.2	14.0	53.8	8.0	505	5.1	4.7	0.6
9	18.4	14.4	65.8	5.3	471	3.0	4.8	0.0
10	17.9	14.1	62.6	8.3	505	1.4	4.6	4.4
11	17.8	15.2	55.5	5.3	392	3.0	3.7	0.0
12	19.1	15.5	31.4	4.2	462	2.8	4.9	5.8
13	18.7	14.7	21.2	5.6	462	3.8	4.6	5.8
14	18.4	15.3	12.6	4.6	456	4.7	4.6	23.7
15	18.7	15.0	19.3	8.0	578	5.4	5.5	4.4
16	18.5	13.5	27.4	4.8	627	4.9	6.7	0.4
17	19.4	14.1	28.3	8.3	539	3.0	5.1	0.0
18	20.0	13.9	23.4	6.3	545	2.8	5.6	5.8
19	18.2	14.8	40.1	3.5	335	2.1	3.5	6.6
20	16.8	15.2	50.4	1.3	246	2.7	2.5	4.7
21	17.6	14.6	28.6	5.1	429	4.0	4.1	TR
22	18.1	14.6	27.9	10.2	605	4.0	5.3	0.0
23	17.9	13.4	38.1	10.1	602	5.0	5.3	0.0
24	17.9	13.5	27.0	7.7	598	5.5	5.7	0.0
25	18.9	14.5	30.0	7.2	505	3.0	4.9	0.0
26	18.8	14.7	41.4	6.6	475	2.0	4.6	0.0
27	18.1	14.1	34.5	7.6	444	3.5	4.0	0.0
28	18.6	12.9	42.8	9.5	548	4.0	5.0	0.0
29	19.5	14.0	39.4	8.9	475	5.0	4.3	0.0
30	18.2	13.5	44.1	10.6	663	4.5	6.0	0.0
31	19.4	11.7	41.4	11.7	605	4.5	5.4	0.0

APPENDIX 1:D: DAILY WEATHER SUMMARY FOR THE MONTH OF JANUARY 1979

Date	Mean air temperature °C	Mean dew point °C	Wind run miles/day	Sunshine hours (n)	Radiation (Langleys)	Evaporation (Pan A) (mm)	Calculated Penman estimate of evaporation (mm)	Rain (mm)
1	18.2	11.6	62.3	11.2	602	5.0	5.4	0.0
2	18.2	12.0	36.8	10.6	550	5.0	4.7	0.0
3	18.1	11.4	66.1	10.9	593	5.5	5.3	0.0
4	18.0	12.0	38.9	11.2	648	5.5	5.7	0.0
5	16.7	12.5	41.2	9.1	575	4.1	5.0	0.0
6	16.7	13.0	57.0	7.8	484	3.9	4.3	0.4
7	16.0	14.6	69.1	2.9	271	1.4	2.5	0.9
8	16.9	14.1	52.6	3.9	289	3.0	2.7	0.0
9	17.1	13.5	57.4	7.8	481	2.5	4.3	0.0
10	17.5	12.9	52.5	6.9	493	4.0	4.7	0.0
11	18.2	13.3	64.6	7.4	447	3.6	4.3	2.6
12	18.4	12.7	49.2	8.9	581	4.5	5.5	0.0
13	17.8	13.2	44.3	8.2	563	3.9	5.3	0.4
14	18.6	13.1	40.4	8.8	553	3.6	5.2	0.1
15	17.7	13.4	53.9	8.6	563	3.5	5.2	TR
16	18.3	15.2	54.9	6.1	456	3.5	4.4	1.0
17	16.2	14.1	75.6	7.0	438	3.5	3.8	0.0
18	16.2	13.8	94.6	6.0	380	2.7	3.4	3.2
19	17.6	13.9	57.3	5.6	432	3.0	4.2	0.5
20	19.2	14.9	57.9	7.4	481	3.9	4.7	0.9
21	17.7	15.3	73.0	4.7	353	1.7	3.4	0.2
22	18.8	14.5	62.6	8.2	502	3.8	4.8	0.3
23	18.6	13.5	47.4	8.6	517	3.6	4.8	2.1
24	18.3	13.4	48.7	8.1	557	3.6	5.3	0.05
25	18.2	14.2	49.1	6.1	496	4.0	4.9	3.0
26	18.1	13.6	62.3	8.9	536	4.2	4.9	1.7
27	18.8	14.5	50.3	7.0	548	4.0	5.5	0.5
28	19.9	13.7	30.6	2.4	417	3.0	4.9	9.0
29	18.5	16.0	13.2	0.8	316	2.0	3.6	9.5
30	19.7	14.4	14.5	4.8	414	5.3	4.3	20.3
31	19.1	15.1	18.2	2.4	329	1.6	3.6	4.6

APPENDIX 1:E: DAILY WEATHER SUMMARY FOR THE MONTH OF FEBRUARY 1979

Date	Mean air temperature °C	Mean dew point °C	Wind run miles/day	Sunshine hours (n)	Radiation (Langleys)	Evaporation (Pan A) (mm)	Calculated Penman estimate of evaporation (mm)	Rain (mm)
1	18.0	15.4	17.1	0.9	228	3.1	2.5	20.6
2	18.1	15.4	17.6	0.7	256	-	2.9	55.4
3	18.2	15.4	21.1	2.7	435	3.1	4.6	3.6
4	18.9	14.1	7.8	1.3	310	1.8	3.6	8.8
5	19.1	15.1	30.3	6.9	560	3.0	5.5	TR
6	18.5	14.6	32.1	9.2	623	5.0	5.8	0.0
7	19.0	15.1	37.8	9.9	596	4.6	5.5	0.6
8	19.3	15.2	40.8	9.7	645	4.5	6.1	0.0
9	18.9	13.6	26.9	8.6	620	4.2	5.9	2.7
10	20.1	12.8	21.2	7.8	602	5.2	6.1	9.7
11	19.3	13.5	29.6	10.4	636	5.5	5.9	0.0
12	18.9	15.5	28.6	6.7	493	3.4	4.7	0.9
13	17.3	14.3	39.4	8.2	511	4.0	4.5	0.0
14	17.9	14.0	31.9	10.1	593	5.0	5.2	TR
15	18.2	14.5	44.2	10.8	617	5.0	5.4	0.0
16	18.4	14.2	43.3	10.4	563	5.0	4.9	0.0
17	18.5	12.6	39.9	10.9	666	5.0	6.0	0.0
18	20.3	13.0	23.6	9.4	575	3.9	5.5	0.9
19	18.6	15.5	23.2	0.8	253	1.0	2.9	1.0
20	18.6	14.6	33.6	9.1	545	4.5	4.9	0.0
21	18.2	12.3	29.1	8.6	605	5.5	5.7	0.0
22	18.7	14.9	29.8	5.2	365	-	3.5	82.6
23	19.1	14.6	44.8	5.3	593	4.2	6.2	0.2
24	19.2	14.1	43.4	8.9	490	4.5	4.5	0.0
25	19.0	13.9	47.6	10.0	645	4.5	6.1	0.0
26	19.2	14.0	49.4	10.5	639	7.1	6.0	18.1
27	18.4	14.1	66.1	8.8	598	5.0	5.7	0.0
28	17.4	13.9	59.1	8.2	487	3.0	4.3	0.0

