SOIL MOISTURE AND TENSIOMETER MEASUREMENTS MADE TO ASSIST THE MANAGEMENT OF SUPPLEMENTARY IRRIGATION OF MAIZE IN EASTERN ONTARIO

BY

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A thesis submitted to the Faculty of
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partial fulfilment of the requirements
for the Degree of Master of Science

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SHORT TITLE

Measurements for management of supplemental irrigation of maize

ABSTRACT

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SOIL MOISTURE AND TENSIOMETER MEASUREMENTS MADE TO ASSIST THE MANAGEMENT OF SUPPLEMENTARY IRRIGATION OF MAIZE IN EASTERN ONTARIO

Field experiments were conducted in 1996, to evaluate the need of supplemental irrigation of maize on some sandy soils in Eastern Ontario. Field and laboratory measurements of soil properties were conducted. Plow layer and deficit irrigation management approaches were evaluated. Irrigation requirements using rain and evaporation data of the humid 1996 summer, as well as data from the drier 1974 summer, were evaluated. The results show that using a root zone depth less than 300 mm led to more water losses by drainage, more irrigation water requirements and more frequent irrigation applications, as compared to using a 400 mm root zone. Therefore, it is recommended that a 400 mm root zone depth be used for scheduling irrigation applications of 25 mm. Wilting began to appear at 60 % soil moisture depletion. Thus, 50 % moisture depletion is suggested as the time to start irrigation to avoid crop stress.

The principal assumptions for tabulation of irrigation scheduling were: 1) That the soil is at field capacity at the beginning of June; And 2) That upward flux from a water table is negligible, since the summer water table is deeper than 2 m. These assumptions are based on the facts that rain in May keeps the soil moist, the maize is small at the end of May and that AET (Actual Evapotranspiration) is less than PET (Potential Evapotranspiration).

The measurements show that soil moisture depletion varies from site to site within the fields. The water balance was calculated using weather data and available soil moisture holding capacities for three locations on the farm. The tensions that the plant roots exerted to obtain water from the soil were measured with tensiometers and tabulated as a guide for irrigation management.

RESUME

M.Sc. Génie Agricole et des Biosystèmes

Sandra Ibarra

UTILISATION DES TENSIOMETRES ET MESURES DE LA TENEUR EN EAU DU SOL POUR FACILITER LA GESTION DE L'IRRIGATION DU MAIS DANS L'EST DE L'ONTARIO

Au cours de l'été 1996, on a mené des expériences au champ pour évaluer les besoins en irrigation du maïs cultivé sur des sols sableux de l'est de l'Ontario. On a mesuré les propriétés des sols, directement au champ et en laboratoire. Plusieurs méthodes de gestion des irrigations ont été testées. Les besoins en irrigation ont été évalués à partir des données de précipitations et d'évaporation de 1996, une année humide et, de l'année 1974, plus sèche. Les résultats montrent que lorsqu'on utilise une valeur de 300 mm comme profondeur de la zone racinaire pour prédire les irrigations, les pertes d'eau dues au drainage, les besoins en eau d'irrigation et la fréquence des irrigations sont plus élevés que si l'on utilise une profondeur de 400 mm. Il est donc recommandé d'utiliser une profondeur racinaire de 400 mm pour planifier les irrigations de 25 mm. Le flétrissement se produit lorsque le pourcentage de l'eau du sol utilisé est de 60%. Afin de réduire le stress hydrique des plantes, on suggère de débuter les irrigations lorsque 50% de l'eau du sol a été utilisée.

Lors du calcul des besoins et des moments d'irrigation, les hypothèses suivantes ont été retenues: 1) Le sol est à la capacité au champ au début de juin; 2) La remontée capillaire à partir de la nappe phréatique est négligeable puisque durant l'été la profondeur de la nappe est supérieure à 2 m. Ces hypothèses s'appuient sur le fait que les précipitations de mai maintiennent le sol humide, que le maïs est petit à la fin de mai et que l'évapotranspiration actuelle est plus faible que l'évapotranspiration potentielle.

Les mesures montrent que le taux d'utilisation de l'eau du sol par les plantes varie à l'intérieur d'un même champ. On a fait un bilan hydrique à partir de données d'évapotranspiration obtenues d'un bac d'évaporation recouvert d'un grillage et qui donne des valeurs d'évapotranspiration situées à mi-chemin entre celles mesurées par Agriculture Canada pour la région d'Ottawa et les valeurs d'utilisation de l'eau du sol par les plantes mesurées sur la ferme. On a également mesuré la tension exercée par les racines pour obtenir l'eau. Ces valeurs peuvent être utilisées pour faciliter la gestion de l'irrigation.

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LIST OF SYMBOLS AND ABBREVIATIONS

AET: Actual evapotranspiration
AW: Available water
AW_n and AW_{n-1}: Available water at days n and n-1
BD: Bulk density
BDL: Bulk density limit
BDM: Bulk density maximum
cm^3: Cubic centimetre
C_u: Soil coefficient of uniformity
d: Density of water
D: Drainage
DAS: Days after silking
D_{60} and D_{10}: Soil particle diameter for which 60 and 10 percent of soil by weight is smaller
DP: Drainable porosity
ET: Evapotranspiration
FC: Field capacity
FC_w: Field capacity by weight
FC_v: Field capacity by volume
g: Acceleration of gravity
g/cm^3: Grams per cubic centimetre
h: Total pressure head
h_a: Pneumatic component of the pressure head
h_m: Matric pressure head
h_{min}: Lowest pressure head
I: Irrigation
LAI: Leaf area index
mm: millimetre
MC: Moisture content

MC_{sat}: Moisture content at saturation

MC_{vp}: Volumetric water content at given pressure

MCv_{sat}: Volumetric water content at saturation

MCw_{sat}: Mass of water content at saturation

M_s: Mass of the soil

M_w: Mass of the water

P: Hydrostatic pressure

P_{atm}: Atmospheric pressure

PET: Potential evapotranspiration

P_g: Gas phase pressure in the soil

P_{vap}: Vapour pressure

R_{ef}: Effective precipitation

SM: Soil moisture

ΔSM: Change in soil moisture

Δt: Time interval

U: Upward water flux

V_a: Volume of the core

V_p: Volume of water at a given pressure

WUE: Water use efficiency

CHAPTER I

INTRODUCTION

1.1 Background

The limited water supply accompanied by increasing water demand, increasing water quality degradation and increasing water cost, have placed great importance on the need for efficiency in water management solutions.

Irrigation water is one of the essential elements required to produce food for a rapidly growing world population. The amounts of irrigation water applied to the soil are determined by how irrigation systems are managed.

The quality of water consumed in irrigated agriculture, or the depletion of soil water content, is not affected significantly by the type of irrigation system employed. Rather, the irrigation system delivers and distributes the water, but the crops dictate the amount of water consumed.

Irrigation management consists of determining when to irrigate, the amount of water to apply at each irrigation, and operation and maintenance of the irrigation system. The major management activity involves irrigation scheduling and determining the amount of water to apply. The crop response to an irrigation application, or to a specific irrigation management practice, is critically important in evaluating the economics of irrigation application and in devising efficient irrigation management strategies.

Irrigation strategies vary with both depth of active root zone and depth of remaining available water. This project consists of the field determination of soil moisture consumption by maize in a sandy soil in cool humid environment of South Eastern Ontario, Canada.

1.2 Objectives

1. To evaluate supplemental irrigation requirement to provide water to meet the Potential Evapotranspiration demand of maize on sandy soils in Eastern Ontario.
2. To evaluate alternatives of irrigation management strategies.
3. To provide data and practical guide-lines to be used by the farmer in determining when and how much irrigation water to apply.

1.3 Scope

The scope of this thesis is restricted to the following conditions and measurements.

- Evaluation of soil physical properties responsible for loss of water from the root zone. This evaluation was done by gravimetric methods.
- Evaluation of soil water release characteristics by the filter funnel method and tensiometry.
- Monitoring of soil moisture content with tensiometer and soil sampling by auger at least twice a week.
- Determination of an approximation to Potential Evapotranspiration by means of a screened evaporation pan and soil moisture depletion.
- Daily rainfall and maximum and minimum air temperature at the field.
- Visual observations of crop development.
- Elaboration of practical guide-lines for managing supplemental irrigation with the use of a rain gauge, a screened evaporation pan, tensiometers and soil sampling.

CHAPTER II

LITERATURE REVIEW

For a successful implementation of an irrigation management project, it is essential to evaluate the soil and water resources and the crop requirements. One of the goals of the irrigation manager is to implement scheduling strategies to maintain a soil water status which does not stress crops for much of the growing season. The schedules must also prevent overirrigation which can leach fertilizers and reduce the root zone aeration below optimal levels. This yield objective is often best implemented with irrigation systems that can irrigate frequently and apply water efficiently. With these strategies the maximum crop yield objective may be achieved.

Another management strategy is to assure adequate water supplies at the critical crop growth stage. This management strategy may not produce maximum yields but can achieve to maximum water use efficiency. Unmeasured irrigation tends to waste water, nutrients and energy; and may cause soil degradation by water-logging and salinization, particularly where drainage is neglected.

Scientific developments have been paralleled by a series of technical innovations in the methodology of water control which have made it possible to establish and maintain nearly optimal soil moisture conditions practically continuously.

The use of brackish water has become more feasible, as has the irrigation of coarse textured soils and of steep and stony lands previously considered totally unproductive. Such advances and their consequences could hardly have been foreseen in previous decades.

2.1 SOIL WATER CONTENT.

The portion of soil above the water table is unsaturated. In this portion of soil, the pores are partly occupied by water and partly by air. The soil water in this zone is referred to as soil moisture; and it varies with depth and with time.

For irrigation studies the moisture in the upper soil layer to depths of 1.0 m is of primary importance for plant growth. The water content of this layer is variable, mainly due to variations in daily weather conditions especially rainfall, temperature and wind.

The water release characteristics of the soil are indicators of the moisture available for crops. Water content is generally described in terms of the mass of water in a unit mass of soil (kg/kg), or as the volume of water in a unit volume of soil (m^3/m^3).

Transpiration by the vegetation and evaporation directly from the soil (jointly referred as evapotranspiration) cause a water loss from the soil into the atmosphere. Evapotranspiration and deep percolation deplete the soil moisture storage. Rainfall and irrigation replenish this storage. Deeper down, variations occur in parallel with seasonal weather variations over a longer term.

Soil water content can be measured *directly* or *indirectly*.

Direct measurements are possible by *gravimetric methods*. Gravimetric methods involve sampling the soil and weighing (wet weight), oven drying for 2 to 24 h at 105°C and reweighing the sample (dry weight). The errors in gravimetric methods are less than 0.4% for samples having a dry mass of 20 g or more (Campbell and Mulla, 1990).

Two types of gravimetric measurements may be obtained, depending upon the method used to collect soil from the field, namely *disturbed and undisturbed methods*. When soil is disturbed, some soil properties change (bulk density, pore size and the relation between water content and soil matric suction). A swelling clay is particularly vulnerable to changes in water characteristics when removed from the profile location. Undisturbed sampling may reduce the effect in soil property changes, but a sample in place at some depth within the soil profile experiences an earth pressure which confines it. The confining pressures of the profile can be reproduced with a triaxial apparatus for depths greater than 2 m (Holmes et al., 1967). For disturbed samples, water content is usually determined on a mass basis (kg/kg). With undisturbed samples the water content can be expressed as a volumetric water content (m^3/m^3). When undisturbed soil samples are collected using a core sampler of known volume, the volumetric water content is determined and the bulk density can be calculated.

With gravimetric measurements, care must be taken in heterogeneous profiles to take representative samples for each soil layer. Gravimetric methods are accurate and have low equipment cost. Gravimetric methods are destructive sampling and time consuming.

Indirect methods of estimating water content include *nuclear* and *microwave*, *electrical resistance* and *tensiometric methods*. The nuclear measurements are made in situ and are not destructive, the disadvantages being possible radiation hazards to operators and high cost of instruments. Microwave measurements are a new and promising approach, they are rapid and easy techniques, and measurements are made in situ and not destructive. The major disadvantage is that it is an expensive technique (Campbell and Mulla, 1990). Measurement of moisture tension is described in section 2.2.4.

2.1.1 Field capacity, wilting point and available water.

Veihmeyer and Hendrickson (1949) defined **field capacity** as "The amount of water held in soil after excess water has drained away and the rate of downward movement has materially decreased, which takes place within 2 to 3 days after a rain or irrigation in pervious soils of uniform structure and texture."

With experimental measurements (Richard et al., 1956; Ogata and Richards, 1957), field capacity is no longer considered a constant or an intrinsic soil property, but rather an arbitrary value. It is recognized that internal drainage (redistribution) is indeed continual and shows no sharp changes or constant levels. In the absence of a water table, the process continues indefinitely at a decreasing rate.

As the soil water content decreases from field capacity, soil water availability to plants decreases and transpiration approaches zero. **The soil water content at which plants wilt** and do not recover turgidity even when placed in a 100% relative humidity atmosphere for 12 h is known as the **permanent wilting point**. The wilting point varies with crop, soil and atmospheric conditions. Plant growth may be reduced before the wilting point is reached (Ahuja and Nielsen, 1990). The **field capacity** and **wilting point** are the **upper** and **lower limits** of water availability to plants.

2.2 SOIL-WATER-PLANT RELATION

Experience and intuition suggest that soil physical properties are the major determinants of seedling germination, emergence, and reproductive development of plant. Nasr and Selles,(1994), studied the effect of soil properties in seedling emergence and they concluded that the number of seedlings and speed of emergence were affected by bulk density and aggregate size of the seedbed. In general, increasing bulk density or aggregate size delayed emergence and reduced total emergence. However, the effect of bulk density was small in seedbeds with large aggregates, and the effect of aggregate size was negligible in compacted seedbeds. Increased bulk density delayed emergence mainly by decreasing the volume of voids in the soil.

Ojeniyi and Dexter, (1984), concluded that the identification of the structural features responsible for the loss of water in a prepared seedbed would enable a modification of tillage methods to conserve water for the survival of the seedlings. It is known that water content in a prepared seedbed, as determined by water loss due to evaporation and water inflow from the soil beneath into the seed zone, may be influenced by the structural features of the soil as produced by tillage implements. Therefore, the structural features of the seedbed above the seeding depth (25 to 75 mm) are of importance for **evaporation control**.

2.2.1 Bulk density

The soil bulk density, (BD), is the ratio of the mass of dry solids to the bulk volume of the soil, including the volume of the solids and of the pore space. The mass is determined after drying to constant weight at 105°C, and the volume is that of the core sampler as taken in the field (Blake and Hartge, 1986). Bulk density is a widely used value. It is needed for converting water percentage by weight to water content by volume and for calculating porosity and void ratio when the particle density is known. Bulk density varies with the structural condition of the soil. For this reason it is often used as a measure of soil structure. In swelling soils it varies with the water content (Blake and Hartge, 1986).

The determination of bulk density can be done by:
The Core method whereby, a cylindrical sampler is pressed or driven into the soil to the desired depth and is carefully removed to preserve a known volume of sample as it existed in situ. Core samples should be taken in soils of medium water content. In wet soils, friction along the sides of the sampler and vibrations due to hammering are likely to result in viscous flow of the soil and thus in compression of the sample (Blake and Hartge, 1986).

In Excavation methods the bulk density is determined by excavating a quantity of soil, drying and weighing it, and determining the volume of the excavation, by mean of sand-funnel apparatus, rubber-balloon apparatus, or mensuration apparatus. The disadvantage of this method is the lack of discrimination to a localized horizon, (Blake and Hartge, 1986), and time consumption.

With the Clod method the bulk density can be calculated from the mass and volume. The volume may be determined by coating a clod of known weight with a water-repellent substance and by weighing it first in air, then again while immersed in a liquid of known density, making use of Archimedes' principle. The clod must be sufficiently stable to cohere during coating, weighing and handling. This method usually gives higher bulk density values than the other methods. One reason that it gives, higher values is that the clod does not take the interclod spaces into account (Blake and Hartge, 1986).

Radiation methods consist of transmission or scattering of gamma radiation through soil. Radiation methods have several advantages, among which are; minimum disturbance of the soil, short time required for sampling, accessibility to subsoil measurement with minimum excavation, and the possibility of continuous or repeated measurements at the same point. There is some potential radiation hazard with these methods and they are expensive (Blake and Hartge, 1986).

2.2.2 Particle size

Particle size analysis is a measurement of the size distribution of individual particles in a soil sample. The major features of particle size analysis are the dispersion of soil aggregates into discrete units by chemical, mechanical or ultrasonic means and the separation of particles according to size limits by sieving and sedimentation (Gee and Bauder, 1986).

Particle size analysis data can be presented and used in several ways, the most common being a particle size distribution curve. The percentage mass of particles less than a given particle size is plotted against the logarithm of the "effective" particle diameter.

Particle size analysis is often used to evaluate soil texture, which is based on different combinations of sand, silt and clay fractions that make up the particle size distribution of a soil sample. Details for interpretation of the textural triangle for soil classification purposes are given by the Soil Survey Staff (Wicklund and Richards, 1962).

2.2.3 Soil crust

Crust is the general term used to describe a soil surface that has become hard or impervious upon drying. Soil compaction and soil crusting are the major management created layers which influence water infiltration and impede emergence and growth of seedlings. Crusts are basically of **two types**: 1) **structural crusts** induced by water drop impact, and 2) **depositional crusts** induced by the translocation of fine soil particles and their subsequent deposition at a certain depth below their original location, (Shainberg and Singer, 1985; Fattah and Upadhyaya, 1995). Problems of soil crusting occur extensively in semi-arid and arid regions, and on a variety of soils such as sandy loam, sandy clay and sandy soils (Fattah and Upadhyaya, 1995). Shainberg and Singer (1985), reported that dry crusts did not impede water penetration. When crusts dried, soil aggregates shrank, bent and cracked which returned hydraulic conductivity to the original value.

Fattah and Upadhyaya (1995), concluded that very thin surface crusts (6 mm thick or less) wether dry or wet did not appear to reduce infiltration rates. This is most likely due to the presence of cracks that developed in the crusts immediately upon wetting of the surface. Thin surface crusts corresponding to 60 to 120 passes of a hand held-sprinkler (8.7 to 13.5 mm thick) significantly reduced initial infiltration rate, but did not affect the final infiltration rate. Thick depositional crusts (>13.5 mm thick) reduced the final infiltration rate significantly. The initial infiltration rate depends on the type of crust, and it decreases significantly for a wet crust. The presence of well-defined and relatively large cracks in a dry crust appears to compensate for any reduction in initial infiltration rate.

If a farmer notices that a crust has formed, that may be impeding seedling emergence and growth, he can break up the crust with a rotating harrow.

2.2.4 Soil water potential

The retention of water by soil and its relationship to the soil water energy level was discussed by Buckingham (1907) and has become known as "the potential concept of soil water". Measuring the soil water potential is useful for describing the availability of water to plants and the driving forces which cause water to move in soil.

Soil water potential at a point is the potential energy required to move a unit quantity of water from a reference state to that point. It is convenient to take the water table level ($P_{atm}= 0$) as a reference point, (Smedema and Rycroft, 1983).

The flow velocities of groundwater are too low to generate any significant kinetic forces. The prevailing forces below the water table are normal forces encountered in a standing body of water, and therefore normal positive hydrostatic pressures prevail below the watertable ($P>P_{atm}$), (Smedema and Rycroft, 1983). The positive pressure can easily be measured by piezometers, and this pressure is also referred as piezometric pressure.

In the soil moisture above the water table, two types of forces prevail. The capillary forces are essentially surface tension forces, activated by adhesion between water and soil and by the fineness of the pores. The other type of force is adsorption, which include van der Waals and electrostatic forces exerted on the water by the charged colloidal surfaces of the soil particles. Both capillary and the adsorption forces bind the soil moisture to the soil particles making up the soil skeleton (soil matrix), thereby retaining it above the water table against the gravitational pull. Pressures in the soil moisture are negative ($P<P_{atm}$), and these negative pressures, commonly referred to as tension or suction, may be measured with a **tensiometer**. This instrument

measures the so called matric suction generated by the combined capillary and adsorption forces. These negative pressures may also be termed tensiometric pressures, (Smedema and Rycroft, 1983).

Methods of measuring the soil water potential useful for irrigation, are *tensiometer*, *filter funnel* and *pressure plates*, which perhaps are the techniques most widely used. Other methods are *thermal conductivity*, *electrical resistance methods*, *filter paper methods* and *thermocouple psychrometer*. Methods for measurement of water potential require that a reference phase be equilibrated with the soil until both reach the same water potential (Smedema and Rycroft, 1983).

2.2.4.1) Tensiometry

The tensiometer consists of a sealed, water-filled tube with a porous cup on one end, and some means of measuring pressure (a gauge, manometer or electronic pressure transducer) on the other (see Figure 3.5). The porous cup is permeable to water and to solutes in the soil solution, but not to the soil matrix or to gases. Water moves through the cup until the water pressure inside the tensiometer is equal to the potential of the soil water. At equilibrium, the water pressure (suction) in the tensiometer is equal in magnitude to the soil matric potential (Cassel and Klute, 1986).

As the water content of the soil surrounding the water-filled porous tensiometer cup decreases, the energy level of the soil decreases relative to that of the water in the tensiometer cup, and water moves out of the tensiometer through the pores in the cup and into the soil. The pressure in the water in the tensiometer cup is then reduced. If the soil surrounding the porous cup receives additional water, the soil water pressure is increased, and soil water flows through the walls of the porous cup into the tensiometer, thereby increasing the pressure of the water in the tensiometer cup.