APPENDIX 1:F: DAILY WEATHER SUMMARY FOR THE MONTH OF MARCH 1979

	Mean air temperature °C	Mean dew point °C	Wind run miles/day	Sunshine hours (n)	Radiation (Langleys)	Evaporation (Pan A) (mm)	Calculated Penman estimate of evaporation (mm)	Rain (mm)
1	17.6	8.1	58.4	10.4	687	6.0	6.4	0.0
2	18.3	11.2	53.6	9.7	754	7.0	7.4	0.0
3	18.2	7.9	53.5	10.5	705	6.0	6.7	0.0
4	19.9	9.2	39.7	11.1	775	6.0	7.5	0.0
5	19.8	11.4	35.9	11.0	760	6.5	7.3	0.0
6	18.8	12.1	55.1	10.7	690	5.0	6.5	0.0
7	18.6	13.0	40.8	8.7	681	5.5	6.6	0.0
8	18.8	13.4	35.9	10.0	669	6.5	6.3	0.0
9	19.3	12.0	30.1	10.6	748	6.5	7.2	0.0
10	18.7	13.1	32.2	8.5	575	3.0	5.4	0.0
11	19.0	13.9	24.0	8.5	584	4.4	5.5	0.4
12	20.7	14.2	30.8	8.6	581	4.0	5.8	0.0
13	19.6	15.4	36.8	6.3	538	4.5	5.5	5.5
14	19.7	15.4	32.0	8.9	499	5.8	4.6	7.3
15	19.0	13.7	30.6	5.6	557	3.3	5.8	0.3
16	19.2	14.4	30.0	9.0	550	4.5	5.1	0.0
17	19.6	15.5	29.7	7.3	462	4.1	4.4	12.6
18	19.0	15.7	28.2	4.1	502	6.1	5.3	23.2
19	18.6	14.6	32.3	6.1	465	3.0	4.5	23.2
20	18.7	14.9	52.3	4.7	444	5.8	4.6	32.8
21	18.6	13.5	52.4	8.8	575	5.5	5.4	0.0
22	18.1	11.6	44.6	10.7	693	5.0	6.4	0.0
23	18.7	12.7	32.6	9.6	642	6.0	6.0	0.0
24	19.4	14.6	52.8	8.7	626	5.7	6.2	2.7
25	20.0	14.3	30.4	7.5	481	4.1	4.7	12.6
26	18.7	14.3	42.8	7.3	529	4.0	5.1	0.0
27	19.4	12.4	37.1	8.9	639	5.5	6.2	0.0
28	18.6	12.5	35.2	11.1	651	5.0	5.8	0.0
29	18.3	13.2	34.9	9.9	611	6.5	5.5	0.0
30	18.4	13.1	29.4	11.0	651	3.5	5.8	0.0
31	19.8	13.9	38.7	9.9	629	5.5	6.0	0.0

APPENDIX 1:G: DAILY WEATHER SUMMARY FOR THE MONTH OF APRIL 1979

Date	Mean air temperature °C	Mean dew point °C	Wind run miles/day	Sunshine hours (n)	Radiation (Langleys)	Evaporation (Pan A) (mm)	Calculated Penman estimate of evaporation (mm)	Rain (mm)
1	19.6	14.1	25.6	8.9	496	5.5	4.5	0.0
2	19.2	13.1	24.9	8.7	563	3.5	5.3	0.0
3	19.8	14.4	33.7	6.8	429	4.5	4.2	0.0
4	18.6	15.0	39.1	6.0	374	3.1	3.5	0.6
5	18.7	15.0	32.9	5.9	377	3.3	3.6	29.8
6	18.8	15.7	27.8	4.2	325	2.6	3.2	3.1
7	19.8	15.9	26.3	5.2	468	5.5	4.8	0.0
8	19.8	14.9	25.0	3.9	435	5.6	4.7	28.1
9	19.5	15.4	22.1	2.8	359	2.7	4.0	2.7
10	18.7	14.2	28.0	2.7	329	2.7	3.6	5.7
11	18.7	15.0	32.8	5.2	411	3.9	4.1	2.4
12	18.0	16.0	13.1	0.0	277	3.4	3.2	27.9
13	19.6	15.4	20.1	1.3	395	3.7	4.6	29.7
14	18.9	14.7	34.1	5.7	560	3.5	5.8	6.0
15	18.4	14.9	54.0	9.0	617	4.7	5.8	1.2
16	18.9	14.6	52.8	9.8	520	5.0	4.6	0.0
17	18.8	14.3	54.7	9.6	626	5.0	5.9	0.0
18	18.7	14.1	68.5	8.1	550	4.1	5.4	3.6
19	18.2	15.4	68.4	7.4	441	2.6	4.0	0.6
20	17.8	15.1	53.9	3.2	347	3.6	3.6	1.1
21	19.0	13.9	47.1	9.1	678	4.2	6.6	0.7
22	19.0	14.2	23.4	2.9	417	3.5	4.6	TR
23	19.8	14.2	31.8	7.8	587	5.7	5.9	21.7
24	18.4	15.4	33.6	8.3	553	3.9	5.1	6.4
25	18.2	14.6	37.4	7.1	541	5.2	5.2	14.8
26	18.3	16.1	60.9	5.6	456	3.2	4.5	8.2
27	18.4	15.4	61.8	1.6	383	2.4	4.4	2.4
28	18.4	14.7	60.8	3.2	429	1.8	4.7	7.8
29	17.7	14.9	57.8	4.4	371	4.9	3.7	5.4
30	17.7	14.5	31.9	4.8	408	3.5	4.0	0.0

APPENDIX 1:H: DAILY WEATHER SUMMARY FOR THE MONTH OF MAY 1979

Date	Mean air temperature °C	Mean dew point °C	Wind run miles/day	Sunshine hours (n)	Radiation (Langleys)	Evaporation (Pan A) (mm)	Calculated Penman estimate of evaporation (mm)	Rain (mm)
1	18.4	14.7	74.1	5.4	462	1.3	4.7	5.3
2	18.3	14.8	45.1	5.2	444	4.3	4.4	3.8
3	18.6	14.7	53.6	7.5	487	4.5	4.6	0.5
4	19.1	14.6	50.1	6.1	499	3.0	5.1	0.0
5	19.0	13.7	62.1	8.4	511	4.4	4.9	2.4
6	18.1	14.7	49.3	2.6	368	2.0	4.0	TR
7	19.5	15.0	44.7	5,9	493	5.6	5.1	15.1
8	18.2	15.6	40.6	1.7	313	2.2	3.4	14.2
9	18.8	15.5	38.9	2.4	325	3.8	3.6	12.3
10	18.5	14.8	55.2	3.3	426	6.0	4.7	38.5
11	18.5	14.1	21.9	4.5	426	3.5	4.4	0.0
12	19.1	13.2	37.0	7.8	579	5.4	5.7	11.9
13	18.9	14.6	26.8	7.2	514	3.2	5.0	8.2
14	18.3	14.7	32.3	2.9	386	2.9	4.1	0.9
15	18.0	14.5	37.3	4.9	344	3.6	3.3	0.1
16	18.2	13.1	53.1	7.6	487	3.0	4.6	0.0
17	17.8	13.1	43.5	8.9	511	4.0	4.5	0.0
18	17.5	12.9	40.5	9.7	596	4.5	5.3	0.0
19	18.0	13.2	43.9	5.6	477	3.5	4.8	0.0
20	17.2	13.1	26.6	5.4	411	2.5	3.9	0.5
21	17.4	14.7	24.5	2.3	268	1.1	2.7	2.1
22	17.4	13.3	70.5	4.4	438	3.2	4.6	8.7
23	17.4	15.7	64.1	0.9	213	1.3	2.3	7.8
24	17.1	14.1	55.9	4.1	401	2.2	4.0	2.7
25	16.3	12.6	72.9	5.1	392	4.4	3.8	3.9
26	16.0	15.3	42.4	0.2	177	2.4	1.8	32.4
27	16.2	15.5	10.2	0.1	180	1.3	1.8	14.8
28	17.6	14.9	62.7	1.7	274	2.6	3.0	0.6
29	17.5	14.2	65.2	5.6	383	3.3	3.6	0.3
30	17.5	14.0	37.3	3.9	322	3.5	3.2	0.0
31	17.8	13.2	39.6	4.0	374	1.5	3.9	0.5

APPENDIX 1:I: DAILY WEATHER SUMMARY FOR THE MONTH OF JUNE 1979

Date	Mean air temperature °C	Mean dew point °C	Wind run miles/day	Sunshine hours (n)	Radiation (Langleys)	Evaporation (Pan A) (mm)	Calculated Penman estimate of evaporation (mm)	Rain (mm)
1	16.2	14.2	63.7	1.6	301	2.7	3.2	14.7
2	15.0	13.9	18.8	0.0	128	0.4	1.3	1.9
3	16.2	13.5	51.5	1.1	349	2.5	3.8	0.0
4	16.4	13.5	46.6	1.1	310	2.0	3.4	1.0
5	16.4	13.3	32.9	2.5	344	3.0	3.5	0.0
6	16.8	12.5	26.2	6.9	544	3.5	5.1	4.0
7	17.0	12.8	65.4	7.4	579	3.5	5.5	0.0
8	17.3	13.5	72.6	3.8	389	4.0	4.1	4.5
9	18.0	13.3	27.1	6.1	511	2.5	5.0	2.5
10	17.5	13.6	21.9	4.5	441	3.0	4.4	0.0
11	18.8	13.9	37.4	4.9	395	3.0	4.0	0.0
12	19.5	14.1	37.9	8.1	566	3.5	5.6	0.0
13	17.4	12.8	50.3	7.6	502	5.0	4.6	0.0
14	17.4	13.0	21.6	6.6	468	2.3	4.3	0.3
15	16.0	12.5	14.9	2.4	213	2.0	2.1	TR
16	16.2	11.6	22.9	3.9	398	2.0	3.9	0.0
17	16.0	11.4	25.0	4.7	408	2.5	3.9	0.0
18	15.3	11.8	33.2	5.1	459	2.5	4.2	TR
19	15.5	11.8	37.0	1.9	325	3.0	3.4	0.0
20	15.9	11.8	28.7	2.8	307	3.0	3.1	0.0
21	16.3	11.9	23.2	2.6	380	2.0	4.0	0.0
22	15.9	13.0	32.8	2.2	319	1.9	3.3	0.4
23	17.0	12.9	26.8	5.5	423	2.0	4.0	1.0
24	14.7	12.2	21.4	0.0	259	2.5	2.8	0.5
25	15.2	12.2	14.0	2.2	316	2.0	3.1	TR
26	16.7	12.4	26.0	4.4	359	2.8	3.4	8.3
27	18.5	13.9	29.7	6.4	502	3.0	4.9	0.5
28	17.6	15.2	36.1	3.6	341	1.9	3.3	0.4
29	15.6	12.6	16.5	2.3	180	2.0	1.7	0.0
30	15.3	10.3	24.7	2.7	395	2.5	4.1	0.0

APPENDIX 1:J: DAILY WEATHER SUMMARY FOR THE MONTH OF JULY 1979

Date	Mean air temperature °C	Mean dew point °C	Wind run miles/day	Sunshine hours (n)	Radiation (Langleys)	Evaporation (Pan A) (mm)	Calculated Penman estimate of evaporation (mm)	Rain (mm)
1	15.0	11.3	25.6	1.0	283	1.5	3.1	0.0
2	15.9	12.7	40.3	6.8	435	2.4	3.8	1.9
3	13.9	12.7	33.4	0.0	110	2.0	1.1	1.5
4	14.4	12.3	32.0	0.0	177	0.1	1.9	0.6
5	16.2	12.1	23.1	3.4	338	2.5	3.3	TR
6	14.0	12.9	27.6	0.0	122	1.0	1.2	1.0
7	15.2	13.7	30.0	0.0	125	1.4	1.3	8.9
8	16.8	13.5	54.9	4.6	307	0.9	2.9	2.4
9	16.4	9.9	46.3	10.1	508	5.0	4.1	0.0
10	16.7	9.9	32.0	10.5	529	3.5	4.3	0.0
11	15.1	10.8	32.9	3.8	341	3.5	3.3	0.0
12	14.3	11.0	13.4	0.0	198	0.5	2.2	0.0
13	14.0	11.6	33.4	1.0	204	1.4	2.1	0.4
14	13.7	12.0	46.8	0.0	122	1.7	1.3	0.2
15	16.2	12.1	40.9	3.4	316	2.3	3.2	1.3
16	15.2	12.4	25.6	1.5	249	1.0	2.5	0.0
17	15.5	10.7	29.1	8.8	557	3.0	4.7	0.0
18	14.7	11.0	40.5	3.8	377	2.6	3.6	0.1
19	16.8	12.4	55.4	5.2	341	2.9	3.2	1.4
20	17.4	10.5	40.5	7.9	529	3.0	4.9	0.0
21	16.9	10.2	38.2	5.9	547	3.5	5.5	TR
22	15.8	10.3	50.6	6.1	392	2.5	3.6	0.0
23	17.4	11.0	27.5	4.7	429	3.0	4.4	0.0
24	15.8	11.2	29.5	4.0	468	4.0	4.7	0.0
25	16.4	13.7	52.8	6.4	395	2.2	3.4	13.7
26	14.6	12.4	23.5	0.0	134	1.0	1.5	TR
27	14.8	11.6	13.3	0.0	186	1.5	2.1	0.0
28	17.1	12.4	41.3	6.1	447	3.0	4.2	TR
29	16.6	12.3	38.7	3.9	374	3.0	3.7	0.0
30	15.6	10.0	24.3	4.8	435	3.0	4.2	0.0
31	15.1	10.2	32.1	6.3	471	3.0	4.2	0.0

APPENDIX 1:K: DAILY WEATHER SUMMARY FOR THE MONTH OF AUGUST 1979

Date	Mean air temperature °C	Mean dew point °C	Wind run miles/day	Sunshine hours (n)	Radiation (Langleys)	Evaporation (Pan A) (mm)	Calculated Penman estimate of evaporation (mm)	Rain (mm)
1	13.0	11.3	35.3	0.0	119	1.0	1.2	0.0
2	15.9	11.5	39.6	1.6	316	2.0	3.5	0.0
3	15.3	10.7	33.0	2.6	414	3.0	4.3	0.0
4	15.4	11.6	32.7	7.8	535	4.0	4.6	0.0
5	16.3	13.0	36.8	7.7	514	3.0	4.5	0.0
6	18.2	12.0	54.0	8.5	593	4.0	5.7	0.5
7	15.4	12.6	30.5	1.4	189	0.3	1.9	1.3
8	16.0	12.3	17.3	1.6	344	2.5	3.7	0.0
9	16.4	11.0	36.6	7.0	490	2.8	4.5	0.3
10	16.1	13.1	29.8	0.8	228	1.2	2.5	1.2
11	15.0	13.0	32.3	1.2	219	2.4	2.2	0.4
12	15.6	9.7	36.1	2.8	335	1.4	3.5	1.2
13	15.1	13.2	37.7	0.0	204	0.0	2.2	4.0
14	13.4	12.8	29.0	0.0	116	2.3	1.1	0.8
15	14.4	12.6	12.9	0.0	128	0.5	1.3	TR
16	16.9	13.0	44.3	4.0	356	2.8	3.5	0.8
17	16.1	13.1	25.0	0.4	234	1.5	2.6	0.5
18	17.5	12.5	51.3	4.6	429	4.5	4.4	0.0
19	16.6	12.4	58.6	3.4	386	2.0	4.1	0.5
20	17.3	11.5	54.4	7.5	493	3.5	4.6	0.0
21	17.9	10.2	50.7	8.9	590	4.0	5.6	0.0
22	17.8	8.2	46.8	9.1	669	6.5	6.5	0.0
23	16.4	11.1	36.5	7.3	532	2.5	4.9	0.0
24	15.4	11.6	37.3	5.9	474	3.5	4.3	0.0
25	15.1	11.1	26.7	4.6	420	2.0	3.9	0.0
26	16.1	11.1	46.7	4.7	380	4.2	3.8	0.0
27	16.3	10.6	62.1	1.9	353	2.5	4.1	1.2
28	17.9	10.2	51.7	6.9	535	4.0	5.4	0.0
29	18.0	10.4	38.1	8.6	520	3.0	4.8	0.0
30	17.1	9.7	48.4	9.1	569	5.5	5.2	0.0
31	17.1	12.9	49.6	4.3	414	2.0	4.2	0.0