Carefully prepared water columns are capable of withstanding tensions in excess of 250 kPa (Briggs, 1950). The water in tensiometers, however, cavitates at tensions around 85 kPa. This limits the useful range of measurement of matric potentials between 0 and -85 kPa. This is an important range for irrigation management, since water uptake by plants often begins to slow below potential uptake rate if the root zone moisture tension becomes greater than the tensiometer range (Cassel and Klute, 1986).

The tensiometer is the most precise of the devices available for making this measurement. To avoid cavitation, it is important to fill a tensiometer with deaerated water, to purge it with a hand operated vacuum pump when water is added and to check and add water when needed.

2.2.4.2) Filter funnel

The filter funnel is a device in which a saturated soil sample can be drained stepwise to a known matric potential with a volume measurement of the water removed during each step. This is a suction cell apparatus (Haines, 1930) on which the wet soil sample is in hydraulic contact with bulk water through a porous plate. Atmospheric pressure is applied to the soil and the pressure in the bulk water is reduced to subatmospheric levels, thereby reducing its hydraulic head. Water flows out of the sample until hydraulic equilibrium is reached. The water content and the matric pressure head at equilibrium are then determined. The absolute pressure in the bulk water cannot be reduced below its vapour pressure at the ambient temperature, because it then spontaneously vaporizes. Consequently, the theoretical lowest pressure head that can be established in the suction apparatus is given by

$$h_{min} = (P_{vap} - P_{atm})/(dg)$$

where P_{vap} is the vapour pressure, **d** is the density of water, and **g** is the acceleration of gravity. In practice, because of the dissolution of gases from the bulk water, the suction apparatus is limited to less than about 850 cm of water suction at low elevations (Klute, 1986).

The filter funnel should be of convenient size to contain the soil sample in an appropriate sampling cylinder. The water is removed by through porous media or plates with maximum pore diameters of approximately 5 µm. Those with smaller pores have reduced permeability values and require longer times for sample equilibration during drainage steps.

2.2.4.3) Pressure plate

The pressure plate apparatus allows equilibration of the matric potential of soil samples to some specified water potential. This is a pressure cell apparatus that avoids the limitation of vaporization in the suction cell apparatus by keeping the body of water under the porous plate at about atmospheric pressure and raising the gas phase pressure applied to the soil sample, so that no water in the system is actually subjected to pressures greatly less than atmospheric (Klute, 1986).

The analysis of hydraulic equilibrium when the ambient gas phase pressure on the soil sample is not atmospheric requires recognition of a pneumatic component of the pressure head, h_a, which is given by $(P_g - P_{atm})/dg$, where P_g is the gas phase pressure in the soil. Thus, when the gas phase pressure is not atmospheric, the total pressure head, h is given by

$$h = h_a + h_m$$

where h_m is the matric pressure head that is related to the water content, not the total pressure head (Klute, 1986).

The water content of the samples, (from the suction cell or pressure cell apparatus) can then be determined in order to establish a soil water characteristic, or water release function. The water characteristic can be used, along with water content measurements, to infer water potential. The suction cell is often used to infer the saturation point (water content at P_{atm}) and the field capacity (water content at -6 to -12 kPa). The permanent wilting point (water content at -1500 kPa) is obtained by the pressure plate apparatus (Klute, 1986).

2.3 IRRIGATION SCHEDULING

Irrigation scheduling involves estimating the earliest date to permit an efficient irrigation, and the latest date to avoid adverse effects on the crop. Within this time period, farm managers plan the irrigations for the next 5 to 10 days to complete cultivations, crop spraying and other necessary cultural practices. Irrigation scheduling also involves estimating the amount of water that may be applied. In many cases, the amount applied may be predetermined by the irrigation system.

Traditional irrigation scheduling practices consider a combination of two approaches 1) soil and/or crop monitoring, and 2) soil water balance computations. For the monitoring methods, the soil water content or matric potential is generally measured at several places in the field to decide when to irrigate. Methods based on plant measurements generally involve **monitoring leaf water potential** or canopy temperature. Soil water balance calculations require estimates of soil storage capacity, rooting depth, allowable depletion and crop evapotranspiration to develop an irrigation schedule.

2.3.1 Irrigation scheduling with tensiometers

The tensiometer is the most used device for monitoring water potential to schedule the application of water. To use the tensiometer as an apparatus to measure the water content in the soil, it is essential to have a previous inventory of the soil resources in the field. Information concerning the kinds of soils, slope and water-holding properties should be obtained. When the suction indicated by the tensiometers installed at appropriate depths in the root zone reaches a prescribed value, irrigation water is applied.

Tensiometers should be installed at sites or stations that are representative of the major soil types and of land use in the field. Each tensiometer station must be located so that it will not be damaged by machinery or labourers. For row crops, the tensiometers are usually installed in the row. The soil in the vicinity of the tensiometer should not be compacted by foot or vehicle traffic, which may reduce the infiltration of water.

The number of tensiometers installed at each station is dependent upon the crop and its stage of growth. Cassel and Klute 1986, state that two tensiometers per station are often used, with the porous cup of one at a depth equal to one-fourth of the active rooting depth and the cup of the other at the bottom of the rooting zone. The upper tensiometer is used to schedule the irrigations and the lower one is used as an indicator of leaching.

The tensiometers should be read often enough to detect trends in the soil water suction. Three, four or more readings per week are required for this purpose in sandy soils under conditions of high evaporative demand. The suction values are plotted versus time, to predict the readings for the next few days, and therefore to anticipate the next irrigation day.

Despite their demonstrated effectiveness, growers' acceptance of tensiometers and other soil-water sensors has not been widespread due to field variability and lack of convenience and other farm management constraints (Hook et al., 1984).

2.3.2 Scheduling with the soil water balance.

Irrigation scheduling with a soil water balance depends on the soil water depletion where stress occurs. Irrigation can be scheduled from crop water use data and the amount of water required to recharge the root zone at a selected depletion level. Evaporation pans are used to estimate evapotranspiration or total water use by the crop. The depth of water applied with each irrigation may be determined from the soil physical properties, the crop root depth and the efficiency and capacity of the irrigation system.

Well scheduled irrigation, should remove the detrimental effects of poor rainfall distribution and overcome water stress problems associated with shallow rooting affected by tillage and possible toxic levels of chemicals in the subsoil.

Any attempt to control the supply of water to crops must be based on a understanding of soil-water dynamics. Field capacity tends to be higher in clayey than in sandy soils. Moreover, it is generally greater in layered than in uniform soil profiles of similar texture, as layering inhibits the internal drainage of water.

Increased rainfall can lead to significant fertilizer leaching and deep percolation losses of water. In humid areas, systems should usually be operated to partially refill the profile with each irrigation, but retain some reservoir for rain. The biggest problem comes when irrigating soils with low water-holding capacities which do not provide much margin for error in either applying irrigation water or managing the system to maximize the effectiveness of rainfall.

In humid areas, because rainfall frequently refills the root zone, fewer long periods of accurate evapotranspiration estimates are needed because accumulated errors are reset to zero after deep infiltrating rains.

2.3.2.1 Root zone water storage capacity

The water storage capacity of the root zone must be calculated when using the soil water balance to schedule irrigations. The amount of water that can be used by the crop depends on the water holding characteristics of the soil and on the rooting depth of the crop. The maximum effective depth used for scheduling, which is usually less than the maximum depth where roots are found, represents the depth of the soil profile that has enough rooting density for extraction of available water if needed. The soil water available to plants is commonly described using the field capacity and the permanent wilting point.

2.3.2.2 Evapotranspiration

Methods of estimating evapotranspiration (ET) fall within three general categories, direct, indirect methods, and simulation models of the soil water balance.

Direct measurements methods.

Direct measurement of ET can be done by *soil water depletion*, *lysimeters* and *water balance* methods.

The soil water depletion, this method gives evapotranspiration values under field conditions. It can be determined by measurements of change of soil water over a period of time. The major potential error in this method is caused by drainage from the zone sampled or the upward movement of water from a saturated zone into the zone sampled. The soil is usually sampled 2 to 4 days after an irrigation and again 7 to 15 days later, or just before the next irrigation. The average rate of ET is calculated using the following equation:

$$ET= \Delta SM/\Delta t$$

Where ET is average evapotranspiration in mm/day; ΔSM is change in soil moisture in mm and Δt is the time interval in days, without rain or irrigation.

Lysimeters are tanks filled with soil in which crops are grown under natural conditions to measure the amount of water lost by evapotranspiration and drainage. This method is used to study climatic effects on ET and to evaluate estimating procedures (Jensen et al., 1989). Soil conditions inside the lysimeters must be essentially the same as those outside. The lysimeter must be surrounded by the same crop that is growing in the lysimeter and located at a distance of 100 m or more from the edge of the field (Jensen et al., 1989).

Tanner (1967) stated that lysimetry is the only hydrological method in which the experimenter has complete knowledge of all of the terms in the balance equation. The primary limitation is the cost of lysimeters, which limits their wide use and multiple installation. There is no agreement as to which method provides the best ET estimate in comparison to lysimeters.

The Water balance, or the inflow-outflow method, has been used on large areas such as valleys in which the inflow and outflow are determined from streamflow and precipitation measurements, and where the basin is confined to eliminate other significant sources of inflow or outflow. In the water balance equation, ET is directly inferred from the residual of the soil water balance after all other terms have been measured. ET is given by the water balance equation.

$$ET= AW+R_{ef}+I-D-U$$

Where AW is soil water available (mm); R_{ef} is effective precipitation (mm); I is irrigation water (mm); D is drainage below the root zone (mm) and U upwards flow (mm).

Indirect measurement method.

There are theoretical and empirical methods of estimating ET. The literature has a considerable number of papers relating potential ET and actual ET for different crops and soils. Calculation of reference crop evapotranspiration is a procedure commonly used in irrigation management programs and is related to empirical methods or evaporation pans.

The indirect methods of estimating ET can be grouped in *energy balance methods*, *heat and mass transfer methods*, *combination of energy and heat and mass transfer methods* and *evaporation methods*.

These models are being developed and evaluated for a variety of crops and conditions. The current models provide a mechanism of estimating actual

ET and also of separating soil water evaporation and plant transpiration. These physically based models have a minimum of empiricism. The indirect methods are easily simulated using computer models of actual ET and they provide a more complete description of the interactions between the soil-plant-atmosphere components. They provide a clearer understanding of the physics of energy exchanges.

Energy balance methods. These methods can be used for hourly or shorter values, especially during daylight hours. The instrumentation requirements and technical procedures involved generally limit the energy balance methods to research studies . The results can be very reliable if the measurements are accurate because they are obtained under natural environment (Jensen et al., 1989).

Heat and mass transfer methods require complex instrumentation and well trained personnel to obtain accurate results. They can be used as field determination of ET.

Combination methods have been used for estimation of ET from climatic data.

Evaporation Pans. Research of ET methods has progressed in the past 20 years. The information on ET is being used each day in applications ranging from irrigation scheduling to watershed hydrology and environmental analyses. The ease of use, simplicity of data and low cost have prompted the wide adaptation of the evaporation pan. The literature abounds in references to the use of evaporation pans and the development of crop coefficients for the estimate of potential ET from pan data. When installed in "standard" grass weather station environments with adequate maintenance, evaporation pans can reliably estimate potential ET, especially if the pan evaporation is averaged for time periods over 7 days (Howell et al., 1983).

Thom et al. (1981) made a comprehensive analysis of the Penman model compared to pan evaporation, and concluded that pan evaporation was adequately described by a combination equation with an adjustment in the psychometric constant and wind function for the pan.

Pan evaporation data have been used to develop curves for potential consumptive use of water by crops. Relationships among meteorological parameters and pan evaporation have been developed for locations around the world. Technology has also been introduced into the evaporation pan with several techniques proposed to automate the readings in order to make it compatible with data acquisition systems (Phene & Campbell, 1975). Limitations to the use of evaporation pans are related to the environment in which they are located. The pan serves as a source of available water for wildlife, and screens are necessary to protect the pan.

Howell et al. (1983) compared evaporation measurements from "screened" and Standard Class A pans with potential ET estimates by the Penman and Van Bavel equations. In comparing the evaporation from screened and uncovered evaporation pans, it was found that the screen reduced the rate by 10%. They concluded this effect was due to reduced radiation rather than aerodynamic effects. The study shows that the Penman calculation of potential ET was 91% of the screened pan evaporation, and the Van Bavel calculation of potential ET was 95% of the screened pan evaporation.

Thom et al. (1981) reported a 8.5% loss of rainfall by splash out of the pan. Pruitt (1966) developed coefficients that can be applied to evaporation pans to adjust for environmental changes.

The Campbell and Phene (1976) study conducted at Florence, South Carolina (a humid environment) reported that a 50 mm mesh screen covering a class A pan reduced the pan evaporation and was directly equated to potential ET as defined by Van Bavel (1966) when the roughness length parameter was 0.1 m (roughness parameter for momentum used in combination methods of calculating ET, it is a function of the crop height, 1/10 of crop height).

2.3.3 Different considerations of irrigation scheduling.

Plow layer management approach. This approach involves the recharge of only the plow layer with each irrigation (Rhoads and Stanley, 1981). This method is especially suited to humid regions because it leaves part of the root zone unrecharged to reduce percolation loss when rain occurs soon after irrigation.

Deficit irrigation. This consideration refers to incomplete refilling of the available water capacity in the root zone. The advantages include soil water conservation, less erosion, lower costs and reduced leaching. For soils with deep rooting zones, the plant can utilize soil water that is initially stored in the subsoil when the growing season begins, excess rainfall and irrigation water that percolates into the subsoil during the growing season and applied irrigation water that is stored in the surface soil. For soils with shallow root restricting barriers, properly scheduled deficit irrigation can provide adequate water, but in prolonged dry periods, more frequent irrigation will be required because the subsoil moisture is either not available, or only slowly available, to the plant.

Economic Considerations. The first decision required of irrigation planners is whether or not to install a crop-watering system. Increased yield in response to irrigation must have a higher value than installation, maintenance and energy costs. A study in Illinois indicated that a maize yield increase of 4.5 to 5.6 Mg/ha due to irrigation was required to be financially feasible (Schoney and Massie, 1981). A North Dakota economic analysis of maize production indicated that supplemental irrigation on soils with water-holding capacities > 250 mm over the top 1 m of soil is not profitable (Wilson and Eidman, 1983).

However, dry periods of 2 weeks or more can cause significant yield losses on sandy soils in humid regions. Results of an experiment in Florida showed that corn yield on sandy soil without irrigation was 0.6 Mg/ha. However, with irrigation the yield was 13.9 Mg/ha (Haise and Hagan, 1967).

2.4 MAIZE CHARACTERISTICS AND REQUIREMENTS

2.4.1 Vegetative growth of grain maize

Vegetative development is dependent on crop variety, soil type and environmental factors. Generally, a shorter vegetative growth period is associated with higher temperatures, while water deficits lengthen the vegetative growth period. Development of adequate leaf area necessary for interception and utilization of incident radiation is important, and has been shown to be closely related to final grain yield. Following seed germination and seedling emergence, maize typically initiates and expands 20 to 21 leaves during a period which may range from 60 to 65 days. Appearance of new leaves may be as rapid as one every 3 days. Maximum leaf area index (LAI) typically ranges between 3 and 5 for crops grown under optimal conditions (Rhoads and Bennett, 1990).

Full plant height is attained near silking which occurs 2 to 3 days after tasselling. Stresses imposed near the silking period have been shown to have dramatic effects on final grain yields. Numerous studies have demonstrated that the pollination and early seed establishment periods are quite sensitive to water deficits. After pollination, seeds develop through blister stage 10 to 14 days after silking (DAS), followed by dough (24-28 DAS), dent (35-42 DAS) and physiological maturity (55-65 DAS) for a typical maize hybrid (Rhoads and Bennett, 1990).

2.4.2 Root growth of maize

The root system of maize is highly dependent on the depth, layering, density and chemistry of the soil profile and the fluctuation of the available water.

Studies have shown that root dry matter in the upper 0.30 m of sandy soil profiles with varying depths to the water table ranged between 69 and 97% of the total amount of roots observed. Maximum rooting depths for a fully grown and well-watered maize are commonly between 1.2 and 1.5 m, (Rhoads and Bennett, 1990). Most of the water requirements of maize have been shown to be supplied by root uptake in the upper 1.0 m of sandy soils. Both water and nutrient uptake patterns are related to the extent and distribution of the root system (Rhoads and Bennett, 1990). Although little information is available concerning production of new roots and senescence of older roots during water stress periods, some enhanced root senescence undoubtedly occurs with severe stress (Rhoads and Bennett, 1990).

2.4.3 Evapotranspiration requirements of maize.

Evaporation from the soil is the major component of total ET during the early stages of crop growth. However, after leaf area increases, crop transpiration gradually becomes the dominant component of ET. The daily water use rates of maize increase in parallel with increases in leaf area and light interception, and generally peak between 7 and 8 mm/day near the date of complete closure of the crop canopy (Reddy et al., 1982). Seasonal ET for maize is a function of the length of the growing season and the environment in which the crop is grown. Average values of maize ET ranging from 430 to 650 mm per season have been computed. In the cooler environment of southern Alberta, Canada, Krogman et al. (1980) reported a seasonal ET of 436 mm for an early hybrid. Two studies in Kansas have shown values that range from 600 to 650 mm (Mayaki et al., 1976; Rosenthal et al., 1977). Data from Georgia was 430 mm (Hook, 1985), while from Florida ranged from 430 to 440 mm (Hammond, 1981).

It has been clearly demonstrated that high maize yields can be produced with less water required for ET in the more humid environments, resulting in increased water use efficiency (WUE). However, irrigation management becomes a more complex factor , especially where the soils have low water-holding capacities.

Studies by Dale and Shaw (1965), Corsi and Shaw (1971), Shaw and Felch (1972), Jensen (1968) and Stewart and Hagen (1973) found a linear relationship between yield response and the ratio of actual to potential transpiration.

2.4.4 Water stress effect on maize

Yield response to soil moisture stress is important in developing strategies for irrigation management under water limiting situations. The duration and intensity of stress is dependent on the environmental conditions, water-holding capacity of the soil and crop growth stage during which water deficits occur.

Morey et al. (1980) evaluated the yield response of maize over three years on soil consisting of 300 to 450 mm of Hubbard loamy sand underlaid with gravelly coarse sand. The available soil moisture-holding capacity was low (40 to 90 mm of water) in the top 450 mm of soil. Even though average growing season precipitation is approximately 470 mm, the low available moisture-holding capacity often leads to stress conditions. They found significant differences between irrigated and non irrigated treatments.

The transpiration estimate is a function of crop growth stage, atmospheric demand (pan evaporation) and soil moisture tension. For soil moisture tensions less than 0.15 atmospheres, it is assumed that ET is at the potential rate with no reduction due to soil moisture conditions. As soil moisture stress increases, predicted transpiration decreases (Denmead and Shaw, 1962).

To standardize comparisons, a variable called transpiration ratio is defined as the ratio of ET occurring under predicted soil moisture conditions to potential ET; ET/PET.

Water deficits during silking, tasselling and pollination are especially detrimental to yield and may result in the delay of silking (Barnes and Woolley, 1969; Hall et al., 1980), reduced silk elongation (Herrero and Johnson, 1981) and inhibition of pollination. Stresses imposed shortly before or after silking considerably reduce seed numbers (Musick and Dusek, 1980). Stress imposed later during the grain-filling period may cause increased leaf senescence, a shorter duration of the seed-filling period, increased lodging and lower individual seed weights. The primary effect of water stress during the grain-filling period is a reduction in current photosynthate supply which is critical for optimum seed filling. The period most susceptible to water stress is the period surrounding silking and tasselling.

Little research has been done to compare crop response to rapid imposition of stress which occurs on sandy soils, with the more gradual development of water stress which is associated with clay soil types. Most studies have focused on relatively severe stress periods which cause large reductions in yield. Kramer (1963), summarized studies that show that even relatively lower, average soil-water stresses cause measurable decreases in growth.

Collins et al. (1984), studied the influence of soil moisture and soil bulk density on the imbibition of maize seeds in sandy soils. They concluded that changes in bulk density of the soil over the range from 0.90 to 1.31 Mg/cm produced no significant effects on water uptake. The seed coat permeability of maize is the major restriction on entry of water into the seed during imbibition.

Irrigation scheduling by tensiometers, gypsum blocks and other in situ soil moisture sensors has effectively met maize water needs. To date, the highest yields of maize have been obtained when matric potential in the upper 300 mm of soil has been maintained above -25 kPa (for sands) to -40 kPa (for clays) (Rhoads and Stanley, 1973, 1974; Bruce, 1972; Phene and Beale, 1976).

2.5 SUMMARY

For irrigation studies, the upper 1 m of soil is of primary importance. The water losses from this layer of soil are due to evapotranspiration and deep percolation. Therefore, the water content varies with depth and with time.

Measurements of the soil water content may be done by direct gravimetric methods, and by indirect methods. The gravimetric methods consist of sampling the soil, weighing, drying and then reweighing. These methods are destructive sampling methods, but studies have shown that they are accurate to 96 % or more with a sample of at least 20 g. The indirect methods are in situ, non destructive and accurate, but they are expensive and the operator needs extensive training.

Studies have shown that soil particle distribution, bulk density and soil crust are determining characteristics in seedling emergence, and vegetative growth of crops. These characteristics also influence water infiltration and water holding capacity significantly.

Carefully prepared and installed tensiometers have proved to be the most precise devices for measuring the suction of water in soil. Once the soil has been evaluated, tensiometers can be used easily for irrigation scheduling purposes.

Research has shown that potential ET calculated with the Penman and Van Bavel equations are 91% and 95%, respectively, of potential ET measured by screened evaporation pans.

Most of the water requirements of maize have been shown to be supplied by root uptake in the upper 1.0 m of sandy soils. Water deficits during silking, tasselling and pollination are especially detrimental to yield and may result in the delay of silking, reduced silk elongation and inhibition of pollination. Little research has been done to compare crop response to rapid imposition of stress such as that which can occur on sandy soils.