APPENDIX 1:4: DAILY WEATHER SUMMARY FOR THE MONTH OF SEPTEMBER 1979

Date	Mean air temperature °C	Mean dew point °C	Wind run miles/day	Sunshine hours (n)	Radiation (Langleys)	Evaporation (Pan A) (mm)	Calculated Penman estimate of evaporation (mm)	Rain (mm)
1	18.2	12.4	86.9	6.9	584	3.4	6.1	1.9
2	17.4	12.5	84.6	3.6	365	3.3	4.0	0.3
3	18.0	10.7	94.7	7.9	566	4.5	5.6	0.0
4	17.7	8.7	148.2	8.6	581	5.0	6.4	0.0
5	16.1	11.3	60.2	1.6	234	3.0	2.7	0.0
6	17.7	10.2	48.5	9.4	587	3.5	5.4	0.0
7	16.7	12.1	86.1	9.4	596	5.0	5.4	0.0
8	18.4	12.0	85.4	2.6	316	3.6	3.9	7.6
9	17.0	12.2	59.2	4.2	356	1.5	3.6	TR
10	16.6	11.8	74.5	4.2	408	2.5	4.3	TR
11	15.8	11.7	58.6	2.4	356	3.3	3.8	0.3
12	17.2	11.3	57.7	4.8	441	3.1	4.6	0.6
13	17.8	11.4	50.3	6.7	508	3.5	5.0	0.0
14	18.2	10.0	50.7	7.5	599	5.5	6.1	0.0
15	17.9	7.6	64.8	10.6	689	4.5	6.5	0.0
16	17.0	9.4	66.8	10.8	684	5.0	6.2	0.0
17	18.7	10.9	46.8	7.8	629	4.5	6.4	0.5
18	19.2	11.0	51.1	8.6	629	5.0	6.3	0.0
19	18.3	11.5	54.3	4.4	432	5.0	4.8	0.0
20	17.4	10.1	67.3	6.8	611	3.5	6.3	0.0
21	16.7	9.5	71.6	7.2	605	5.5	6.1	0.0
22	19.2	9.4	73.8	8.5	578	5.5	6.0	0.0
23	18.2	8.9	69.5	9.9	672	5.5	6.6	0.0
24	17.3	10.0	51.0	8.1	614	5.0	5.9	0.0
25	18.5	9.7	55.9	6.5	569	2.4	6.0	0.0
26	17.1	11.4	33.4	3.1	368	4.2	4.0	1.4
27	17.6	11.6	63.8	5.2	523	3.5	5.5	1.2
28	18.9	12.6	69.2	3.9	451	3.8	5.2	0.0
29	18.6	12.5	70.7	4.4	401	5.5	4.5	1.8
30	16.5	7.6	63.3	11.0	693	5.0	6.2	0.0

APPENDIX 2: AMMOUNT OF RAINFALL (mm) RECEIVED BETWEEN SAMPLING DATES DURING THE SEASONS (SHORT AND LONG RAINS RESPECTIVELY)

(a) SHORT RAINS (SR)

PERIOD	7/11-27/11	27/11-18/12	18/12-8/1	8/1-15/1	15/1-29/1	29/1-19/2	19/2-5/3	5/3-12/3	12/3-17/4
DAYS	20	21	21	7	14	21	14	7	36
RAINFALL (mm)	60.1	120.7	18.4	3.1	22.5	138.6	100.9	0.4	234.2

(b) LONG RAINS (LR)

PERIOD	9/4-23/4	23/4-30/4	30/4-7/5	7/5-14/5	14/5-21/5	21/5-28/5	28/5-4/6	4/6-18/6	18/6-25/6
DAYS	14	7	7	7	7	7	7.	14	7
RAINFALL (mm)	81.6	66.7	12.0	100.2	1.5	72.4	18.0	12.3	1.9

PERIOD	25/6-9/7	9/7-16/7	16/7-23/7	23/7-30/7	30/7-6/8	6/8-20/8	20/8-27/8	27/8-10/9	10/9-17/9
DAYS	14	7	7	7	7	14	7	14	7
RAINFALL (mm)	25.5	1.9	1.5	13.7	0.0	11.5	1.2	9.8	0.9

APPENDIX 3:A: PERCENTAGE SOIL MOISTURE ON 7TH NOVEMBER 1978 UNDER FIVE RANDOMLY SELECTED SITES IN REP. 8 F14

REPLICATES Soil depth (cm)	1	2	3 % θD_w	4	5	$\bar{X}$	B.D.	% θV	(mm) moisture
0 - 10	36.20	39.44	40.10	37.22	36.81	37.95	1.01	38.33	38.3
10 - 20	37.95	36.24	40.54	37.35	38.37	38.09	1.02	38.85	38.9
20 - 30	38.95	37.93	40.44	37.77	36.62	38.34	1.09	41.79	41.8
30 - 50	35.97	29.72	37.50	37.35	34.85	35.08	1.08	37.89	75.8
50 - 70	36.77	31.32	29.93	34.14	29.29	32.29	1.14	36.81	73.6
70 - 90	31.62	33.90	31.05	31.66	29.36	31.52	1.12	35.30	70.6
90 - 120	32.96	40.27	32.11	34.07	33.87	34.66	1.14	39.51	118.5
120 - 150	33.16	35.06	32.13	34.75	34.87	33.99	1.23	41.81	125.4
150 - 180	33.10	35.82	37.10	35.24	35.84	35.42	1.22	43.21	129.6
TOTAL									712.5

Key: % θD_w - percentage moisture content oven dry weight basis; $\bar{X}$ - mean; BD - Bulk density; % θV - percentage moisture content by volume

APPENDIX 3 : B. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 27TH NOVEMBER , 1978 UNDER EIGHT CROPS

SOIL DEPTH (cm)	FB	IP	W	LS	SB	SF	M	SP	$SE_{\bar{X}}$
0 - 10	41.00	39.41	38.33	39.09	40.87	41.74	42.32	41.07	0.49
10 - 20	41.67	39.30	38.54	40.65	40.00	40.90	41.31	38.15	0.46
20 - 30	43.38	41.91	39.28	42.04	41.81	42.38	42.86	46.06	0.67
30 - 50	39.00	38.07	37.62	39.96	37.21	42.47	38.83	36.28	0.67
50 - 70	38.05	37.48	36.17	38.81	33.65	42.52	40.24	41.96	1.05
70 - 90	36.69	37.16	35.52	37.80	34.74	35.50	34.97	35.44	0.39
90 - 120	38.41	39.11	37.85	40.00	37.80	41.25	37.18	38.09	0.48
120 - 150	41.92	38.77	40.68	41.44	41.41	43.82	39.34	40.90	0.55
150 - 180	41.91	49.64	41.52	42.71	40.89	43.37	40.87	40.30	1.06

APPENDIX 3 : C: VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 18TH DECEMBER, 1978 UNDER EIGHT CROPS

Soil depth (cm)	FB	IP	W	LS	SB	SF	M	SP	$SE_{\bar{X}}$
0 - 10	37.33	44.92	34.88	33.52	37.41	37.30	38.82	36.89	1.19
10 - 20	38.90	41.78	36.10	35.35	38.08	39.69	34.81	39.22	0.85
20 - 30	40.69	43.26	39.00	40.36	42.90	41.42	42.02	42.04	0.50
30 - 50	40.56	41.08	37.82	41.22	42.82	40.11	40.91	43.14	0.58
50 - 70	42.40	42.74	39.12	42.73	44.98	43.95	44.12	45.52	0.70
70 - 90	42.73	44.24	39.19	42.56	44.13	43.11	43.33	42.27	0.56
90 - 120	40.49	43.02	41.01	44.65	45.18	45.14	43.74	43.01	0.63
120 - 150	43.95	44.83	44.18	46.81	48.83	46.99	46.65	44.22	0.62
150 - 180	42.85	43.37	43.18	45.08	43.20	43.60	45.79	42.54	0.40

APPENDIX 3 : D. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 8TH JANUARY, 1979 UNDER EIGHT CROPS

Soil depth (cm)	FB	IP	W	LS	SB	SF	M	SP	$SE_{\bar{X}}$
0 - 10	23.48	29.98	21.83	21.73	23.31	24.22	23.74	20.50	1.01
10 - 20	24.01	29.66	23.60	22.63	25.97	27.75	28.92	24.02	0.94
20 - 30	27.98	32.98	28.24	28.06	33.38	32.47	31.25	31.47	0.81
30 - 50	30.32	33.39	30.49	32.13	36.02	32.46	30.53	33.74	0.70
50 - 70	34.55	38.02	37.08	36.39	39.33	35.17	37.57	39.07	0.61
70 - 90	36.09	41.79	37.13	39.10	40.60	38.72	38.53	41.26	0.70
90 - 120	38.85	40.13	38.97	40.12	39.63	40.86	41.23	39.75	0.29
120 - 150	42.04	43.30	41.61	43.78	41.06	43.14	46.43	42.23	0.59
150 - 180	40.48	43.60	40.55	44.52	41.63	42.03	44.31	43.38	0.57

APPENDIX 3 : E. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 15TH JANUARY, 1979 UNDER EIGHT CROPS

Soil depth (cm)	FB	IP	W	LS	SB	SF	M	SP	$SE_{\bar{X}}$
0 - 10	22.87	23.82	21.12	21.94	22.31	24.03	22.53	23.17	0.34
10 - 20	24.34	27.21	25.18	22.83	22.81	25.68	22.55	21.20	0.70
20 - 30	29.42	31.16	26.63	30.50	28.85	30.37	29.87	30.86	0.51
30 - 50	25.66	33.37	32.07	30.16	33.57	31.15	31.97	35.55	1.04
50 - 70	33.87	36.43	32.66	36.48	34.53	33.28	35.11	38.48	0.68
70 - 90	36.85	39.55	37.91	36.29	34.15	37.25	37.36	38.58	0.57
90 - 120	37.34	39.84	36.00	39.20	34.33	38.34	39.97	39.01	0.70
120 - 150	39.11	42.37	39.85	42.44	40.02	41.33	43.42	41.17	0.52
150 - 180	39.76	41.85	39.11	43.70	35.78	41.52	42.55	43.22	0.92

APPENDIX 3 : F. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 29TH JANUARY, 1979 UNDER EIGHT CROPS

Soil depth (cm)	FB	IP	W	LS	SB	SF	M	SP	$SE_{\bar{X}}$
0 - 10	26.00	26.26	24.77	32.96	28.56	30.50	25.73	25.83	1.01
10 - 20	27.78	27.17	27.24	28.12	27.78	25.15	25.77	27.53	0.37
20 - 30	28.34	31.92	29.23	31.90	30.65	31.89	30.53	28.50	0.54
30 - 50	32.32	34.13	28.46	31.78	30.55	30.03	30.55	32.03	0.61
50 - 70	36.43	38.18	33.42	34.75	35.70	32.87	33.71	33.40	0.65
70 - 90	35.97	37.70	35.44	36.31	37.99	33.17	34.73	36.42	0.55
90 - 120	38.03	38.17	34.86	40.15	38.33	33.98	35.99	35.99	0.73
120 - 150	38.02	41.92	37.12	40.98	40.31	37.16	38.94	40.13	0.63
150 - 180	39.35	41.79	40.24	45.30	41.58	37.06	42.87	39.33	0.89

APPENDIX 3 : G. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 19TH FEBRUARY 1979 UNDER FIVE CROPS

Soil depth (cm)	LS	SB	SF	M	SP	$SE_{\bar{X}}$
0-10	28.43	32.79	31.32	34.42	35.56	1.24
10-20	30.27	32.42	34.60	33.27	33.83	0.74
20-30	37.06	35.71	35.65	36.34	37.66	0.39
30-50	37.20	36.32	36.27	36.96	37.21	0.21
50-70	41.71	38.59	38.27	39.62	39.80	0.60
70-90	42.54	38.56	38.46	39.55	39.79	0.74
90-120	39.43	38.67	37.08	37.83	39.97	0.52
120-150	42.77	40.89	38.47	41.38	42.29	0.75
150-180	42.42	40.09	38.66	41.92	38.88	0.77

APPENDIX 3 : H. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 5TH MARCH, 1979 UNDER FIVE CROPS

Soil depth (cm)	LS	SB	SF	M	SP	$SE_{\bar{X}}$
0-10	31.49	33.90	33.24	33.82	31.20	0.58
10-20	33.45	35.46	36.37	34.36	32.81	0.65
20-30	38.52	41.68	41.45	36.62	37.06	1.07
30-50	40.59	39.52	39.51	37.76	37.08	0.64
50-70	45.24	42.15	42.32	40.74	35.02	1.68
70-90	42.24	42.30	42.10	40.48	39.46	0.57
90-120	44.33	40.03	40.72	41.80	40.81	0.75
120-150	47.81	41.96	39.56	43.00	41.73	1.37
150-180	46.86	41.72	39.25	39.94	42.48	1.33

APPENDIX 3 : I. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 12TH MARCH, 1979 UNDER FOUR CROPS

Soil depth (cm)	SB	SF	M	SP	$SE_{\bar{X}}$
0 - 10	27.51	25.65	23.91	25.66	0.74
10 - 20	30.80	29.44	27.64	28.17	0.71
20 - 30	37.57	36.33	31.59	31.75	1.55
30 - 50	36.69	36.19	33.00	33.50	0.93
50 - 70	39.87	39.17	36.67	34.76	1.17
70 - 90	40.06	39.45	38.46	36.22	0.84
90 - 120	39.90	36.81	38.11	35.97	0.86
120 - 150	41.03	38.24	39.48	39.64	0.57
150 - 180	42.18	38.19	42.24	40.85	0.95

APPENDIX 3 : J. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 17TH APRIL, 1979 UNDER ONE CROP