In humid areas, deficit irrigation is the system that is most recommended for the operation of irrigation systems. This criterion retains a reservoir for rain to refill the soil profile. Care should be taken in soils with low water holding capacity. Sandy soils with low water-holding capacities can accumulate only limited amounts of water during the noncropping season, and yield depends primarily on precipitation and irrigation during the cropping season.

The literature review presented in this chapter gives the advantages and disadvantages of different methods of soil evaluation, crop water requirements and irrigation scheduling techniques. The simplest and easiest techniques are gravimetric methods for soil evaluation, tensiometry combined with evaporation pan for water consumption and deficit irrigation technique.

The study presented in this report is on sandy soil in a humid region. The type of stress at which the crop may be exposed is mild. Little research has been done on effects of mild water deficits on maize growth, development and yield. No published data on water consumption of maize in Eastern Ontario and Québec were found.

CHAPTER III

SITE AND PROCEDURE DESCRIPTION.

3.1 LOCATION

The fields used in this research are located Eastern Ontario, in The Lamoureux farm, IX and X Concessions of Plantagenet Township, Prescott County in the Ottawa Valley. Prescott and Russell Counties are a smooth plain that lies between 74°23' and 75°10' West Longitude, and 45°18' and 45°30' North Latitude.

The Lamoureux farm consists of lots number 17, 18, and 19 in the IX Concession of North Plantagenet Twp., and lots 17 and 18 in the X Concession of South Plantagenet Twp. The farm is divided into fields, fields 1, 2 and 3 in the X concession and fields 4, 5, 6 and 7 in the IX concession. The X Concession road divide the farm, from west to east. The fields selected for this research are fields 1, 4 and 5 (Figure 3.1). The area is 13 hectares each for fields 1 and 4, and 26 hectares field 5.

3.2 SOIL DESCRIPTION

The soils of these fields are Uplands fine sand (Ufs) and Rubicon fine sand (Rfs) according to the soil survey of Russell and Prescott counties (Wicklund, 1962), (Figure 3.2). The Upland and Rubicon series of soils are developed on sandy outwash or sandy deltaic deposits. The short description of these soils given below has been obtained from the soil survey of Russell and Prescott counties:

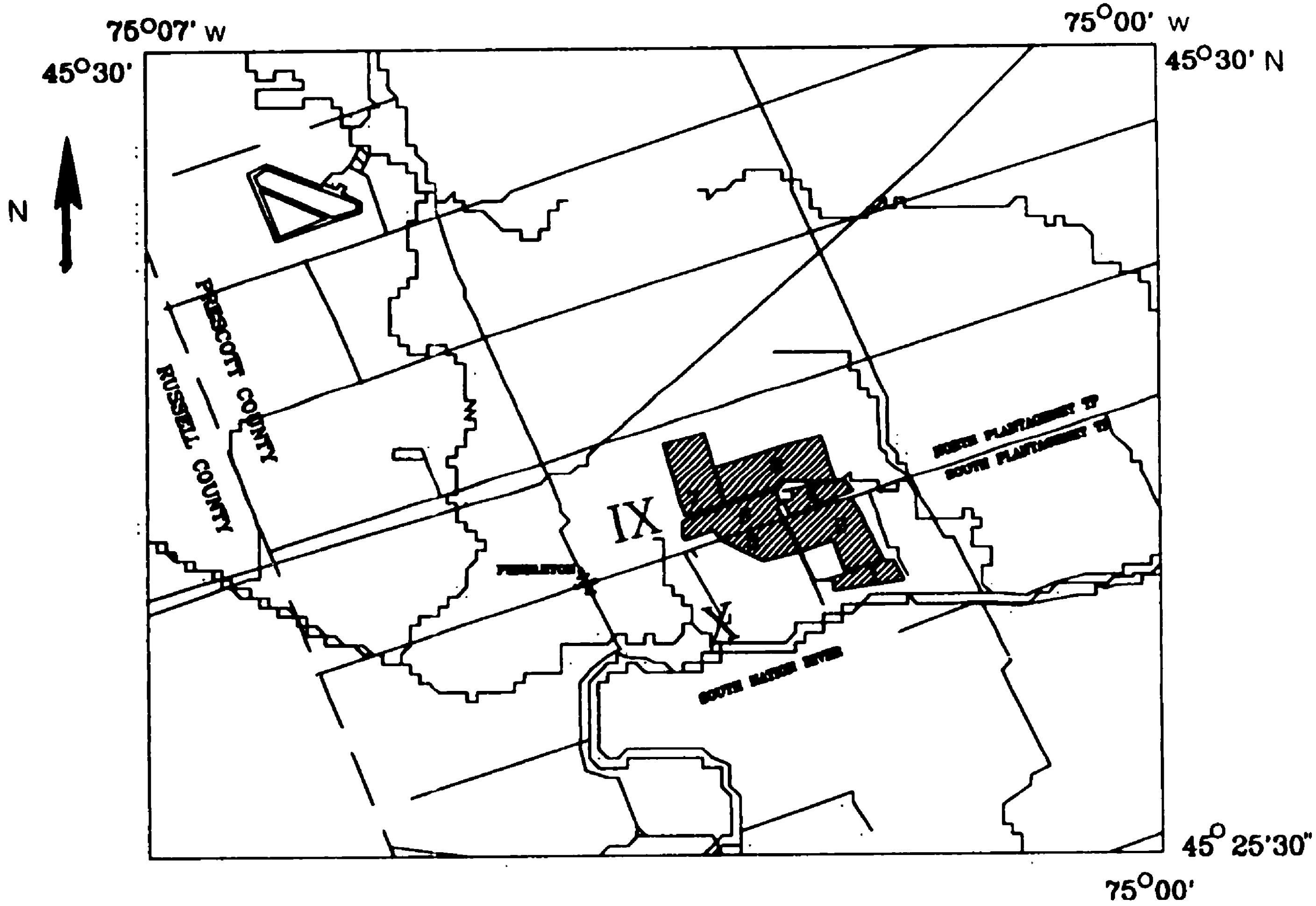


Figure 3.1 Location of the Lamoureux farm

Upland Series: The upland series are well drained soils that occur on fine sand deposits which are non-calcareous, deep, and have quite variable topography. The sandy deposits have uniformly fine particles in which the silt and clay content is very low. Although cultivation and the production of crops is carried on most of the areas where these soils occur, they are poor agricultural soils. They possess little fertility and have, in addition, a low moisture holding capacity. Fertilizer use for crop production on these soils should probably be designed only for the immediate feeding of the crop and not in an attempt to build up the soil for subsequent crops.

Rubicon Series: The Rubicon Series are imperfectly drained soils associated with the Upland Series. These soils occur almost exclusively on the flatter topographic areas where there are few, if any, stream courses cut in the sand plain or where the sand deposits overlie a clay deposit at a depth of a few feet.

In these locations water moves very slowly and the soil is often saturated to the surface for several month of the year. As a result, the soil has developed strongly mottled horizons. In many of these locations a fairly thick iron pan layer develops that is soft during the periods when the soil is wet, but during the dry summer months becomes very hard and impermeable.

A large percentage of this soil is under cultivation. Like the Uplands series, these are rather poor agricultural soils but, as a result of their topographic position, they have a better moisture reserve for the dry months of the year.

3.3 PROBLEM DESCRIPTION

In the past, the fields of The Lamoureux farm were utilized to grow potatoes under supplemental irrigation. The source of irrigation water is the South Nation River. In 1996 the farmers decided to grow maize and soybean, on which they have no previous experience. The irrigation systems that the farm possesses are a travelling sprinkler and a self propelled lateral sprinkler.

The Ottawa Valley, is a generally temperate humid environment with mean annual temperature of 5.9°C and yearly average precipitation of 906.9 mm (Atmospheric Environment Service Canada data collected between 1951 and 1984). The supplemental irrigation must be economically feasible for maize and soybean production.

The fields were monitored during the summer of 1996 to evaluate the local soil-water-crop relationships and to propose an irrigation management practice. The research was mainly focused on maize, which is the major crop that the farmer decided to grow. The farmer did not irrigate in 1996 as rains came at good times with satisfactory amounts for most of that growing season.

The fields of the farm (Figure 3.2) contains Uplands and Rubicon soil series. Soil samples were taken from the most critical locations within the field, according to the soil survey and previous experience of the farmer. These were spots that get dryer than the rest of the field, or that keep wetness longer than the rest of the fields (Figure 3.3).

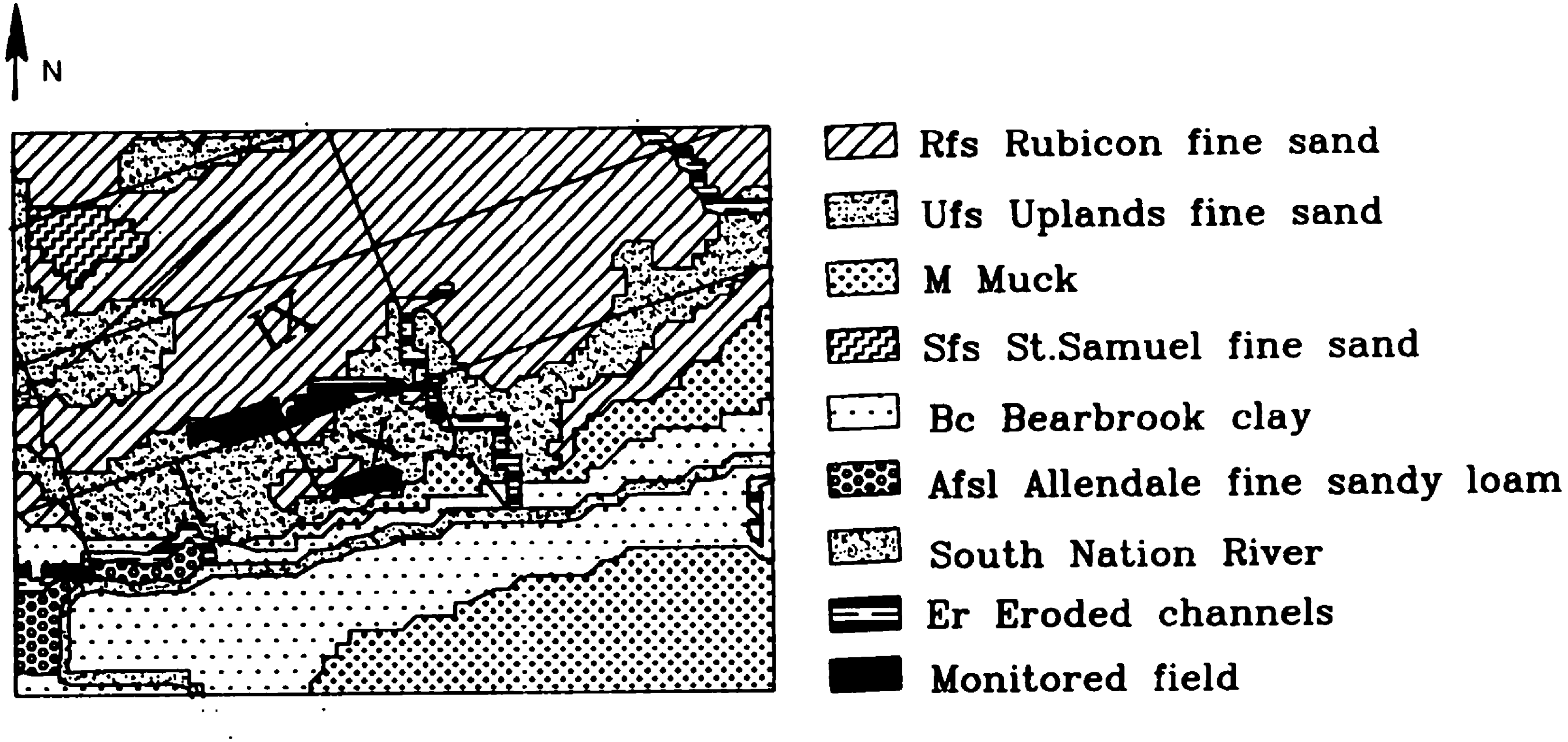


Figure 3.2 Soil Map of the study area

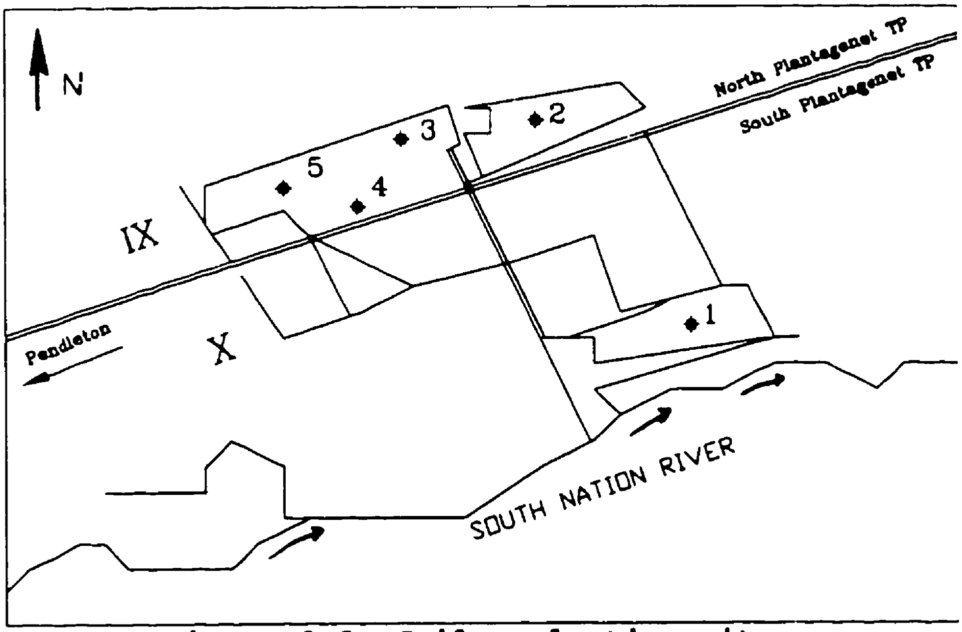


Figure 3.3 Soil evaluation sites

The soil-water relations were evaluated using gravimetric methods by means of undisturbed soil samples, followed by disturbed soil sampling and tensiometry for the rest of the summer. Observations of different stages of crop development and meteorological data were made.

3.4 EXPERIMENTAL PROCEDURE AND EQUIPMENT DESCRIPTION

3.4.1 Soil properties determination

Gravimetric methods were used to measure soil properties and water content. Undisturbed samples were taken in five locations (Figure 3.3). These were used to do the soil evaluations in the different soil types within the farm. Disturbed samples were taken every other day at the same time that tensiometers were read. The disturbed samples were taken in three locations (sites 1, 3 and 5). Two samples on each site (Figure 3.4). Undisturbed and disturbed sampling were done in three layers of the soil profile (layers A, B and C).

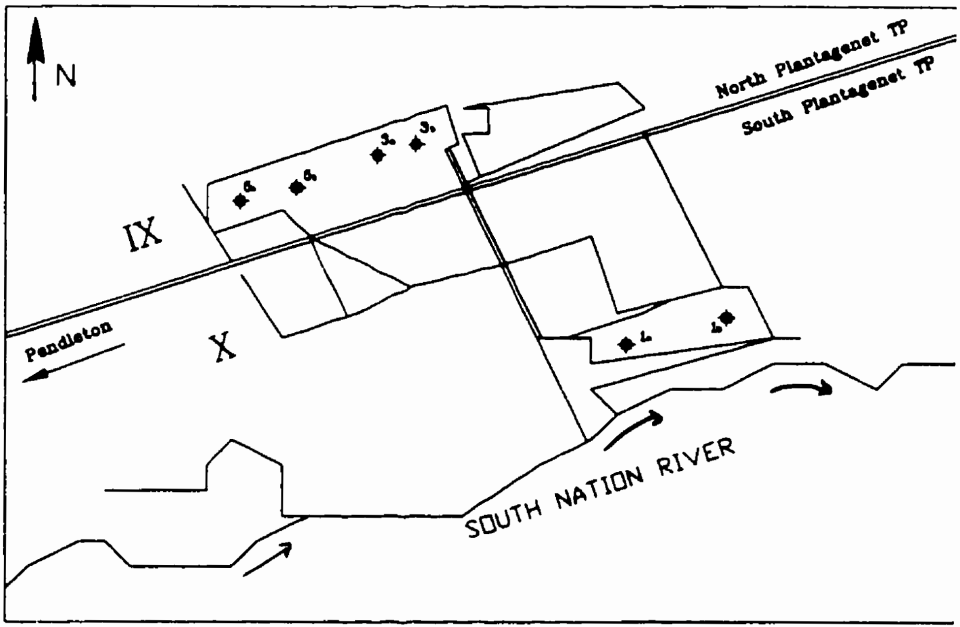


Figure 3.4 Monitored sites

3.4.1.1 Undisturbed Method.

Water content.

Samples were taken in the five locations (Figure 3.3). The samples were taken in early June two days after a few days of rain (54 mm in 9 days). This amount of rainfall wetted the root zone to field capacity, according to the definition of Veihmeyer and Hendrickson (1931) and SSSA (1984). The results of moisture content at field capacity were also confirmed by laboratory measurements.

Cores 100 mm diameter and 100 mm height were taken at three depths within the soil profile: 50-150 mm, 300-400 mm, and 500-600 mm. These three depths represent layers A,B,and C respectively. They will be referred to with the layer name in the rest of the thesis. Layer A is 0 to 200 mm; layer B is 200 to 400 mm and layer C is 400 to 600 mm deep from the ground surface.

Two aluminum cores of undisturbed soil were taken at each layer, at each site, making a total of 30 cores. The cores were inserted in the undisturbed soil with the proper core driver and carefully removed to prevent soil disturbance. They were trimmed with a fine saw and placed into individual cans to maintain the core structure and volume. Then the samples were weighed in the field to avoid evaporation losses using a 0.1 g precision balance. The samples then were dried in an oven at 105°C for 24 hours, and reweighed.

The data obtained was used to calculate *bulk density (BD), field capacity* (FC), and *particle size analysis of the soil.* The procedure was the following:

Bulk density (BD), is the ratio of mass of dry solids to the bulk volume of the soil ($g.cm^{-3}$).

[(dry mass - mass of empty core) / (volume of the core)]

$$M_S/V_a \qquad (1)$$

M_S= mass of the soil (g)
V_a= volume of the core (cm^3)

Field Capacity (FC). The samples used to measure the bulk density were then used to measure field capacity.
The soil water content at FC was calculated by:

$$FC_W = M_W/M_S \quad (2)$$

or

$$FC_V = FC_W \times BD/WD = M_W/(V_a{*}WD) \quad (3)$$

FC_W= FC by weight (g water/g soil)
FC_V= FC by volume (cm^3 water/cm^3 soil)
M_S= oven-dried mass of soil (g)
M_W= mass of water (g)
BD= soil bulk density (g/cm^3)
WD= water density (g/cm^3)
V_a= bulk soil volume (cm^3)

The results of the measurements are given in chapter 4.

Particle Size Analysis. Standard mechanical particle size analysis was performed on all samples. The set of U.S. standard sieves used for this analysis include sieves number 20, 35, 60, 100, 200,and 325 with a pan underneath. The corresponding opening sizes for these sieves are listed in Table 3.1 along with other equipment required.

Table 3.1 Apparatus for Sieve Analysis

EQUIPMENT	SPECIFICATION								
Sieves	No.	20	35	60	100	200	325	pan	lid
	Opening (mm)	0.85	0.50	0.25	0.15	0.075	0.045	---	---
Balance	electronic, sensitive to 0.1 g								
Oven	105°C, constant temperature								
Mortar & Pestle	ceramic pestle								
Shaker	mechanical, horizontal rotation								

The procedure followed the description by Loveland and Whalley in Soil Analysis (1991).

- The samples used were the same as the ones used to measure field capacity. They were dried in the oven for 24 hours at 105°C.
- The sieves and pan were cleaned and dried. The weight of each sieve and the pan were measured and recorded. The sieves were nested in order of descending opening size.
- The sample of approximately 1 kg was broken into individual particles with the help of a mortar and pestle.
- The sample was placed in the top sieve.
- The nested sieves, closed with a lid, were mechanically shaken for 10 minutes.
- The sieves were carefully separated. The weight of each sieve and the pan, with their respective amounts of retained soil were recorded.
- Calculations of percent of soil passing each sieve were made, and the corresponding grain size distribution curve was plotted.
- The procedure was repeated for each soil sample.

The results of grain size distribution curves are in Appendix A.

Water potential.

Water potential was measured by the filter funnel method and tensiometry. The relationship between water content and matric potential (matric suction) in a drying soil can be given in graphical form, as the soil moisture retention curve.

The samples were taken in the same sites and at the same time as the samples taken for bulk density and particle size analysis. The cores for this analysis were 70 mm diameter and 40 mm height. The procedure for taking the samples was the same as that for water content analysis, except that these samples were not placed inside cans. These cores were covered at the bottom with cheese cloth, secured with elastic bands and then placed in plastic bags tightly closed.