Soil depth (cm)	SP
0 - 10	39.80
10 - 20	41.35
20 - 30	43.61
30 - 50	42.30
50 - 70	45.08
70 - 90	44.27
90 - 120	44.36
120 - 150	44.28
150 - 180	42.69

APPENDIX 4:A: PERCENTAGE SOIL MOISTURE ON 9TH APRIL, 1979 UNDER SIX RANDOMLY SELECTED SITES IN F12 OF THE EXPERIMENTAL SITE

Replicates / Horizon (cm)	1	2	3	4	5	6	X̄	BD	% θv	moisture (mm)
			%	θD_w						
0 - 10	41.48	41.46	40.92	46.39	42.06	44.55	42.84	1.01	43.27	43.3
10 - 20	44.77	43.40	44.38	42.91	42.21	43.83	43.58	1.02	44.45	44.5
20 - 30	41.62	39.21	41.45	42.54	38.63	39.40	40.48	1.09	44.12	44.1
30 - 50	41.36	37.19	40.02	41.36	40.19	43.69	40.64	1.08	43.89	87.8
50 - 70	41.68	36.60	39.23	41.02	41.23	41.34	40.18	1.14	45.81	91.6
70 - 90	39.47	36.33	38.82	42.35	40.61	41.01	39.77	1.12	44.54	89.1
90 - 120	37.72	38.78	40.61	40.87	41.08	41.08	40.02	1.14	45.62	136.9
120 - 150	36.91	37.99	37.50	38.27	41.48	39.81	38.66	1.23	47.55	142.7
150 - 180	37.51	35.04	39.48	37.44	38.87	39.91	38.04	1.22	46.41	139.2
TOTAL										819.2

Key: % θD_w - percentage moisture content oven dry weight basis; X̄ - mean; BD - bulk density;

% θV - percentage moisture content by volume.

APPENDIX 4:8: VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 23RD APRIL, 1979 UNDER FOUR CROPS

Crop Horizon (cm)	FB	IP	M	SP	$SE_{\bar{X}}$
0 - 10	34.01	35.84	34.60	33.30	0.54
10 - 20	37.40	38.31	39.48	38.19	0.43
20 - 30	40.65	40.85	42.29	41.18	0.37
30 - 50	39.17	39.91	40.21	39.71	0.22
50 - 70	42.94	43.13	43.64	42.83	0.18
70 - 90	42.99	43.77	41.61	41.89	0.50
90 - 120	46.59	45.92	44.52	45.04	0.46
120 - 150	47.21	46.65	47.59	48.11	0.31
150 - 180	46.19	47.08	46.54	46.34	0.19

APPENDIX 4 : C. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 30TH APRIL, 1979 UNDER FOUR CROPS

Crop / Horizon (cm)	FB	IP	M	SP	$SE_{\bar{X}}$
0 - 10	45.03	46.01	47.63	49.06	0.89
10 - 20	43.56	46.01	45.97	45.35	0.57
20 - 30	45.09	48.13	46.18	46.90	0.64
30 - 50	41.88	43.44	42.76	43.43	0.37
50 - 70	43.84	45.17	44.71	44.70	0.28
70 - 90	43.60	45.42	44.00	43.84	0.41
90 - 120	44.97	48.31	44.77	46.93	0.84
120 - 150	47.10	49.04	48.63	48.30	0.42
150 - 180	46.36	47.28	47.31	47.70	0.28

APPENDIX 4 : D. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 7TH MAY, 1979 UNDER FOUR CROPS

Crop / Horizon (cm)	FB	IP	M	SP	$SE_{\bar{X}}$
0 - 10	39.01	36.89	36.47	39.81	0.81
10 - 20	38.54	42.16	38.35	39.68	0.88
20 - 30	40.68	41.29	41.88	41.65	0.26
30 - 50	38.76	39.19	39.81	40.09	0.30
50 - 70	42.29	41.19	43.79	41.64	0.57
70 - 90	42.27	41.75	42.32	42.01	0.13
90 - 120	43.23	43.02	43.64	43.33	0.13
120 - 150	46.89	45.61	46.74	48.43	0.58
150 - 180	45.74	45.96	46.38	46.71	0.22

APPENDIX 4 : E. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 14TH MAY, 1979 UNDER FOUR CROPS

Crop / Horizon (cm)	FB	IP	M	SP	$SE_{\bar{X}}$
0 - 10	44.62	45.25	46.84	45.86	0.47
10 - 20	46.84	44.14	44.32	44.39	0.64
20 - 30	44.79	46.96	44.01	44.06	0.69
30 - 50	43.01	44.53	41.98	43.71	0.54
50 - 70	43.91	45.16	45.38	45.12	0.33
70 - 90	43.44	45.48	44.11	44.73	0.44
90 - 120	45.58	46.44	46.19	45.22	0.28
120 - 150	49.56	47.97	49.18	49.22	0.35
150 - 180	48.75	49.85	47.87	48.25	0.43

APPENDIX 4 : F. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 21ST MAY, 1979 UNDER FOUR CROPS

Crop / Horizon (cm)	FB	IP	M	SP	$SE_{\bar{X}}$
0 - 10	31.29	35.49	36.94	37.88	1.46
10 - 20	36.32	39.51	37.11	39.33	0.80
20 - 30	39.53	42.02	40.29	42.30	0.67
30 - 50	39.69	40.79	40.32	39.86	0.25
50 - 70	41.87	44.00	43.64	42.74	0.48
70 - 90	43.61	43.79	43.96	43.38	0.12
90 - 120	46.96	45.90	46.09	44.95	0.41
120 - 150	47.16	48.57	48.13	48.41	0.32
150 - 180	47.80	49.14	47.51	47.08	0.44

APPENDIX 4 : G. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 28TH MAY, 1979 UNDER FOUR CROPS

Crop / Horizon (cm)	FB	IP	M	SP	$SE_{\bar{X}}$
0 - 10	46.97	46.49	45.86	44.97	0.43
10 - 20	45.35	46.03	45.85	45.48	0.16
20 - 30	47.70	46.37	46.79	47.11	0.28
30 - 50	44.26	45.39	45.25	44.98	0.25
50 - 70	46.50	47.95	47.05	47.55	0.31
70 - 90	44.79	48.18	46.19	46.19	0.70
90 - 120	46.32	47.81	46.16	47.72	0.44
120 - 150	47.95	49.06	49.95	50.61	0.58
150 - 180	49.06	47.78	48.87	50.20	0.50

APPENDIX 4 : H. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 4TH JUNE, 1979 UNDER FOUR CROPS

Crop / Horizon (cm)	FB	IP	M	SP	$SE_{\bar{X}}$
0 - 10	43.42	42.97	42.62	43.86	0.27
10 - 20	43.34	41.81	41.69	42.17	0.38
20 - 30	43.01	41.95	41.80	43.36	0.39
30 - 50	40.62	41.14	40.55	41.99	0.33
50 - 70	43.02	43.45	42.33	43.42	0.26
70 - 90	42.91	43.46	43.23	42.35	0.24
90 - 120	45.00	45.51	43.23	45.20	0.51
120 - 150	45.70	46.90	49.38	47.97	0.78
150 - 180	46.40	47.01	46.13	46.88	0.21

APPENDIX 4 : I. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 18TH JUNE 1979 UNDER FOUR CROPS

Crop / Horizon (cm)	FB	IP	M	SP	$SE_{\bar{X}}$
0 - 10	30.09	34.06	35.74	36.20	1.39
10 - 20	34.43	36.13	36.96	34.86	0.58
20 - 30	37.59	38.68	39.14	39.31	0.39
30 - 50	38.21	39.01	37.57	38.60	0.31
50 - 70	41.19	41.71	39.97	43.63	0.76
70 - 90	42.45	43.03	40.17	43.29	0.71
90 - 120	43.35	45.38	42.80	43.48	0.56
120 - 150	45.63	46.67	46.30	46.47	0.23
150 - 180	43.05	45.48	45.32	46.47	0.72

APPENDIX 4 : J. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 25TH JUNE, 1979 UNDER FOUR CROPS

Crop / Horizon (cm)	FB	IP	M	SP	$SE_{\bar{X}}$
0 - 10	28.90	32.67	30.30	28.96	0.88
10 - 20	30.67	33.96	34.59	35.53	1.06
20 - 30	35.04	36.91	35.85	35.64	0.39
30 - 50	35.43	37.18	35.04	38.40	0.78
50 - 70	38.67	40.41	36.71	39.09	0.77
70 - 90	40.15	40.78	38.19	39.26	0.56
90 - 120	40.82	42.69	41.80	41.02	0.42
120 - 150	43.80	45.04	44.92	43.97	0.32
150 - 180	43.26	43.70	44.53	43.91	0.26

APPENDIX 4 : K. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 9TH JULY 1979 UNDER FOUR CROPS

Crop / Horizon (cm)	FB	IP	M	SP	$SE_{\bar{x}}$
0 - 10	35.32	37.02	31.09	35.80	1.29
10 - 20	30.95	35.31	30.63	33.53	1.11
20 - 30	32.73	34.38	34.02	35.23	0.52
30 - 50	34.86	35.69	36.80	34.95	0.45
50 - 70	38.32	39.23	37.91	37.68	0.34
70 - 90	40.64	40.32	39.60	38.83	0.40
90 - 120	41.66	42.13	41.43	41.35	0.18
120 - 150	44.33	43.64	44.81	44.19	0.24
150 - 180	44.18	44.47	44.68	44.31	0.11

APPENDIX 4 : L. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 16TH JULY, 1979 UNDER FOUR CROPS

Crop / Horizon (cm)	FB	IP	M	SP	$SE_{\bar{X}}$
0 - 10	31.27	31.88	30.69	32.31	0.35
10 - 20	32.34	33.02	31.12	32.39	0.40
20 - 30	35.99	35.04	33.72	35.50	0.49
30 - 50	35.93	35.13	33.38	35.41	0.55
50 - 70	39.12	39.50	36.87	38.55	0.58
70 - 90	40.28	41.12	40.15	39.74	0.29
90 - 120	40.56	41.42	40.53	41.33	0.48
120 - 150	44.26	44.66	44.96	43.38	0.34
150 - 180	44.40	43.98	44.73	43.30	0.31

APPENDIX 4 : M: VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 23RD JULY, 1979 UNDER THREE CROPS

Crop / Horizon (cm)	IP	M	SP	$SE_{\bar{X}}$
0 - 10	28.06	28.25	26.35	0.60
10 - 20	29.38	28.71	30.70	0.59
20 - 30	35.00	32.38	33.87	0.76
30 - 50	34.81	31.95	34.18	0.87
50 - 70	38.87	34.33	37.22	1.33
70 - 90	40.40	36.12	37.93	1.24
90 - 120	41.64	40.99	40.77	0.26
120 - 150	45.02	43.22	44.93	0.59
150 - 180	43.94	42.57	43.80	0.44

APPENDIX 4 : N. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 30TH JULY, 1979 UNDER THREE CROPS

Crop / Horizon (cm)	IP	M	SP	$SE_{\bar{X}}$
0 - 10	32.08	33.42	32.23	0.42
10 - 20	31.35	32.62	32.14	0.37
20 - 30	34.42	32.91	32.74	0.53
30 - 50	35.16	31.56	32.25	1.10
50 - 70	38.19	34.87	36.22	0.97
70 - 90	39.94	37.21	37.42	0.88
90 - 120	40.61	39.71	40.54	0.29
120 - 150	43.96	42.87	43.68	0.33
150 - 180	43.57	43.27	43.75	0.14

APPENDIX 4 : O. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 6TH AUGUST, 1979 UNDER THREE CROPS

Crop / Horizon (cm)	IP	M	SP	$SE_{\bar{X}}$
0 - 10	26.34	26.08	26.17	0.08
10 - 20	28.46	28.38	29.65	0.41
20 - 30	33.19	31.95	32.66	0.36
30 - 50	34.19	31.55	33.15	0.77
50 - 70	38.79	34.35	35.55	1.33
70 - 90	39.87	35.54	36.76	1.29
90 - 120	41.04	38.68	40.58	0.72
120 - 150	43.44	41.96	43.50	0.50
150 - 180	42.21	42.16	43.76	0.53

APPENDIX 4 : P. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 20TH AUGUST, 1979 UNDER TWO CROPS

Crop / Horizon (cm)	M	SP	$SE_{\bar{X}}$
0 - 10	25.63	27.14	0.76
10 - 20	26.45	29.32	1.44
20 - 30	29.06	32.15	1.55
30 - 50	29.50	31.67	1.09
50 - 70	31.69	34.54	1.43
70 - 90	33.84	35.53	0.85
90 - 120	37.10	38.28	0.59
120 - 150	40.91	42.18	0.64
150 - 180	41.07	42.58	0.76

APPENDIX 4 : Q. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 27TH AUGUST, 1979 UNDER TWO CROPS

Crop / Horizon (cm)	M	SP	$SE_{\bar{X}}$
0 - 10	22.21	23.84	0.82
10 - 20	24.76	27.23	1.24
20 - 30	29.88	30.83	0.48
30 - 50	30.48	30.97	0.25
50 - 70	32.22	34.15	0.97
70 - 90	33.00	35.15	1.08
90 - 120	36.04	37.26	0.61
120 - 150	41.30	40.84	0.23
150 - 180	41.62	41.82	0.10

APPENDIX 4 : R. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 10TH SEPTEMBER, 1979 UNDER TWO CROPS

Crop / Horizon (cm)	M	SP	$SE_{\bar{X}}$
0 - 10	24.46	26.08	0.81
10 - 20	24.72	27.81	1.55
20 - 30	28.68	30.91	1.12
30 - 50	29.23	30.19	0.48
50 - 70	31.75	34.19	1.22
70 - 90	33.00	34.29	0.65
90 - 120	36.22	36.36	0.07
120 - 150	40.84	40.10	0.37
150 - 180	41.03	40.98	0.03

APPENDIX 4 : S. VOLUMETRIC PERCENTAGE SOIL MOISTURE ON 17TH SEPTEMBER, 1979 UNDER TWO CROPS

Crop / Horizon (cm)	M	SP	$SE_{\bar{X}}$
0 - 10	20.25	22.11	0.93
10 - 20	23.33	25.93	1.30
20 - 30	28.62	29.33	0.36
30 - 50	28.79	30.08	0.65
50 - 70	31.69	32.76	0.54
70 - 90	32.61	34.47	0.93
90 - 120	35.10	35.03	0.04
120 - 150	39.64	38.59	0.53
150 - 180	41.74	35.77	2.99

APPENDIX 5 (A): WATER BUDGET CALCULATIONS FOR FIELD BEANS (FB) AND IRISH POTATOES (IP) DURING THE SHORT RAINS 1978/79

Period	Days	P	FB			IP		
			ΔW	μ	E_t	ΔW	μ	E_t
7/11 - 27/11	20	60.1	7.9	0	52.2	16.0	0	44.1
27/11 - 18/12	21	120.7	29.9	0	90.8	51.4	0	69.3
18/12 - 8/ 1	21	18.4	-108.8	0	127.2	-79.7	0	98.1
8/ 1 - 15/ 1	7	3.1	-23.6	0	26.7	-27.1	0	30.2
15/ 1 - 29/ 1	14	22.5	19.9	0	2.6	-1.9	0	24.4