The measurements of water retention were done using the Haines filter funnel. With this apparatus water was removed from the soil by applying a controlled vacuum to each sample through a porous ceramic plate, which served as a membrane providing passage for water but not for the soil. The procedure was as follows:

- The Haines filter funnel, connecting tube and burette were filled with water from beneath the plate via the burette in order to completely eliminate air bubbles from the porous plate.
- The soil core was placed in the funnel and saturated from below by raising the water level in the burette above the soil in the funnel.
- The saturated soil was held at zero suction ($MC=MC_{sat}$; $P=0$ cm).
- Subsequently the suction was increased. The sample was equilibrated at 0, 5, 10, 30, 60 and 100 cm of vacuum by lowering the burette. The required distance was measured from the mid-height of the soil sample.
- The burette reading was recorded at each step.
- When the last equilibration was completed, approximately the top half of the soil sample was removed and placed in a previously weighed moisture can to determine its gravimetric water content by drying in an oven for 24 hours at 105°C.
- The undisturbed bottom half of the soil sample was saturated and placed in a previously weighed moisture can to determine the gravimetric water content at saturation.
- The volumetric water content at a given equilibrium point (P) was

calculated using the bulk density values obtained with the previous samples.

$$MCv_P = MCv_{sat} - (V_P/V_a)X100$$

and

$$MCv_{sat} = MCw_{sat} \text{ x } BD$$

where,

MCv_P= volumetric water content at a given pressure P (%H_2O/vol).

MCv_{sat}= volumetric water content at saturation (%H_2O/vol).

V_P= volume of water extracted at a given P (cm^3).

V_a= volume of the core (cm^3).

MCw_{sat}= mass of water content at saturation (%H_2O/weight)

BD= bulk density (g/cm^3).

When P= -100 cm, all menisci in pores with a diameter greater than 30 μ will break and these pores will drain completely. When the outflow has ceased, the moisture content of the sample is determined (Smedema and Rycroft, 1983). The results were plotted as percent water by volume vs. cm of water potential.

The values of MCv_{sat} and FC_v were used to calculate drainable porosity (DP) in %.

$$DP = MCv_{sat} - FC_v$$

The results of soil moisture retention curves, moisture content, and drainable porosity are in Appendix A.

3.4.1.2 Disturbed sampling method

Soil Moisture Content.

Moisture contents were determined by taking disturbed soil samples with an auger at the three layers selected to be monitored during the vegetative growth of the maize. The soil samples were taken at the same location as the tensiometers were installed, and at the time the tensiometers were read. The soil samples were taken and immediately placed in cans and weighed in the field. Then they were transported to the laboratory, placed in the oven for 24 hours at 105°C and reweighed.

Water Potential.

The water potential was determined in the field by tensiometers. Three tensiometers were installed at each site (Figure 3.3), one tensiometer in each layer of the soil profile (Figure 3.4). The preparation and installation of the tensiometers was according to the procedure suggested by the manufacturer (Irrometer Company).

The tensiometers were installed in rows of maize in the selected plots. Readings were made every other day and before and after rainfall (Figure 3.5).

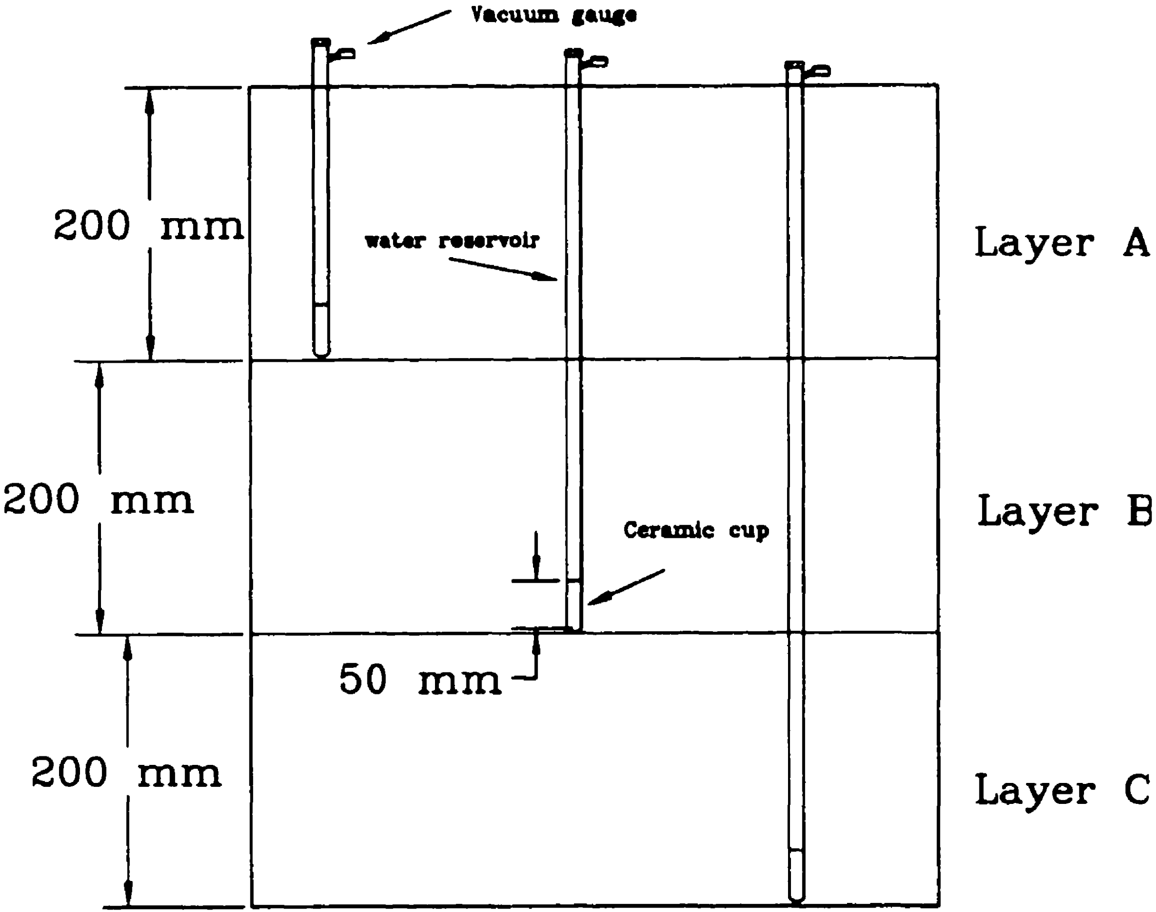


Figure 3.5 Tensiometers layout

Climatologic data.

Rainfall, evaporation and max-min temperature data were collected during the study period. Also climatic data recorded for Ottawa NRC station was used as reference.

A meteorological station was installed on the lawn south of the farm house near the edge of the maize field. The readings of rainfall, evaporation and temperature were made at approximately 8 AM each day.

Rainfall and Temperature. Rainfall was measured using a "Tru-Check" manual rain gauge, with a scale from 0.1 to 150 mm. The temperature was measured by a min-max thermometer placed in a louvred Stevenson screen. The bottom of which was 1.5 m above the lawn grass.

Evapotranspiration was measured during the study period using a screened Class A evaporation pan, which is a cylindrical galvanized steel container 0.254 m deep and 1.206 m in diameter. It was placed on top of a wooden grid 150 mm off the ground to maintain air flow underneath. The evaporation pan was covered with a plastic screen of 12 mm by 12 mm squares. The water level in the pan was replenished each day to 70 mm from the top. The screen was used to reduce pan evaporation to approximate Potential Evapotranspiration, as was described by Campbell and Phene (1976).

Rainfall, evaporation and temperature data are given in Appendix B.

Water balance.

The depth of available water at any day was tabulated using the relationship:

$$AW_n = AW_{n-1} + \text{Rain} + \text{Irrigation} - ET_{s.pan}$$

Where AW_n and AW_{n-1} are available water at days n and n-1 in mm.

CHAPTER IV

RESULTS, ANALYSIS AND DISCUSSION

4.1 SOIL PROPERTIES AND MOISTURE CONTENT

Because of the nature of soil-formation processes, distinct boundaries between soil classification units are rare. However, we may find rather marked local variations. These local variations may result from natural causes, such as sharp topographic variations, or from human soil grading and cultivation. Soil properties vary not only from one location to another, but also among the horizons of a given profile. For example, tillage performed during the post-harvest period to leave a coarse soil structure on top of the tilled layer, serves to reduce soil water loss by evaporation (Hadas and Hillel, 1972). Ojenniyi and Dexter (1984), stated that structural parameters like bulk density and void ratio of tilled soil had more influence on soil water content at the beginning of the cropping season and that large clods on top of the tilled soil does not significantly influence actual water content.

In this research, the evaluation of the soils was done by analyzing samples taken in the three layers (A, B and C) described in Chapter 3. The set of results of structural features, soil properties and laboratory analyses are given in Appendix A. Table 4.1 is a summary of the mean values of soil properties from the five sites shown in Figure 3.3.

Calculations of coefficient of uniformity were done using the relation:

$$C_u = D_{60}/D_{10}$$

where C_u is the coefficient of uniformity, and D_{60} and D_{10} are particle diameters for which 60 and 10 percent of soil by weight is smaller. The percentage of particle of silt, fine sand and medium sand were taken from the particles size distribution graphs in Appendix A.

The bulk density values at which root growth is either unaffected or severely affected were estimated with the equations described by Jones (1983).

$$BDl = 1.1 + 0.005 * (\% \text{ of sand})$$

and

$$BDM = 1.6 + 0.004 * (\% \text{ of sand})$$

where BDl is limit value of bulk density at which there is no inhibition of root growth, and BDM is the maximum value of bulk density at which roots can penetrate the soil (Table 4.1).

The drainable porosity is the difference between the percentage water content by volume at saturation and the percentage water content by volume at field capacity (Table 4.1).

Table 4.1 Soil dry bulk density and particle size distribution.

Site	**Layer**	**Bulk density (g/cm^3)**	**Particle size (%)**			**C_u**	**Bulk density g/cm^3**		**Drainable porosity (%)**
			Silt	F.sand	M.sand		BDL	BDM	
1	A	1.60	6	86	8	2.74	1.57	1.98	23.16
	B	1.49	5	92	3	2.40	1.57	1.98	26.79
	C	1.46	5	92	3	2.40	1.57	1.98	28.69
2	A	1.40	8	83	9	2.02	1.56	1.97	11.52
	B	1.23	14.5	78.5	7	2.67	1.53	1.94	9.36
	C	1.55	6.2	85.8	8	2.67	1.57	1.97	19.76
3	A	1.35	5	74	21	2.42	1.57	1.98	21.18
	B	1.43	10.2	81.8	8	2.31	1.55	1.96	23.16
	C	1.58	6	82	12	2.95	1.57	1.98	13.07
4	A	1.38	7.5	63.5	29	3.10	1.56	1.97	12.39
	B	1.47	6	80	14	2.77	1.57	1.98	18.34
	C	1.52	6	86	8	1.76	1.57	1.98	9.58
5	A	1.41	4	92.0	4	1.94	1.58	1.98	15.63
	B	1.46	5	87.6	5	2.30	1.56	1.97	19.06
	C	1.34	9	81.0	9	2.22	1.55	1.96	26.30

4.1.1 Discussion of soil structural features.

Site No. 1 has the highest values of drainable porosity and the most uniform particle size distribution, compared to the rest of the fields. However, within the profile, the top layer has a bulk density 2% higher than the maximum value at which there is no inhibition to root growth (BDL). This high value could be due to some compaction and could be solved by some loosening technique. In addition this top layer has an 11% higher water holding capacity (Table 4.2) than layers B and C. The higher water holding capacity of this layer may be due to the presence of a 1% higher silt content than the rest of the profile. Having the highest water holding capacity on the top layer may increase water losses by evaporation. This could be part of the explanation for higher soil moisture depletion rates during the months of July and August in this site, compared to the rest of the fields (Table 4.5).

Site No. 2 has the highest percentage of silt and the highest values of moisture retention among the evaluated fields (Table 4.2). Layer B contains the highest percentage of silt in the soil profile, which gives the highest water holding capacity on the middle layer. This reduces water losses by evaporation. The presence of this layer with 14.5 % silt also prevents fast water drainage.

Sites 3 and 4 have the largest amount of medium sand in the top layers, 21% for site 3 and 29% on site 4. The presence of coarser sand on top reduces some water losses by evaporation; in addition it reduces erosion by water and wind.

Site 3 has the higher percentage of silt in the middle layer, which reduces the hydraulic conductivity and retains, more water for longer periods. Site 3 has a bulk density 0.5% higher than the maximum permissible value

(BDL), reducing the drainable porosity. As a result, layers B and C jointly present a less permeable layer that reduces the drainage rate. Site 4 has the highest value of silt in the top layer, which increases the water holding capacity of this layer.

Both sites 3 and 4 present soil crusting after planting in some years. By visual observations the rate of seedling emergence was smaller in site 4 than in the rest of the fields. The crusting in site 4 seemed to be thicker than in site 3.

Site 5 is well drained. It presents an increasing percentage of silt from 4% in layer A, 5% in layer B and 9% in layer C. The percentage of coarser sand is increasing in the same direction, which gives an increasing drainable porosity from layer A to C.

4.1.2 Soil moisture content.

The water release characteristics are given in Appendix A. **Table 4.2** shows a **summary** of the results of total depth of water at **field capacity** for each site. These values represent the total amount of water that the soil can retain.

The soil water content at **permanent wilting point** was determined by planting maize on soil samples taken from each layer of the soil profile. The maize plants were watered to allow the plants to grow until they reached a height of 300 mm. Then they were protected from the rain but not from the sun, until they were wilted and stayed wilted for 5 days with no overnight recovery. At this point the water content in the soil was obtained by weighing, drying and reweighing. After taking the soil samples the plants were watered but did not recover turgidity. **Table 4.3** summarizes the **permanent wilting**

point results. The available water is the difference between depth of water at field capacity, and the depth of water at permanent wilting point (Table 4.4).

From evaluation of the soil physical properties and available water capacity, it can be seen that site 2, has capacity for approximately 15 days of water consumption at a rate of 4.0 mm per day without rain or irrigation. The rate of 4.0 mm per day is a typical value of evapotranspiration in the Ottawa valley region for the summer growing season. Therefore, this site is less likely to need irrigation than the rest of the fields. Sites 3, 4 and 5 are in field 5 (Fig. 3.1). Site 4 has the highest soil moisture retention capacity. Thus, for evaluating irrigation needs of this field sites 3 and 5 were selected. Site 1 in field 1 has the lowest capacity to hold moisture. It is the most critical for irrigation purposes. Sites 1, 3 and 5 were selected for monitoring during the 1996 summer.

The monitoring of the soil water available with time, was done by tensiometers and auger soil sampling. The tensiometers were permanently installed in layers A, B and C, as described in chapter 3. The soil sampling was done one to two meters away from the tensiometers at the three depths where the tensiometers were installed, and at the same time that the tensiometer readings were taken. The mean values of the tensiometer readings and depth of available water are given in Appendix B. The results are also presented in graphical form. Figures 4.1, 4.2 and 4.3 show the available moisture content with time, and Figures 4.4, 4.5 and 4.6 present the relation between the available moisture content and the suction that the plants have to exert in the soil, in order to obtain the water that they need.

Table 4.2 Field capacity (F.C.), obtained by three methods,(mm).

Site	Undisturbed method (cores)			Disturbed method (auger)			Filter funnel method.		
	A	B	C	A	B	C	A	B	C
1	36.2	32.0	29.8	40.9	36.3	30.7	36.3	31.6	29.5
2	76.9	81.1	62.4						
3	68.1	70.2	70.5	71.8	72.9	71.9	73.2	68.3	71.5
4	71.3	56.9	68.9						
5	47.9	54.4	40.3	48.3	46.1	39.2	47.9	54.4	40.3

Table 4.3 Permanent wilting point water content (mm)

Site	layer A	layer B	layer C
1	7.8	13.7	8.4
2	13.0		
3	10.2	18.1	20.8
4	10.5		
5	5.4	18.6	14.7

Notes:

Layer A is 0 to 200 mm deep; layer B is 200 to 400 mm; layer C is 400 to 600 mm.

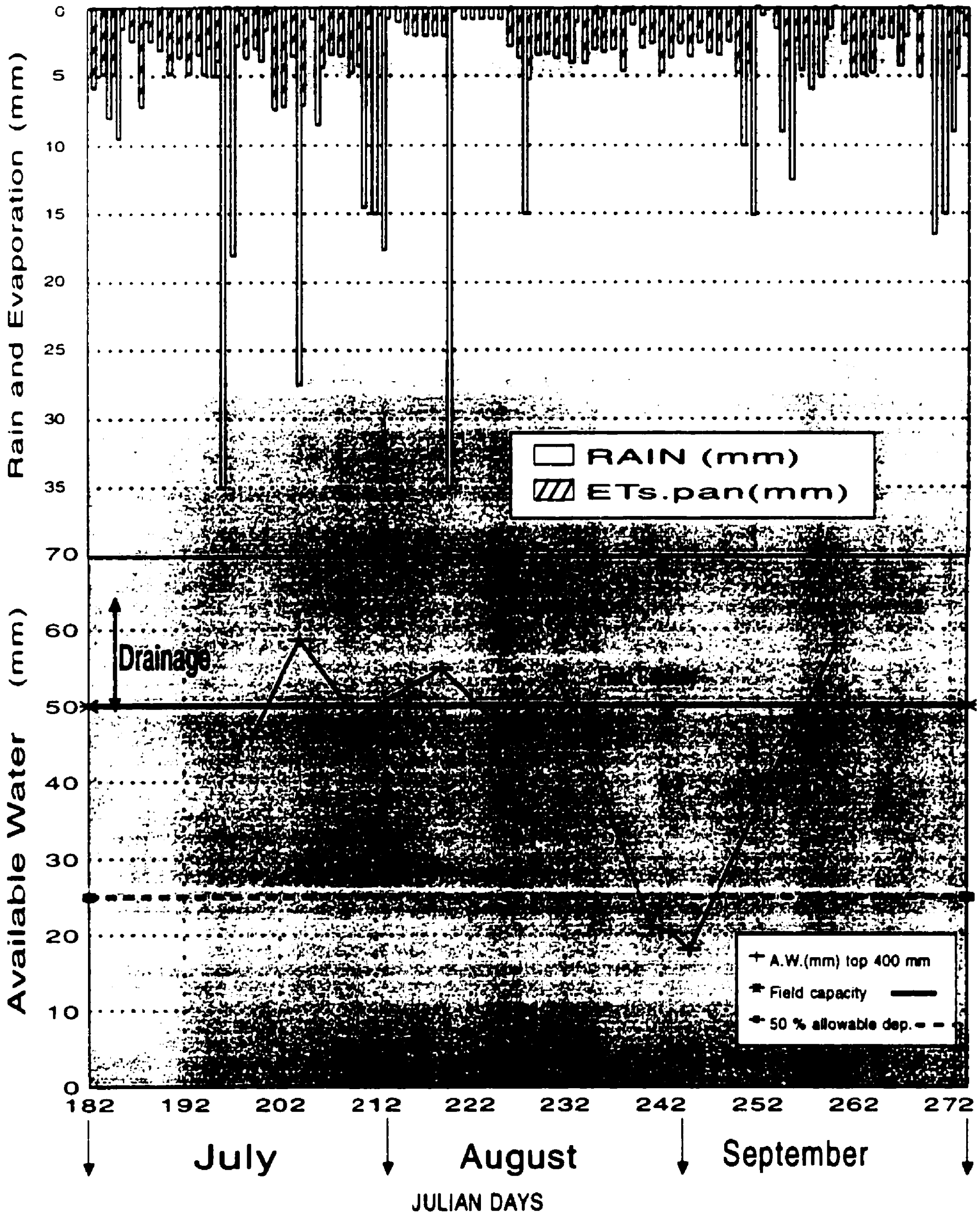


Figure 4.1 Available water with time (mm), summer 1996 (Site 1)

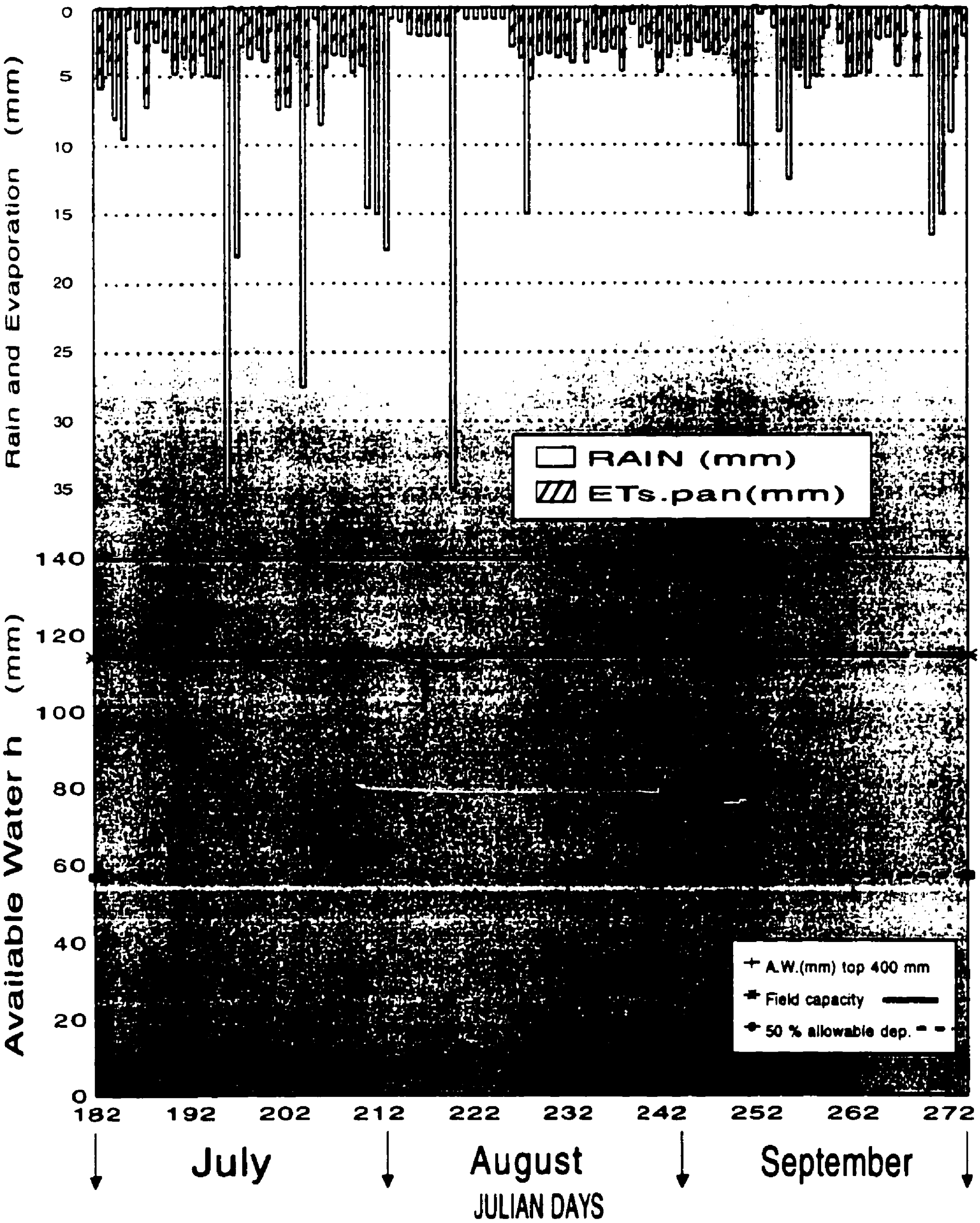


Figure 4.2 Available water with time (mm), summer 1996 (Site 3)

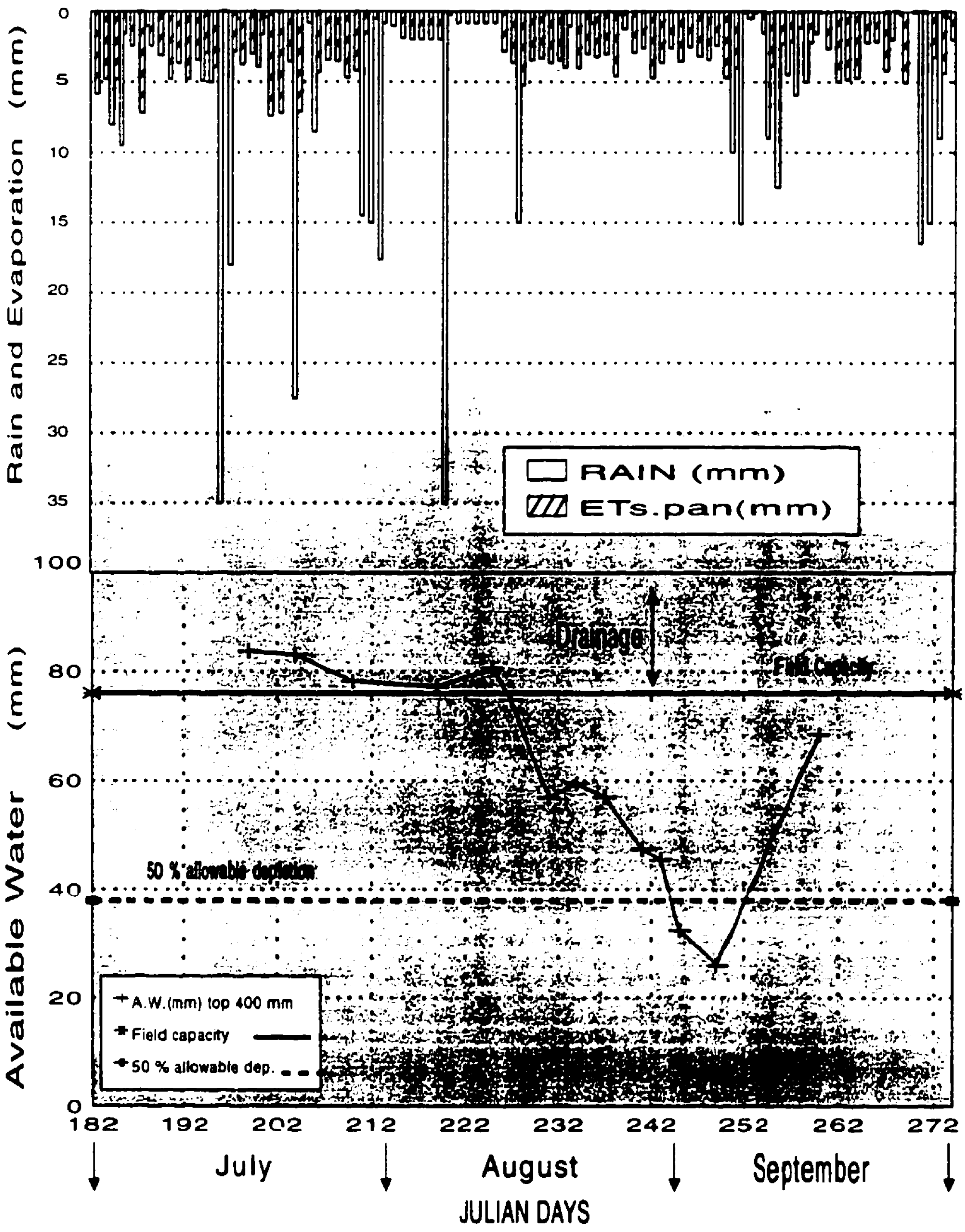


Figure 4.3 Available water with time (mm), summer 1996 (Site 5)

Figure 4.4

Water release characteristics (Site 1)

(tensiometer method)

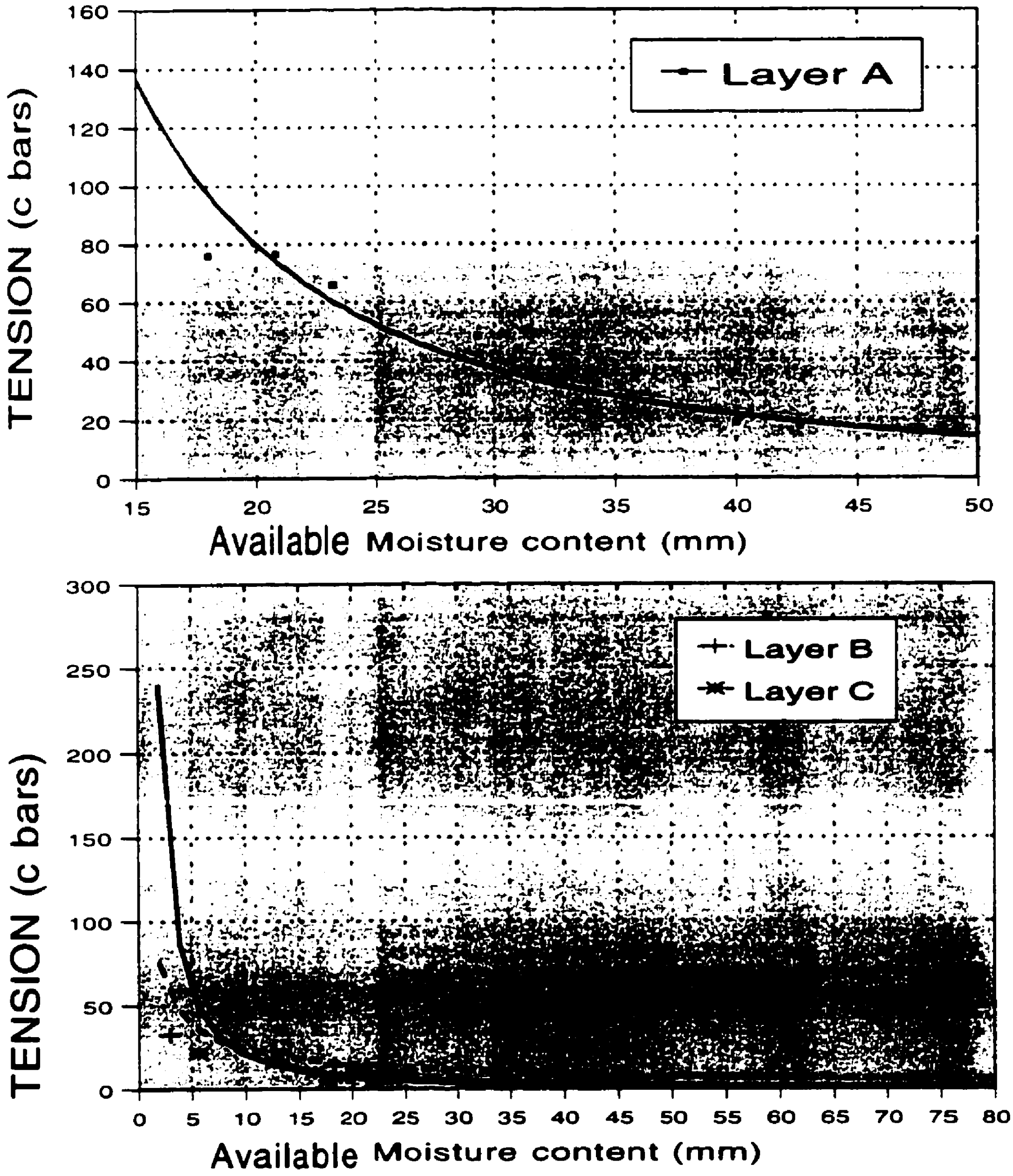


Figure 4.5 Water release characteristics (Site 3)

(tensiometer method)

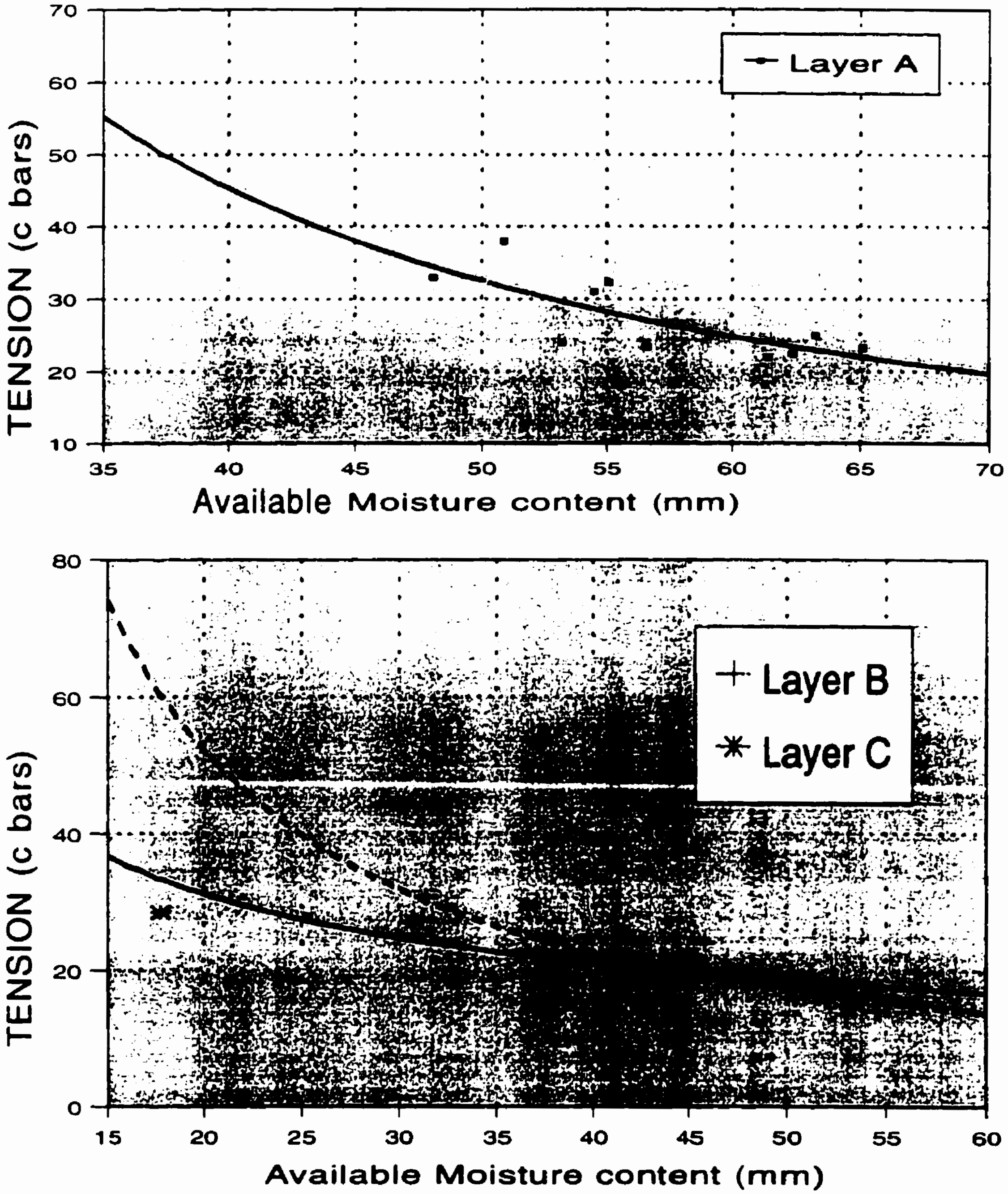


Figure 4.6 Water release characteristics (Site 5)
(tensiometer method)

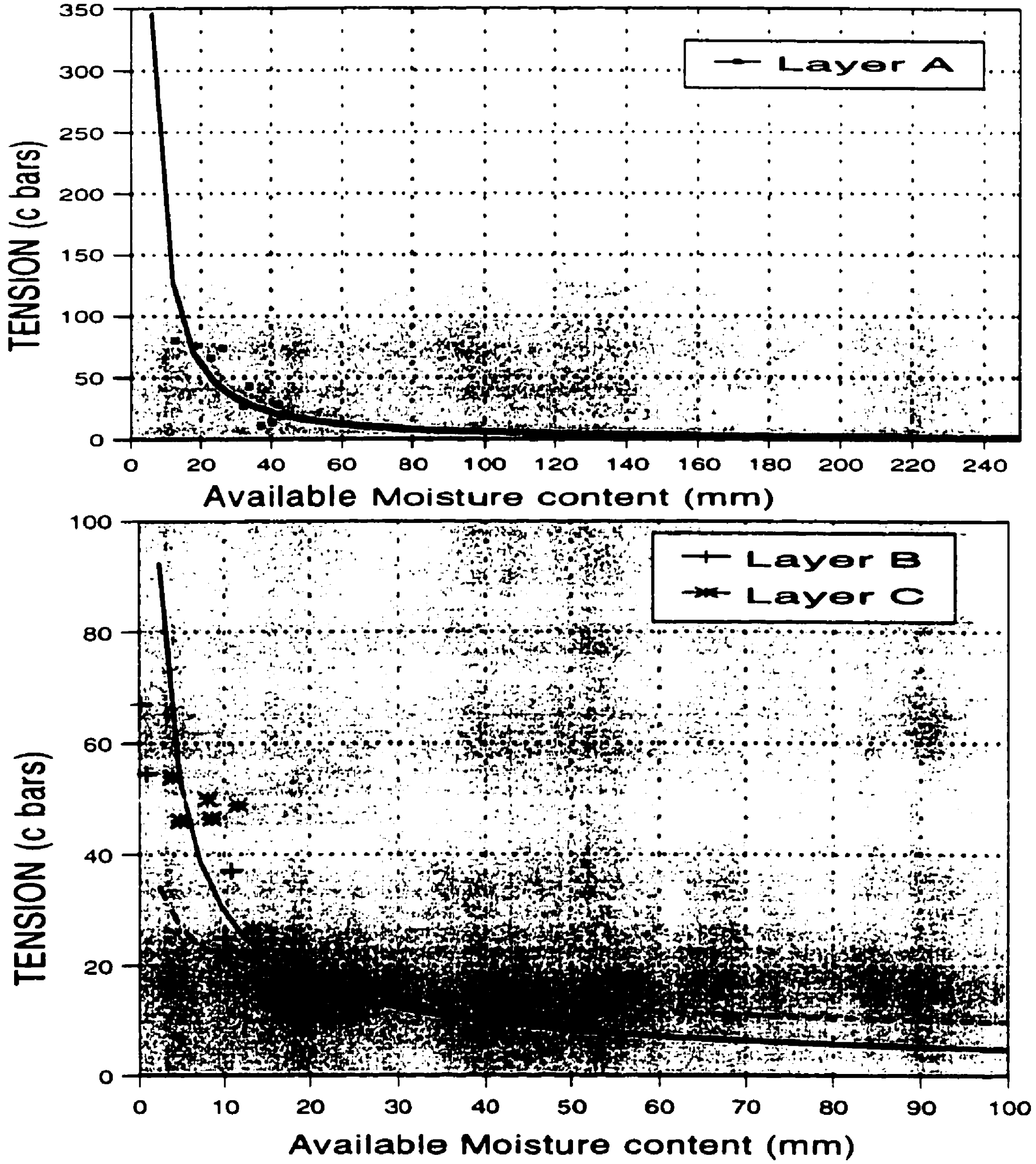


Table 4.4 Depth of available water at field capacity in mm.

Site No.	Layer			Total available water at different soil depth.		
	A	B	C	300 mm	400 mm	600 mm
1	30.0	19.6	30.0	39.8	49.6	79.6
2	63.9					
3	60.8	53.4	50.5	87.5	114.2	164.7
4	60.8					
5	42.7	33.0	25.3	59.2	75.7	100.9

Note: The values of available water were calculated by the mean value of water depth at field capacity (Table 4.2), minus the values of permanent wilting point (Table 4.3).

4.1.3 Climatological data

Evapotranspiration

Evapotranspiration ET, was measured by a screened Class A evaporation pan installed following the instructions described in Chapter 3. The ET obtained by the screened evaporation pan ($ET_{s.pan}$) was compared with the soil moisture depletion. The mean values of soil moisture depletion are compiled in Table 4.5. The data are presented graphically in Figures 4.7, 4.8 and 4.9. The $ET_{s.pan}$ data were also compared with ET values calculated by the Ottawa CDA weather station (ET_{CDA}). The summary of the daily values of ET are in Appendix B. Table 4.6 shows a summary of mean values of ET obtained from the CDA weather station and from the screened evaporation pan at the field. During the month of June the $ET_{s\,pan}$ was 16.8% less than the ET_{CDA}. In July the $ET_{s\,pan}$ was 9.9 % lower than ET_{CDA}, and the $ET_{s\,pan}$ was 23.6 % higher than the total soil moisture depletion of the top 400 mm of site 1, which is the highest among the three sites (Tables 4.4 and 4.5). For the month of August $ET_{s\,pan}$ was 8% lower than the ET_{CDA} and only 0.8% lower than the soil moisture depletion of the site 1. During the month of september the $ET_{s\,pan}$ was 16.4% higher than the ET_{CDA} and 82% higher than the soil moisture depletion of site 1.

The explanation of the low values of soil moisture depletion with respect to $ET_{s\,pan}$ in the month of July may be that the majority of roots did not reach 400 mm at this time, also the ground was not completely covered by the crop, thus, the evaporation from ground surface was higher than the transpiration from the plants. In August, when the roots were at maximum depth, the crop had full canopy and there was not much rain. The soil moisture depletion to the 400 mm depth is about the same as the $ET_{s\,pan}$, and at 600 mm depth is higher, possible due to the plant roots extracting water from the deeper zone where the evaporation is minimun.

Table 4.5 Mean monthly soil moisture depletion (mm/day) and total depletion (mm).

Month	**Soil moisture depletion**								
Soil Depth (mm)	Site No. 1			Site No. 3			Site No. 5		
	200	400	600	200	400	600	200	400	600
July mm/day	3.0	3.4	3.6	1.4	1.9	3.0	1.9	2.4	3.0
Aug. mm/day	3.8	3.5	4.8	3.0	3.5	4.7	2.8	3.2	3.9
Sept. mm/day	1.5	1.5	2.1	1.6	1.7	2.4	1.5	1.9	2.2
Total mm/three months	256	259	311	184	218	311	191	230	279

Note: The total values were obtained by adding the total values of each month.

Rain and temperature.

The daily rainfall values near the Lamoureux house are given in Appendix B. Table 4.6 gives the mean monthly rainfall for summer 1996 obtained from CDA weather station, for Ottawa NRC Atmospheric Environment Service - Environment Canada from the period between 1951 and 1984 and for the field. The total rainfall for the growing season in the field is 8.9 % lower than the CDA weather station. The total rainfall for the 1996 growing season is 18.6 % higher than the mean value of the period 1951 to 1984 for NRC station. Since the 1996 summer had relatively high rainfall, it is important to make an approximated irrigation scheduling for a dryer year.

Table 4.6 Total rain, mean temperature and total ET per month.