Key: P = Precipitation (rainfall)

ΔW = Change in soil moisture storage

μ = Drainage

E_t = Evapotranspiration

APPENDIX 5 (B): WATER BUDGET CALCULATIONS FOR WHEAT (W) AND LINSEED (LS) DURING THE SHORT RAINS 1978/79

Period	Days	P	W			LS		
			ΔW	μ	E_t	ΔW	μ	E_t
7/11 - 27/11	20	60.1	-27.7	0	87.8	14.8	0	45.3
27/11 - 18/12	21	120.7	42.4	0	78.3	44.6	0	76.1
18/12 - 8/ 1	21	18.4	-80.7	0	99.1	-98.9	0	117.3
8/ 1 - 15/ 1	7	3.1	-23.5	0	26.6	-15.9	0	19.0
15/ 1 - 29/ 1	14	22.5	-10.5	0	33.0	55.5	0	105.6
29/ 1 - 19/ 2	21	138.6						
19/ 2 - 5/ 3	14	100.9				64.1	0	36.8

Key: P = Precipitation (rainfall) μ = Drainage

ΔW = Change in soil moisture storage E_t = Evapotranspiration

APPENDIX 5 (C): WATER BUDGET CALCULATIONS FOR SOYABEANS (SB) AND SUNFLOWER (SF) DURING THE SHORT RAINS 1978/79

Period	Days	P	SB			SF		
			ΔW	μ	E_t	ΔW	μ	E_t
7/11 - 27/11	20	60.1	-18.3	0	78.4	38.8	0	21.3
27/11 - 18/12	21	120.7	99.7	0	21.0	28.6	0	92.1
18/12 - 8/ 1	21	18.4	-112.3	0	130.7	-104.7	0	123.1
8/ 1 - 15/ 1	7	3.1 }	-25.4 }	0 }	51.0	-28.1	0	31.2
15/ 1 - 29/ 1	14	22.5				-42.8	0	65.3
29/ 1 - 19/ 2	21	138.6	30.6	0	108.0	65.8	0	72.8
19/ 2 - 5/ 3	14	100.9	43.4	0	57.5	47.5	0	53.4
5/ 3 - 12/ 3	7	0.4	-31.8	0	32.2	-56.9	0	57.3

Key: P = Precipitation (rainfall) μ = Drainage

ΔW = Change in soil moisture storage E_t = Evapotranspiration

APPENDIX 5 (D): WATER BUDGET CALCULATIONS FOR MAIZE (M) AND SWEET POTATOES (SP) DURING THE SHORT RAINS 1978/79

Period	Days	p	M			SP		
			ΔW	μ	E_t	Δ W	μ	E_t
7/11 - 27/11	20	60.1	-5.8	0	65.9	-1.8	0	61.9
27/11 - 18/12	21	120.7	74.2	0	46.5	58.5	0	62.2
18/12 - 8/ 1	21	18.4	-87.8	0	106.2	-89.0	0	107.4
8/ 1 - 15/ 1	7	3.1	-31.4	0	34.5	-48.3	0	73.9
15/ 1 - 29/ 1	14	22.5	-28.3	0	50.8			
29/ 1 - 19/ 2	21	138.6	66.2	0	72.4	72.2	0	66.4
19/ 2 - 5/ 3	14	100.9	17.4	0	83.5	-4.9	0	105.8
5/ 3 - 12/ 3	7	0.4	58.3	0	58.7	-55.2	0	55.6
12/ 3 - 17/ 4	36	234.2				138.1	0	96.1

Key: P = Precipitation (rainfall) μ = Drainage
ΔW = Change in soil moisture storage E_t = Evapotranspiration

APPENDIX 6 (A): WATER BUDGET CALCULATIONS FOR FIELD BEANS (FB) AND IRISH POTATOES (IP) DURING THE LONG RAINS, 1979

Period	Days	P	FB			IP		
			Δω	μ	Et	Δω	μ	Et
9/4 - 23/4	14	81.6	-36.9	0	118.5	-31.6	0	113.2
23/4 - 30/4	7	66.7	25.4	0	41.3	54.3	0	12.4
30/4 - 7/5	7	12.0	-35.3	0	47.3	-73.8	15.1	70.7
7/5 - 14/5	7	100.2	56.2	0	44.0	71.7	0	28.5
14/5 - 21/5	7	1.5	-45.4	1.8	45.1	-34.8	13.0	23.3
21/5 - 28/5	7	72.4	58.1	0	14.3	50.9	0	21.5
28/5 - 4/6	7	18.0	-48.4	14.5	51.9	-54.8	29.1	43.7
4/6 - 18/6	14	12.3	-50.9	0	63.2	-32.2	0	44.5
18/6 - 25/6	7	1.9	-35.2	0	37.1	-34.2	0	36.1
25/6 - 9/7	14	25.5	10.3	0	15.2	- 6.8	0	32.3
9/7 - 16/7	7	1.9	0.9	0	1.0	- 6.3	0	8.2
16/7 - 23/7	7	1.5				- 9.2	0	10.7
23/7 - 30/7	7	13.7				- 3.5	0	17.2
30/7 - 6/8	7	0.0				-15.2	0	15.2

Key: P = precipitation (rainfall)

Δω = change in soil moisture storage

μ = drainage

Et = evapotranspiration

APPENDIX 6 (B): WATER BUDGET CALCULATIONS FOR MAIZE (M) AND SWEET POTATOES (SP) DURING THE LONG RAINS, 1979

Period	Days	P	M			SP		
			Δw	μ	Et	Δw	μ	Et
9/4 - 23/4	14	81.6	-35.9	0	117.5	-39.2	0	120.8
23/4 - 30/4	7	66.7	41.5	0	25.2	54.2	0	12.5
30/4 - 7/5	7	12.0	-46.0	0	58.0	-50.1	7.4	54.7
7/5 - 14/5	7	100.2	49.0	0	51.2	45.6	0	54.6
14/5 - 21/5	7	1.5	-32.5	1.0	33.0	-36.9	2.9	35.5
21/5 - 28/5	7	72.4	55.3	0	17.1	12.3	0	78.1
28/5 - 4/6	7	18.0	-56.0	23.8	50.8			
4/6 - 18/6	14	12.3	-44.2	0	56.5	-34.4	0	46.7
18/6 - 25/6	7	1.9	-37.7	0	39.6	-50.4	0	52.3
25/6 - 9/7	14	25.5	4.3	0	21.2	- 3.2	0	28.7
9/7 - 16/7	7	1.9	-10.0	0	11.9	- 5.5	0	7.4
16/7 - 23/7	7	1.5	-32.4	0	33.9	-13.4	0	14.9
23/7 - 30/7	7	13.7	-16.7	0	30.4	- 5.6	0	19.3
30/7 - 6/8	7	0.0				- 9.6	0	9.6
6/8 - 20/8	14	11.5	-29.4	0	40.9	-21.9	0	33.4
20/8 - 27/8	7	1.2	- 3.3	0	4.5	-19.0	0	20.2
27/8 - 10/9	14	9.8	- 5.0	0	14.8	- 7.6	0	17.4
10/9 - 17/9	7	0.9	-12.4	0	13.3	-34.4	0	35.3

Key:
- P = precipitation
- Δ w = change in soil moisture storage
- μ = drainage
- Et = evapotranspiration