Month	**CDA weather station 1996**			**Field measurements 1996**			**NRC W. Station 1951-84**
	Rain (mm)	Temp. °C	ET (mm)	Rain (mm)	Temp. °C	ET (mm)	Mean value of monthly Rain(mm)
June	89.2	19.3	119.1	78.4	19.3	99.0	85.0
July	149.3	20.0	128.3	151.7	19.6	115.6	83.5
August	86.8	20.0	124.6	72.6	18.0	114.1	81.0
September	124.4	16.3	66.5	107.1	15.7	79.6	84.0
Total	449.7		438.5	409.8		408.3	333.5

Figure 4.7 Mean monthly values of ET

Site 1

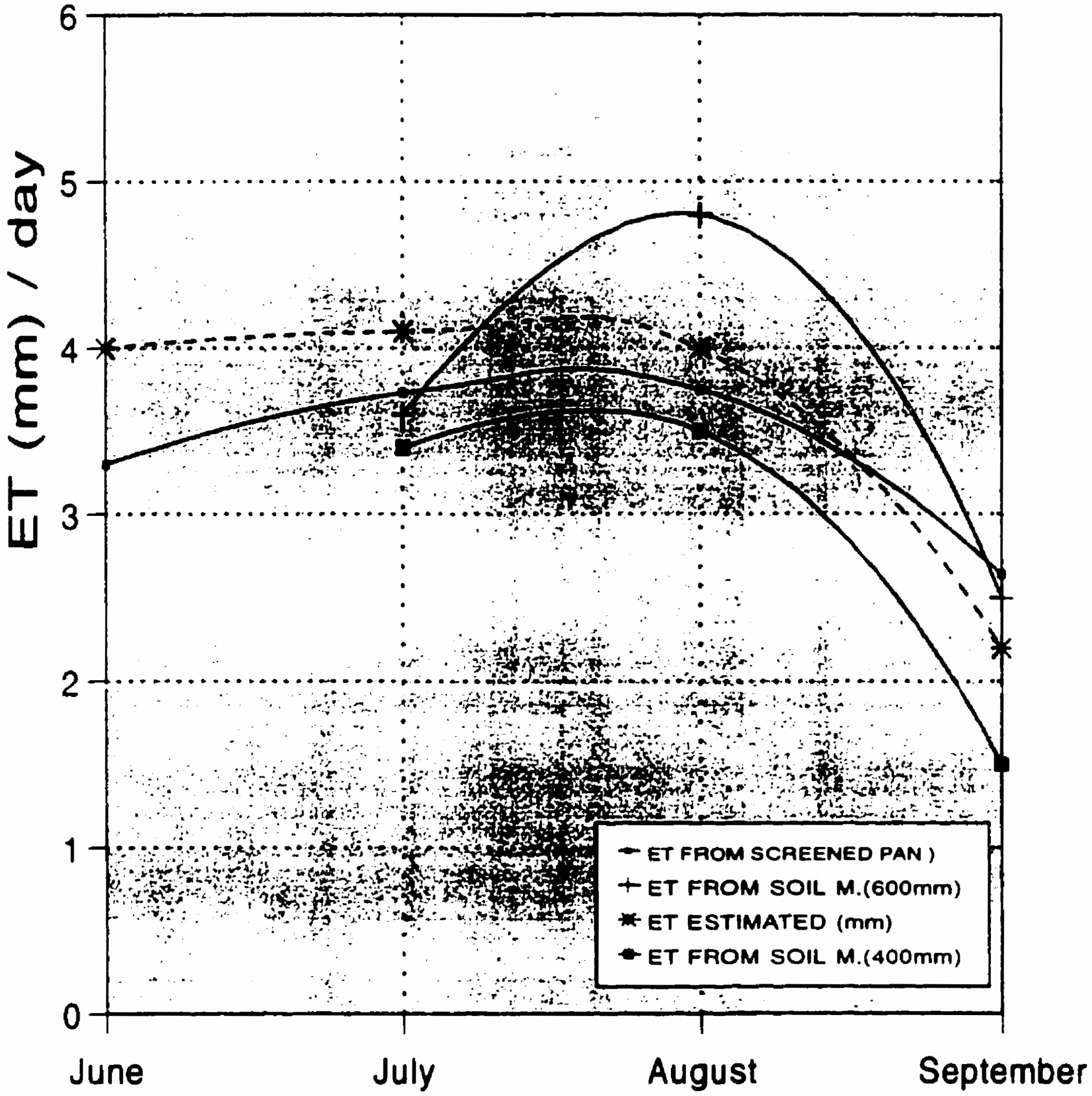


Figure 4.8 Mean monthly values of ET

Site 3

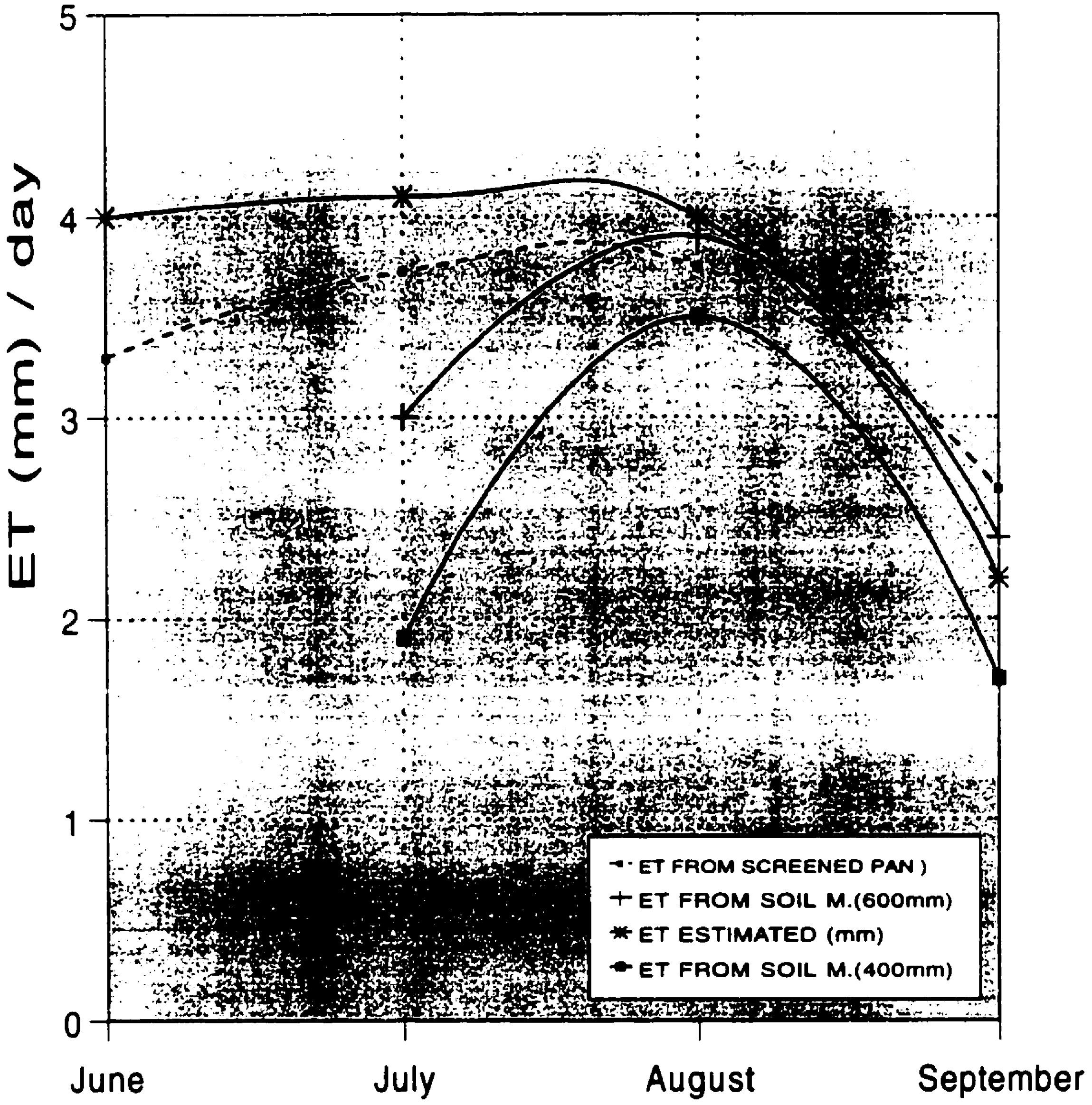
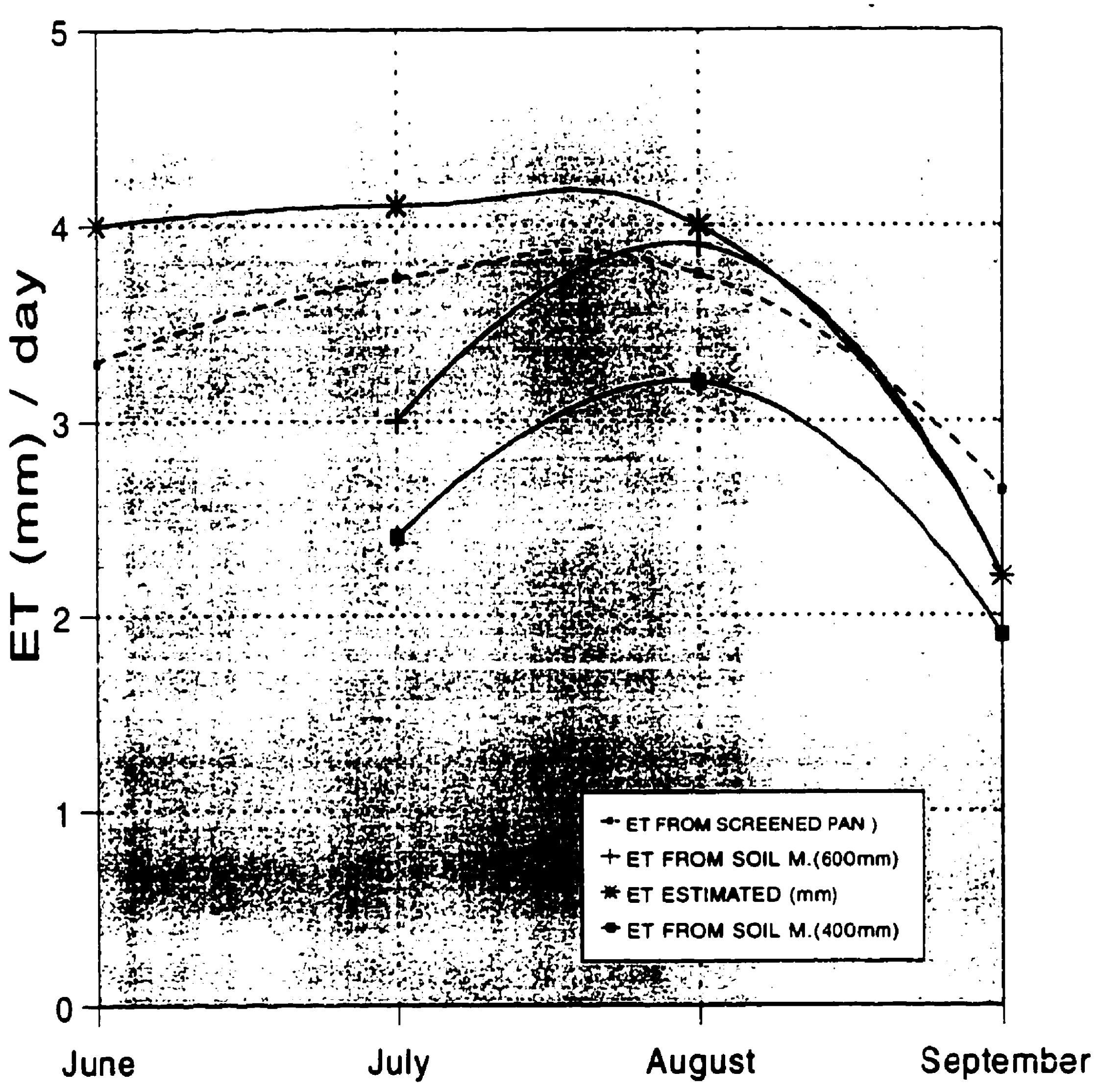


Figure 4.9 Mean monthly values of ET

Site 5



4.1.4 Visual observations

- The population of seed emergence was lower in site 4 than in the rest of the fields.
- By June 15 the mean canopy heights were 190 mm in site 1, 150 mm in site 5 and 122 mm in site 3.
- By July 15 the maize was starting to silk, mean canopy heights were of 190 mm in site 3, 180 mm in site 5 and 200 mm in site 1. At this date the majority of the roots were in the top 200 mm, some reached 400 mm and few reached 500 mm.
- On August 25 the maize in site 1 was partially wilted, some leaf curling was evident at site 5 but no signs of wilting were seen at site 3.
- The maize at site 3 did not show sign of wilting during the entire season.
- At harvesting time, in late October, the majority of the roots were found to be in the top 300 mm in sites 3 and 5, with a few roots reaching a depth of 500 mm. In site 1 the majority of the roots were in the top 500 mm and a few to a depth of 800 mm.
- The size of the ears and grain filling was very uniform in every field.

4.1.5 Suggested irrigation management

The water balance was tabulated using $ET_{s.pan}$ which gave values between the Agricultural Canada estimated PET and the soil moisture depletion of the top of the root zone (Figures 4.7, 4.8 and 4.9).

The depth of available water at any day was tabulated using the relationship:

$$AW_n = AW_{n-1} + \text{Rain} + \text{Irrigation} - ET_{s\,pan}$$

where AW_n and AW_{n-1} are available water at days n and n-1 in mm.

If the value of AW is greater than FC, the amount of AW is dropped to FC two days later. The excess of water is lost by drainage. The minimum value to which the moisture content is allowed to drop is 50 % of FC. **Once the AW reaches 50 % of FC an irrigation is applied**.

At the beginning of June the soil is assumed to be at field capacity. Then the depth of soil moisture allowed to deplete depends on which management approach is to be used. For the summer 1996, which was humid, only sites 1 and 5 appeared to need irrigation. Irrigation needs for a dryer year were also evaluated. For summer 1974 which was a dryer summer, the three sites needed irrigation.

Literature reported in Chapter 2 recommends **plow layer** and **deficit irrigation** approaches for humid regions. Both approaches and a combination of the two of them were evaluated in this research.

<u>The plow layer approach</u> was evaluated in site 1: Complete refilling of the allowable depletion in the plow layer (plow layer zone considered as 300 mm deep in this study), which is the site with lower water holding capacity. The depth of each irrigation application used for this approach was 20 mm.

<u>Combination of plow layer and deficit irrigation approaches</u> were evaluated for sites 3 and 5 (plow layer zone of 300 mm deep and incomplete refilling of AW). The percentage of refilling of the AW was 80 % in the site 5, and 50 % in site 3, to keep the same depth of irrigation application on both sites, which are in the same field.

Deficit irrigation approaches were evaluated using a root zone depth of 400 mm, where the majority of roots were observed. The depth of irrigation water used in the three sites was 25 mm, which represent complete refilling of AW for site 1, 70 % in site 5 and 45 % in site 3.

Tables 4.7 and 4.8 sumarize the results of the different trials.

Discussion of irrigation requirements

The results show that by considering a depth of root zone of 400 mm, both the irrigation and drainage water are reduced as compared to a root zone depth of 300 mm (Tables 4.7 and 4.8). The total reduction in irrigation requirements for the season is less in humid summers than in the drier summers, due to increases in evapotranspiration losses in the drier summer.

The criteria of deficit irrigation on the top 400 mm of root zone, decreases the number of irrigations from 6 to 4 in 1996 and from 9 to 6 in 1974 for site 1 with respect to 300 mm of root zone. Site 5 gives a reduction from 4 to 3 irrigations in the summer 1996, but no difference for 1974. Site 3 has no change in number of irrigations.

The drainage water is reduced in 13.4 mm of water in 1996 and 22 mm in 1974 for site 1; 17 mm in 1996 and 4.8 mm in 1974 for site 5 and 1 mm of water in 1974 for site 3. Therefore is recomemded to use a 400 mm root zone in the water balance irrigation scheduling computations. The results of the water balance computations are given in tables 4.10, 4.11 and Appendix C. Figures 4.10 to 4.14 show the suggested irrigation scheduling for summer 1996 and 1974, using 400 mm of root zone. The tabulations and graphical presentation using 300 mm are given in Appendix C.

Table 4.7 Suggested Irrigation and Drainage water amounts in mm calculated for growing season, 1996

Site	Depth of root zone	Irrig and Drain.	June	July	August	September	Total
1	300 mm of soil	I	40	20	40	20	120
		D	27	42.6	40	27.6	133.3
	400 mm of soil	I	25	25	50	0	100
		D	27	36	36.7	20.2	119.9
5	300 mm of soil	I	25	25	25	25	100
		D	31.5	19.6	34.5	12.6	98.2
	400 mm of soil	I	25	25	25	0	75
		D	27	25.4	28.7	0	81.1

Note: I= Total monthly irrigation water

D= Total monthly drainage water

The farmer did not actually irrigate in 1996. The values in this table come from water balance calculations, and suggested irrigation criteria.

Table 4.8 Suggested Irrigation and drainage water amounts in mm calculated for summer 1974

Site	**Depth of Root zone**	**Irrig. and Drainage.**	**June**	**July**	**August**	**September**	**Total**
1	300 mm	I	60	60	40	20	180
		D	4.8	19	0	0	23.8
	400 mm	I	50	50	50	0	150
		D	1.8	0	0	0	1.8
3	300 mm	I	25	50	50	0	125
		D	2.8	0	0	0	2.8
	400 mm	I	25	50	25	25	125
		D	1.8	0	0	0	1.8
5	300 mm	I	50	50	50	0	150
		D	4.8	0	0	0	4.8
	400 mm	I	50	25	50	25	150
		D	0	0	0	0	0

The irrigation scheduling considers an average rate of soil moisture depletition at each site, this assumption is considering that the $ET_{s.pan}$ is a mid value between the PET estimated from CDA station data and the soil depletion rate. Irrigation management using this approach has an 8 % margin of security in the month of July and August which is the critical period in the growing season.

The irrigation scheduling may encounter some inconveniences in application of water the day suggested due to other farming activities or possibilities on the weather forecasting. The farmer did not irrigate in 1996, even though the water balance computations show a need for irrigation, based on starting to irrigate when the soil moisture in the 400 mm root zone dropped to 50 % of FC. The farmer was preparing to irrigate field 1, but weather forecasts predicted rain coming in one or two days; so the farmer delayed to save fuel, labour and operation costs. The farmer recognized by early July that 1996 was a wetter than average summer, and took a decision not to irrigate. There may have been a slight loss in yield due to not irrigating, but there was also a saving in operation costs. The scheduling proceedure outlined in this thesis can be used by the farmer in future years, when drier weather is expected.

The percentage of over estimation using the $ET_{c,pan}$ gives a degree of security of one or two days. The tensiometer readings indicate the actual soil depletion in each site. Table 4.9 is a summary of the available soil moisture present at each tensiometer reading, for each location. These values can be used as guidance to give priority of irrigation, in case of equipment or personnel restraints. The total amount of available water at 400 mm soil depth is the sum of the available water in layers A + B.

Table 4.9 Tensiometer readings and available moisture content in layers A and B of the root zone.

Tension c.bars	**Site 1**		**Site 3**		**Site 5**	
	A mm	B mm	A mm	B mm	A mm	B mm
5		80				
10	53	39			96	
15	48	23 FC		58 FC	74	95
20	41	13	69	44	54	30 FC
25	36	9	59 FC	37	45 FC	11
30	34	8	53	32	38	6
35	31 FC	5	47	28	34	4
40	29	5	43	25	29	2
45	26	4	40	23	27	2
50	25	3	37	21	24	1
55	24	3	35	19	23	0
60	23	3		18	21	0
65	22	3		17	20	
70	21	2		16	18	
75	21	2		15	17	
80	20	2			16	

Note: Actual values may vary by ± 5 mm, which is the mean standard deviation on the power regression fit for Figures 4.4, 4.5 and 4.6.

Layer: A is 0 to 200 mm deep.
B is 200 to 400 mm deep.

Table 4.10 Suggested irrigation scheduling, Site 1 (June 1996), mm of water depth for 400 mm of root zone depth.

DATE	RAIN	ET	A.W.	Irrigation	Drainage
01	0.0	2	49.6 FC		
02	0.0	2	47.6		
03	0.0	2	45.6		
04	0.0	3	42.6		
05	21.5	2	62.1		
06	6.0	4	64.1		
07	12.0	2	74.1		
08	6.5	4	76.6		
09	0.0	4	49.6 FC		27
10	6.5	2	54.1		
11	0.4	3	51.5		
12	0.0	4	47.5		
13	1.0	3	45.5		
14	0.0	4	41.5		
15	0.0	5	36.5		
16	0.0	4	32.5		
17	0.0	3	29.5		
18	0.0	4	25.5		
19	0.0	3	47.5	25	
20	0.0	3	44.5		
21	0.0	3	41.5		
22	4.0	3	42.5		
23	0.5	3	40.0		
24	0.0	3	37.0		
25	3.0	4	36.0		
26	0.0	4	32.0		
27	7.0	4	35.0		
28		4	31.0		
29	5.0	4	32.0		
30	5.0	4	33.0		
Tot	78.4	99.00		25	27

Table 4.10 cont. Suggested irrigation scheduling, Site 1 (July 1996), mm of water depth for 400 mm of root zone depth.

DATE	RAIN	ET	A.W.	Irrigation	Drainage
01	0.0	5.8	27.2		
02	0.0	4.8	22.4		
03	8.0	4.8	25.6		
04	9.5	1.5	33.6		
05	0.0	2.4	31.2		
06	0.0	7.2	24.0		
07	1.0	2.4	47.6	25	
08	0.0	3.1	44.5		
09	0.0	4.8	39.7		
10	0.0	3.6	36.1		
11	0.0	4.8	31.3		
12	0.0	3.4	27.9		
13	4.9	2.9	29.9		
14	5.0	3.9	31.0		
15	35.0	1.0	65.0		
16	18.0	2.8	80.2		
17	0.5	3.7	49.6 FC		30.6
18	0.0	3.0	46.6		
19	3.9	1.6	48.9		
20	0.4	7.4	41.9		
21	0.0	7.2	34.7		
22	0.0	3.5	31.2		
23	27.5	7.1	51.6		
24	0.0	0.8	50.8		
25	8.5	4.3	55.0		
26	0.0	3.4	49.6 FC		5.4
27	0.0	3.5	46.1		
28	0.0	4.7	41.4		
29	0.0	4.2	37.2		
30	14.5	1.5	50.2		
31	15.0	0.5	64.7		
Tot	151.7	115.6			36.0

Table 4.10 cont. Suggested irigation scheduling, Site 1 (August 1996),mm of water depth for 400 mm of root zone depth.

DATE	RAIN	ET	A.W.	Irrigation	Drainage
01	17.6	1.0	81.3		
02	0.0	3.0	49.6 FC		31.7
03	0.0	5.0	44.6		
04	0.0	5.0	39.6		
05	0.0	5.0	34.6		
06	0.0	4.0	30.6		
07	0.0	5.0	25.6		
08	35.0	2.0	58.6		
09	0.0	4.0	54.6		
10	0.0	5.0	49.6 FC		5.0
11	0.0	5.0	44.6		
12	0.0	5.0	39.6		
13	0.0	6.0	33.6		
14	0.0	2.8	30.8		
15	0.0	3.6	27.2		
16	15.0	5.2	37.0		
17	0.0	3.4	33.6		
18	0.0	3.3	30.3		
19	0.0	3.6	26.7		
20	0.0	3.4	48.3	25	
21	4.0	1.0	51.3		
22	0.0	4.0	47.3		
23	0.0	3.0	44.3		
24	0.8	3.2	41.9		
25	0.0	3.0	38.9		
26	0.0	4.6	34.3		
27	0.2	1.2	33.3		
28	0.0	2.9	30.4		
29	0.0	2.6	27.8		
30	0.0	4.7	48.1	25	
31	0.0	3.6	44.5		
Tot	72.6	114.1		50	36.7

Table 4.10 cont. Suggested irrigation scheduling, Site 1 (September 1996), mm of water depth for 400 mm of root zone depth.

DATE	RAIN	ET	A.W.	Irrigation	Drainage
01	0.0	2.6	41.9		
02	0.0	3.5	38.4		
03	0.0	3.5	34.9		
04	0.0	3.2	31.7		
05	0.0	3.4	28.3		
06	0.0	2.4	25.9		
07	0.0	4.7	21.2		
08	10.0	4.0	27.2		
09	15.1	0.0	42.3		
10	0.5	1.1	41.7		
11	0.0	2.5	39.2		
12	9.0	3.8	44.4		
13	12.5	2.3	54.6		
14	4.5	2.1	57.0		
15	5.9	1.1	49.6 FC		7.4
16	5.0	2.2	52.4		
17	1.5	0.0	53.9		
18	0.0	2.6	49.6 FC		4.3
19	0.0	5.0	44.6		
20	0.0	4.8	39.8		
21	0.0	4.7	35.1		
22	0.0	2.2	32.9		
23	0.0	2.1	30.8		
24	0.0	4.2	26.6		
25	2.0	0.0	28.6		
26	0.2	3.0	25.8		
27	0.0	0.0	25.8		
28	16.5	1.0	41.3		
29	15.0	3.2	53.1		
30	9.4	4.4	49.6		8.5
Tot	107.1	79.6			20.2

Table 4.11 Suggested irrigation scheduling, Site 5 (June 1996), mm of water depth for 400 mm of root zone depth.

DATE	RAIN	ET	A.W.	Irrigation	Drainage
01	0.0	2	75.6 FC		
02	0.0	2	73.6		
03	0.0	2	71.6		
04	0.0	3	68.6		
05	21.5	2	88.1		
06	6.0	4	90.1		
07	12.0	2	100.1		
08	6.5	4	75.6 FC		27.0
09	0.0	4	71.6		
10	6.5	2	76.1		
11	0.4	3	73.5		
12	0.0	4	69.5		
13	1.0	3	67.5		
14	0.0	4	63.5		
15	0.0	5	58.5		
16	0.0	4	54.5		
17	0.0	3	51.5		
18	0.0	4	47.5		
19	0.0	3	44.5		
20	0.0	3	41.5		
21	0.0	3	38.5		
22	4.0	3	39.5		
23	0.5	3	37.0		
24	0.0	3	59.0	25	
25	3.0	4	58.0		
26	0.0	4	54.0		
27	7.0	4	57.0		
28		4	53.0		
29	5.0	4	54.0		
30	5.0	4	55.0		
Tot.	78.4	99.00		25	27.0

Table 4.11 cont. Suggested irrigation scheduling, Site 5 (July 1996), mm of water depth for 400 mm of root zone depth.

DATE	RAIN	ET	A.W.	Irrigation	Drainage
01	0.0	5.8	49.2		
02	0.0	4.8	44.4		
03	8.0	4.8	47.6		
04	9.5	1.5	55.6		
05	0.0	2.4	53.2		
06	0.0	7.2	46.0		
07	1.0	2.4	42.6		
08	0.0	3.1	41.5		
09	0.0	4.8	36.7		
10	0.0	3.6	58.1	25	
11	0.0	4.8	53.3		
12	0.0	3.4	49.9		
13	4.9	2.9	51.9		
14	5.0	3.9	53.0		
15	35.0	1.0	87.0		
16	18.0	2.8	102.2		
17	0.5	3.7	99.0		
18	0.0	3.0	75.6 FC		20.4
19	3.9	1.6	77.9		
20	0.4	7.4	70.9		
21	0.0	7.2	63.7		
22	0.0	3.5	60.2		
23	27.5	7.1	80.6		
24	0.0	0.8	79.8		
25	8.5	4.3	84.0		
26	0.0	3.4	75.6		5.0
27	0.0	3.5	72.1		
28	0.0	4.7	67.4		
29	0.0	4.2	63.2		
30	14.5	1.5	76.2		
31	15.0	0.5	90.7		
Tot	151.7	115.6		25	25.4

Table 4.11 cont. Suggested irrigation scheduling, Site 5 (August 1996), mm of water depth for 400 mm of root zone depth.

DATE	RAIN	ET	A.W.	Irrigation	Drainage
01	17.6	1.0	107.3		
02	0.0	3.0	104.3		
03	0.0	5.0	75.6 FC		23.7
04	0.0	5.0	70.6		
05	0.0	5.0	65.6		
06	0.0	4.0	61.6		
07	0.0	5.0	56.6		
08	35.0	2.0	89.6		
09	0.0	4.0	85.6		
10	0.0	5.0	75.6 FC		5.0
11	0.0	5.0	70.6		
12	0.0	5.0	65.6		
13	0.0	6.0	59.6		
14	0.0	2.8	56.8		
15	0.0	3.6	53.2		
16	15.0	5.2	63.0		
17	0.0	3.4	59.6		
18	0.0	3.3	56.3		
19	0.0	3.6	52.7		
20	0.0	3.4	49.3		
21	4.0	1.0	52.3		
22	0.0	4.0	48.3		
23	0.0	3.0	45.3		
24	0.8	3.2	42.9		
25	0.0	3.0	39.9		
26	0.0	4.6	60.3	25	
27	0.2	1.2	59.3		
28	0.0	2.9	56.4		
29	0.0	2.6	53.8		
30	0.0	4.7	49.1		
31	0.0	3.6	45.5		
Tot	72.6	114.1		25	28.7

Table 4.11 cont. Suggested irrigation scheduling, Site 5 (September 1996),mm of water depth for 400 mm of root zone depth.

DATE	RAIN	ET	A.W.	Irrigation	Drainage
01	0.0	2.6	42.9		
02	0.0	3.5	39.4		
03	0.0	3.5	35.9		
04	0.0	3.2	32.7		
05	0.0	3.4	29.3		
06	0.0	2.4	26.9		
07	0.0	4.7	22.2		
08	10.0	4.0	28.2		
09	15.1	0.0	43.3		
10	0.5	1.1	42.7		
11	0.0	2.5	40.2		
12	9.0	3.8	45.4		
13	12.5	2.3	55.6		
14	4.5	2.1	58.0		
15	5.9	1.1	62.8		
16	5.0	2.2	65.6		
17	1.5	0.0	67.1		
18	0.0	2.6	64.5		
19	0.0	5.0	59.5		
20	0.0	4.8	54.7		
21	0.0	4.7	50.0		
22	0.0	2.2	47.8		
23	0.0	2.1	45.7		
24	0.0	4.2	41.5		
25	2.0	0.0	43.5		
26	0.2	3.0	40.7		
27	0.0	0.0	40.7		
28	16.5	1.0	56.2		
29	15.0	3.2	68.0		
30	9.4	4.4	73.0		
Tot.	107.1	79.6		0.0	0.0

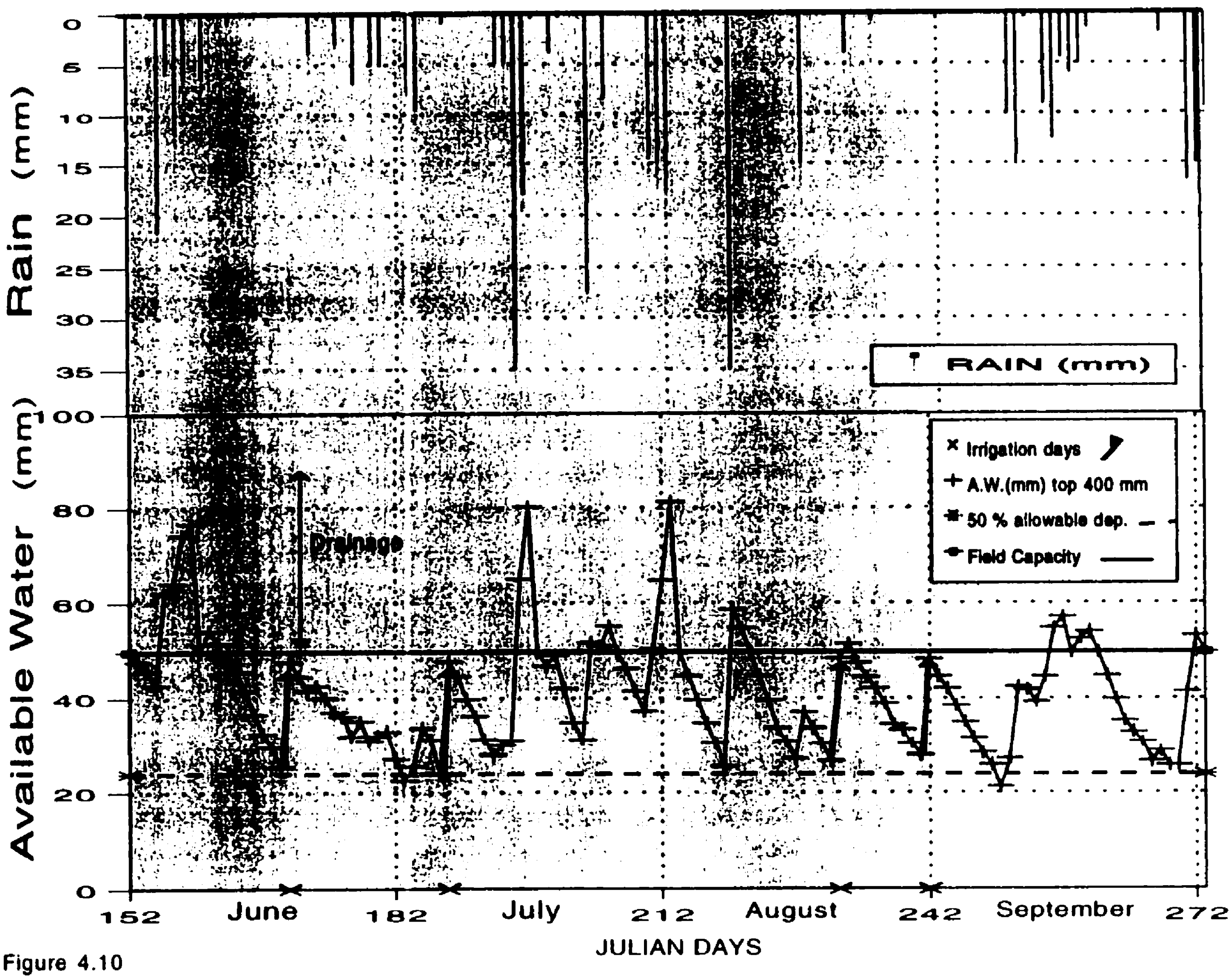


Figure 4.10

SUGGESTED IRRIGATION SCHEDULING FOR RAIN DISTRIBUTION OF 1996, SITE No 1 (ROOT ZONE 400 mm DEEP)

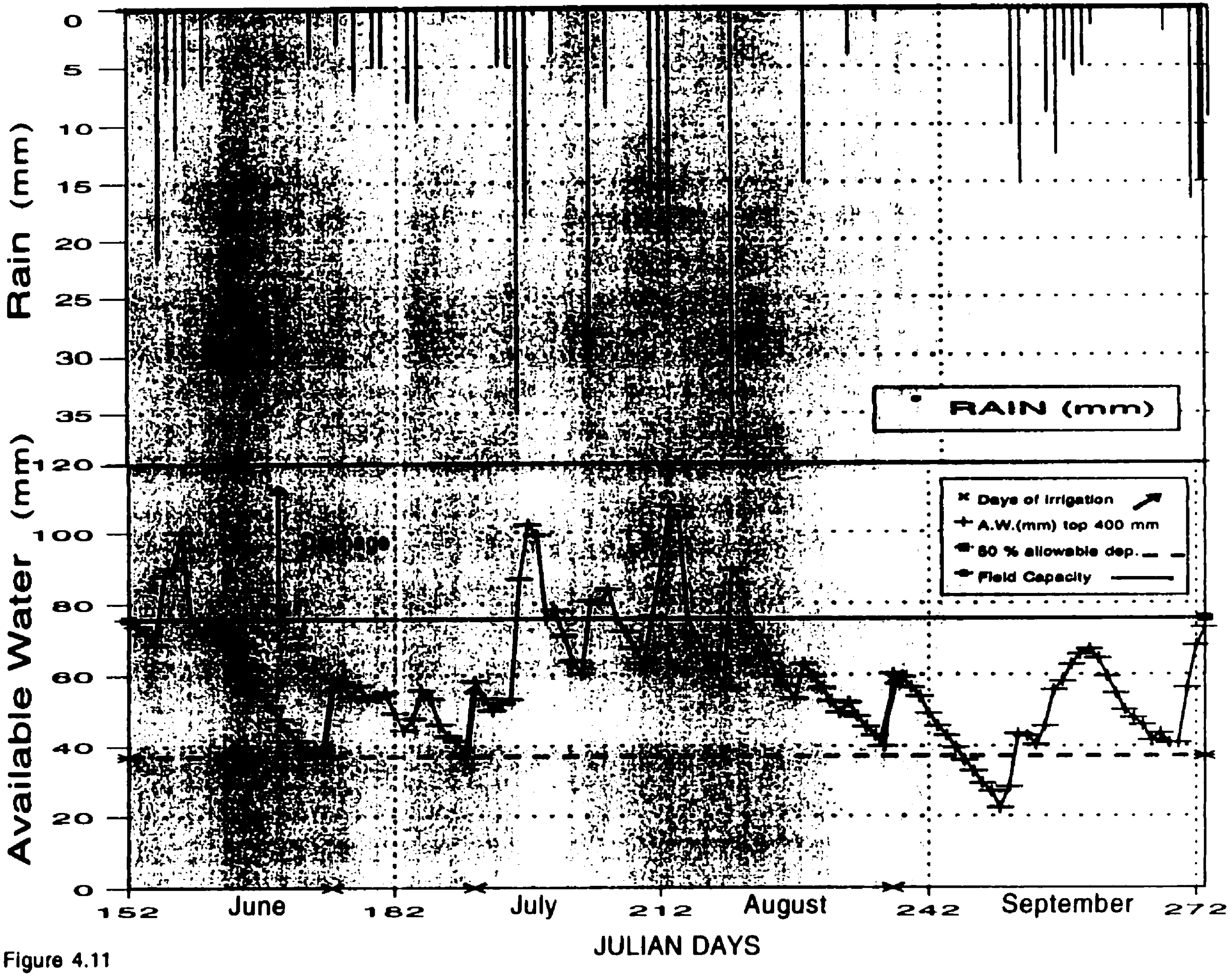


Figure 4.11

SUGGESTED IRRIGATION SCHEDULING FOR RAIN DISTRIBUTION OF 1996, SITE 5 (ROOT ZONE 400 mm DEEP)

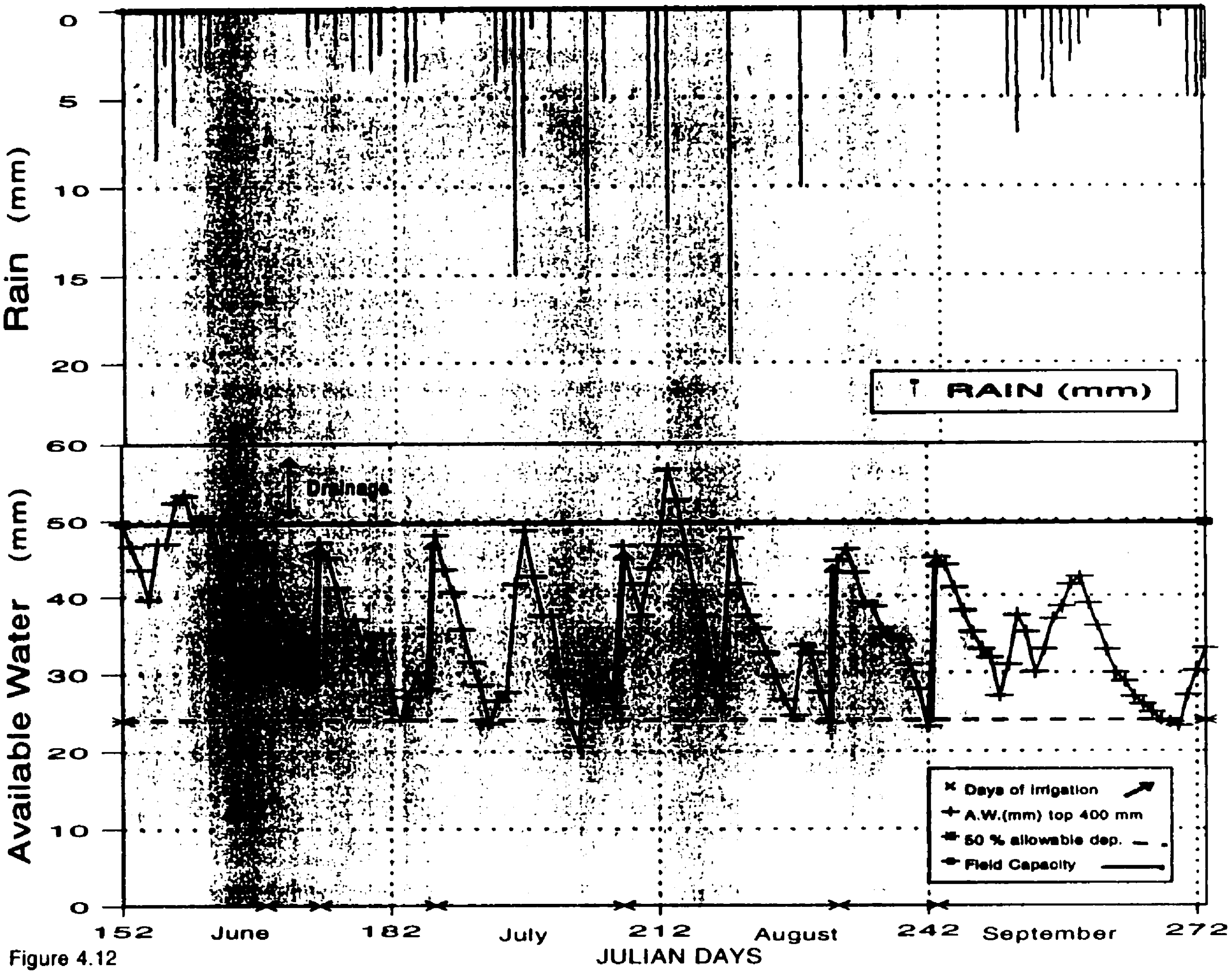


Figure 4.12

SUGGESTED IRRIGATION SCHEDULING FOR RAIN DISTRIBUTION OF 1974, SITE 1 (ROOT ZONE 400 mm DEEP)

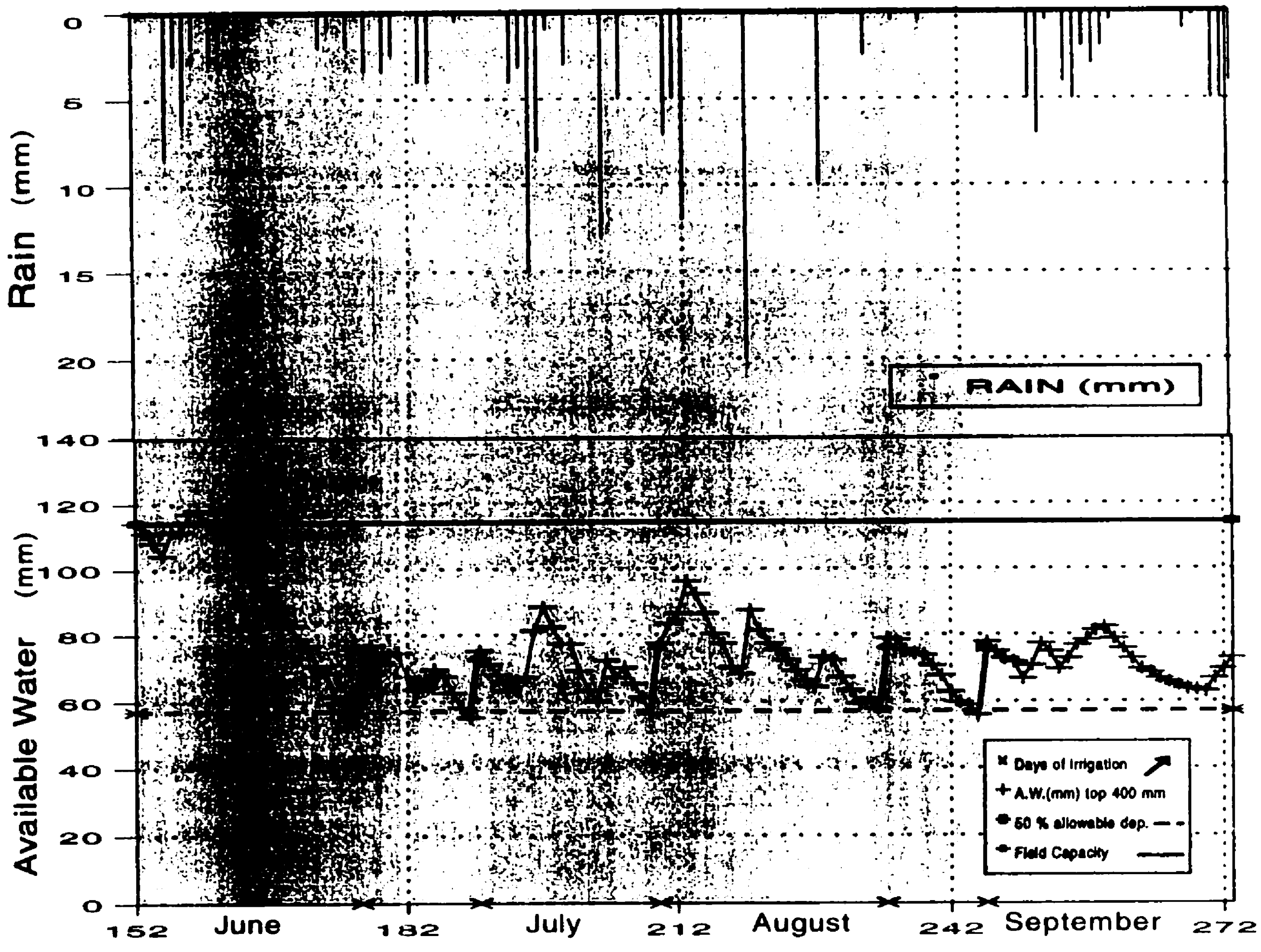


Figure 4.13

SUGGESTED IRRIGATION SCHEDULING FOR RAIN DISTRIBUTION OF 1974, SITE 3 (ROOT ZONE 400 mm DEEP)

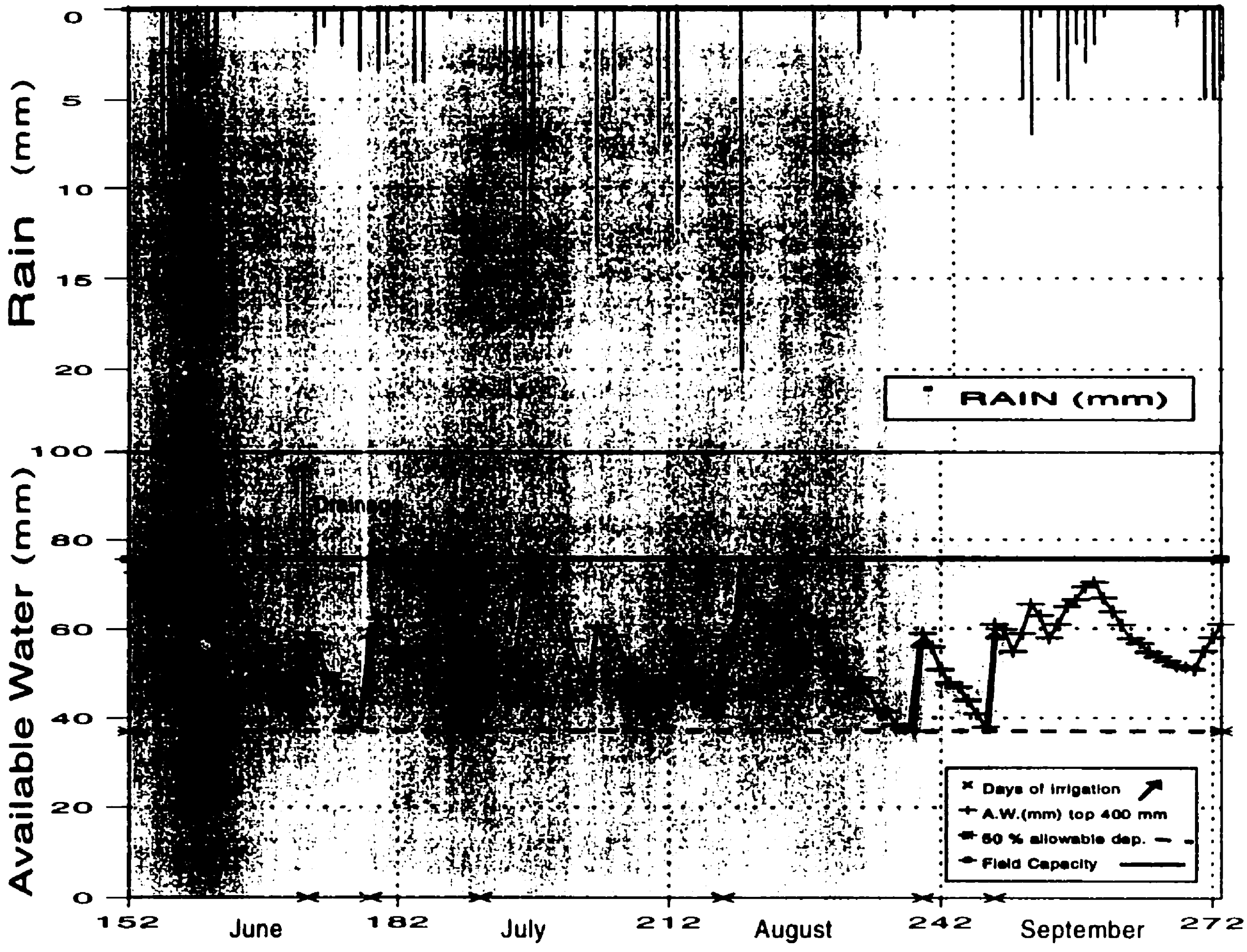


Figure 4.14

SUGGESTED IRRIGATION SCHEDULING FOR RAIN DISTRIBUTION OF 1974, SITE 5 (ROOT ZONE 400 mm DEEP)

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

The main effect of irrigation is to increase the availability of soil water to plants. The goal of scheduling is to avoid depleting the soil water below a critical limit throughout the season. The available water holding capacity shown in Table 4.4 was used as a guide for the decision of irrigation needs of the different fields. The results show that the irregularities in the soil profile greatly affect the water holding capacity (Table 4.4).

The crop will be subjected to water stress before the soil reaches the permanent wilting point. The maize presented signs of wilting by the middle of August 1996 in site 1. At that time, according to the soil moisture content determined by auger sampling, there was still about 18 mm of available water in the top layer, which is about three times the depth of water at wilting point for the same layer (Tables 4.2, 4.3). Thus the allowable depletion should be about this value which is 65 % of the available water at field capacity. For irrigation management, is desirable to leave a margin of security. Thus it is recommended that irrigation be started when the soil moisture is depleted to 50 % of the FC, since it takes a week for the irrigation sprinklers to move accross the farm. The soil moisture will probably be depleted below 50 % FC on part of the farm before it receives irrigation.

From the results of water holding capacity (Table 4.4) it can be seen that the hydraulic conductivity decreases in the direction shown in Figure 4.15. The reduction of hydraulic conductivity in this direction is an explanation for the decrease of soil moisture depletion from site 5 to site 3 during the month of July 1996, when there was more rainfall. The opposite occurs in August when the rainfall was almost half of the rain in July; site 3 had more moisture retained.

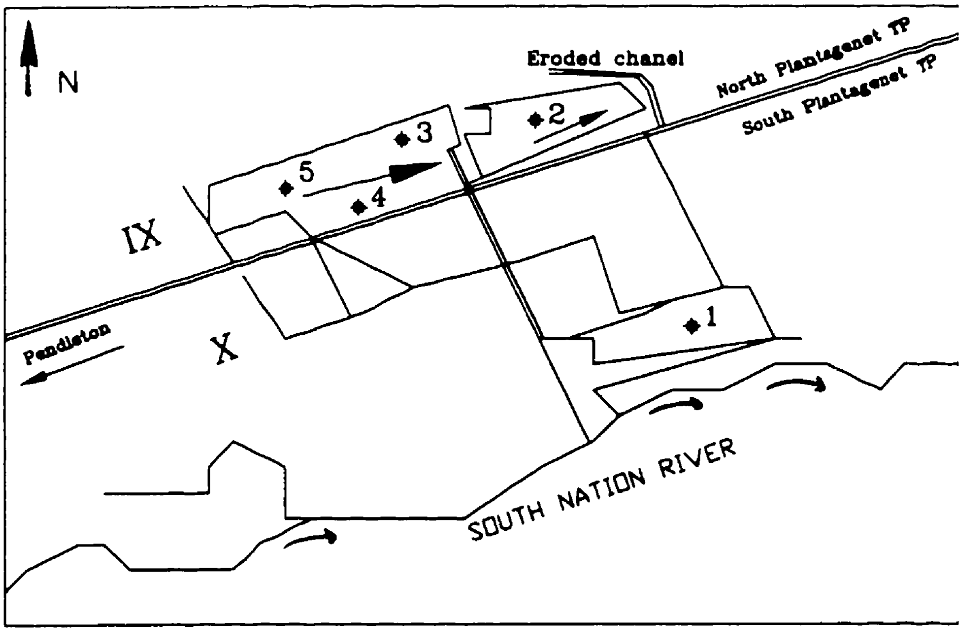


Figure 4.15 Direction of decreassing hydraulic conductivity

The values of total ET from the screened evaporation pan for the season are 7 % lower than the PET values calculated by the CDA weather station, but the values of total rainfall obtained at the field was also 9 % lower than at the CDA weather station (Table 4.6). Comparing the values of ET for the period from July to September, with the soil moisture depletion for the same period, it can be seen that the difference is 0.5 % from the moisture depletion of the top 600 mm of soil in sites 1 and 3, and 9 % from the top 600 mm of soil of site 5 (Tables 4.5 and 4.6). The major difference is during the month of July when the crop was not at full canopy, the roots at this time had reached about 60 % of their final depth.

The soil survey shows that the soil type in fields 6 and 7 (see Figure 3.1) is the same type as site 1. Site 1 has shown the lowest water holding capacity, and as expected the highest soil water depletion. Thus, this is the soil type that requires more irrigation monitoring. The results show that site 3 does not require irrigation when the growing season rainfall is 409.8 mm with a similar distribution of rain as occurred in 1996. Site 5 does require some irrigation during late August and early September.

With all these considerations, an irrigation scheduling was elaborated for sites 1 and 5 using the field data of the 1996 growing season. Examples of irrigation scheduling for the drier 1974 summer were made; using data from the Central Experimental Farm in Ottawa. The results are presented graphically in figures 4.10 to 4.14, and the Appendix C. Site 1 requires 17 % less irrigation water and 10 % less drainage water using a 400 mm root zone depth compared to 300 mm root zone depth. At site 5 a reduction of 25 % the irrigation water and 17 % in drainage is achieved in comparison to 300 mm effective root zone depth. For the 1974 summer the three sites present reduction in irrigation and drainage water, but in minor proportion (Table 4.8).

The site 5 is in the same field as site 3; and the irrigation system that is to be used in that field is a lateral travelling sprinkler, which may not be used only for a portion of the field. For a year with rain distribution close to the summer 1996, it is suggested that irrigation application can be done only in field 1. For a dryer year the irrigation requirements can be tabulated by obtaining the evapotranspiration and rain data, using the soil physical properties given in this thesis and the water balance scheduling system shown.

5.2 Conclusions

- Evapotranspiration measured with the screened evaporation pan, gives a good representation of the mean consumptive water use in this farm.
- The use of tensiometers succesfuly represents the soil moisture depletion on each site of the farm.
- For a summer with rainfall distribution similar to 1996, site 3 does not need irrigation. For practical purposes, site 5, which is in the same field as site 3 should be monitored with tensiometers, and water applied only if the soil moisture depletion gets below 60 % of AW during the silking period. Site 1 is the site that has lower water holding capacity and needs irrigation in 1996 and most other years.
- For a drier summer with rain distribution similar to 1974, all three sites need irrigation.
- The suggested root zone depth for irrigation schedulling calculation is 400 mm in this farm. A smaller depth of soil increases the water losses by drainage, which is not economically or environmentally beneficial. Assuming a root zone depth of 600 mm for available water would be inrealistic because it would lead to water stress of the crop since water is supplied only very slowly from depth greater than 400 mm.
- The depth of irrigation application suggested is 25 mm; which partially refills the allowable soil moisture depletion in sites 3 and 5, and completely refills the soil moisture holding capacity in site 1.

5.3 Recommendations

It is recommended that:

1. Measurements be made to compare evaporation with a class A evaporation pan, a screened evaporation pan and ET as calculated by

Agricultural Canada for two more seasons.

2. Soil moisture monitoring with auger samples and tensiometers of the same sites for two more summers.
3. Selection of other sites in the fields 7, 6 and 2 of the farm, should be considered.
4. The irrigation management and the crop yield be monitored for additional seasons and water use efficiency calculated.
5. The irrigation cost and crop yields be evaluated for economic analysis.

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Appendix A

Table A-1	Water release characteristics.
Figures A-1	Water release curves.
Figures A-2 to A-6	Particle size distribution curves.

Table A-1 Water release characteristics (Filter funnel method)

PRESSURE (cm)	SITE 1 (mm)			SITE 3 (mm)			SITE 5 (mm)		
	A	B	C	A	B	C	A	B	C
0	82.36	85.60	95.00	110.52	116.50	96.68	79.14	95.26	93.14
5	80.00	85.52	93.26	107.90	110.52	93.88	78.16	92.62	92.62
10	79.52	84.20	89.20	101.58	103.16	89.46	77.90	92.10	92.10
20	78.14	81.56	86.04	90.00	94.20	81.58	76.32	90.52	91.04
30	77.36	66.62	80.26	82.10	88.42	79.78	74.74	88.94	88.94
60	66.30	64.20	59.74	76.32	84.74	77.90	70.00	83.68	82.94
100	52.88	42.36	29.48	73.16	78.42	75.78	62.62	72.10	61.58
110	36.32	31.58		68.32	71.5	70.52	47.88	54.42	40.32

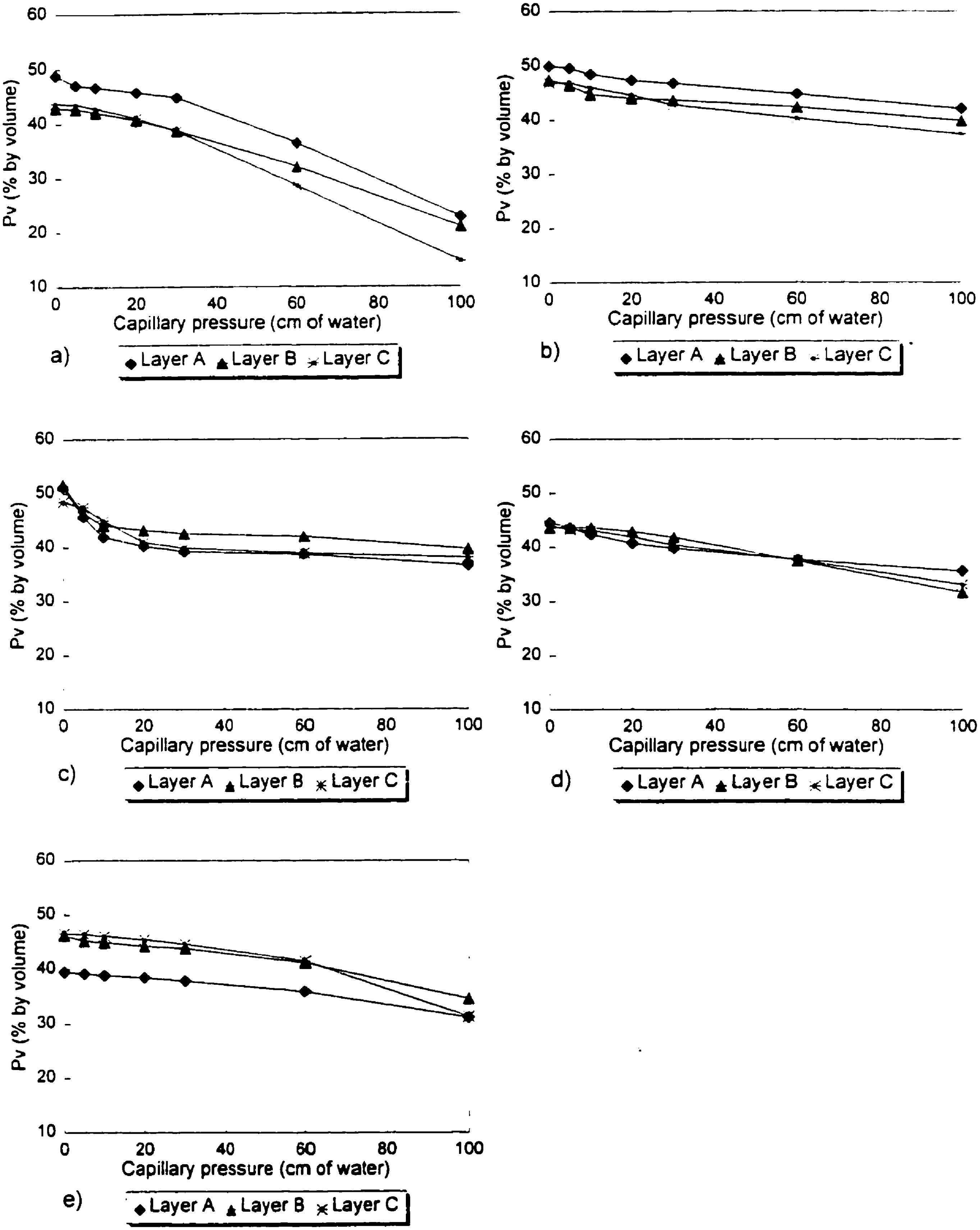
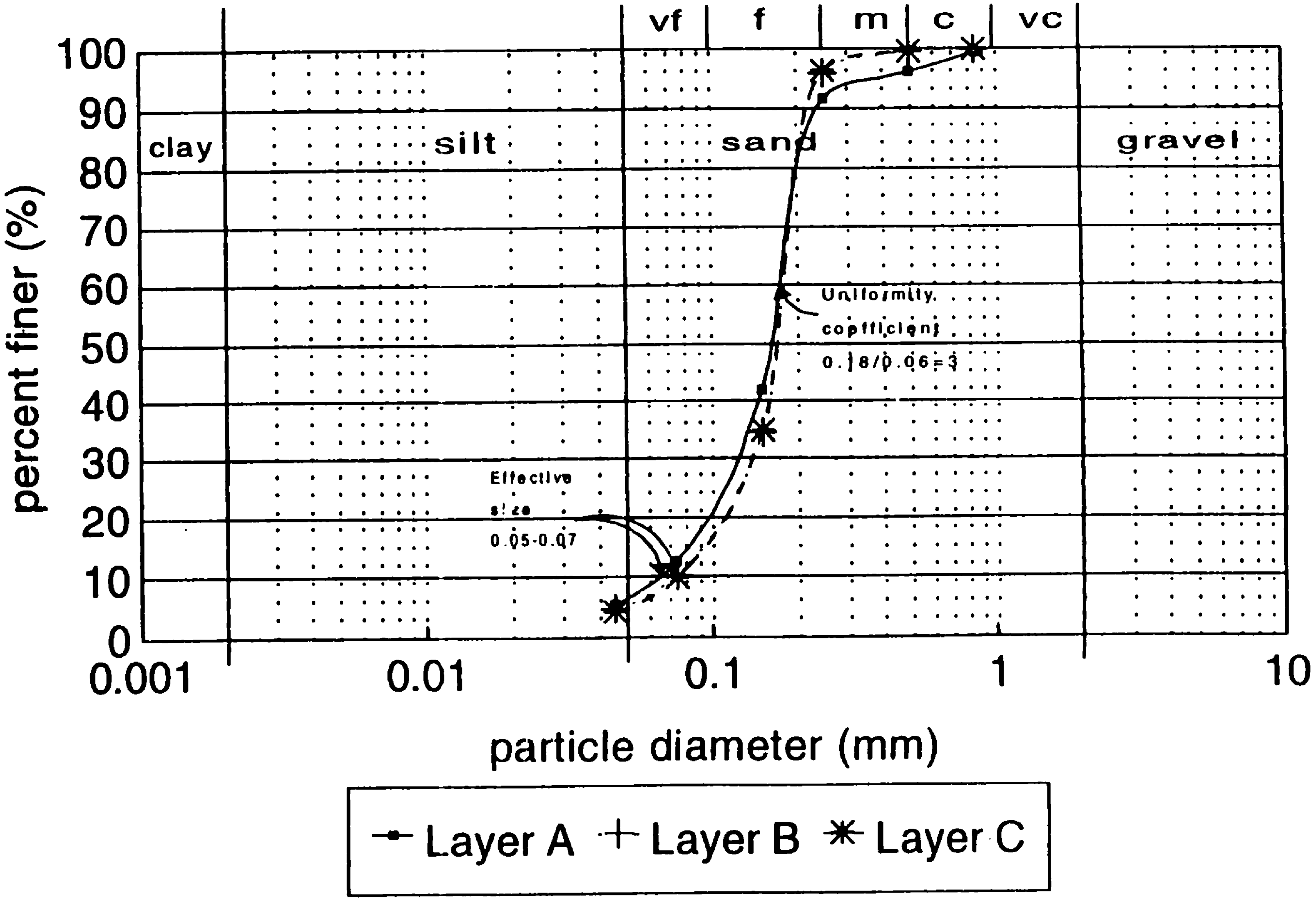


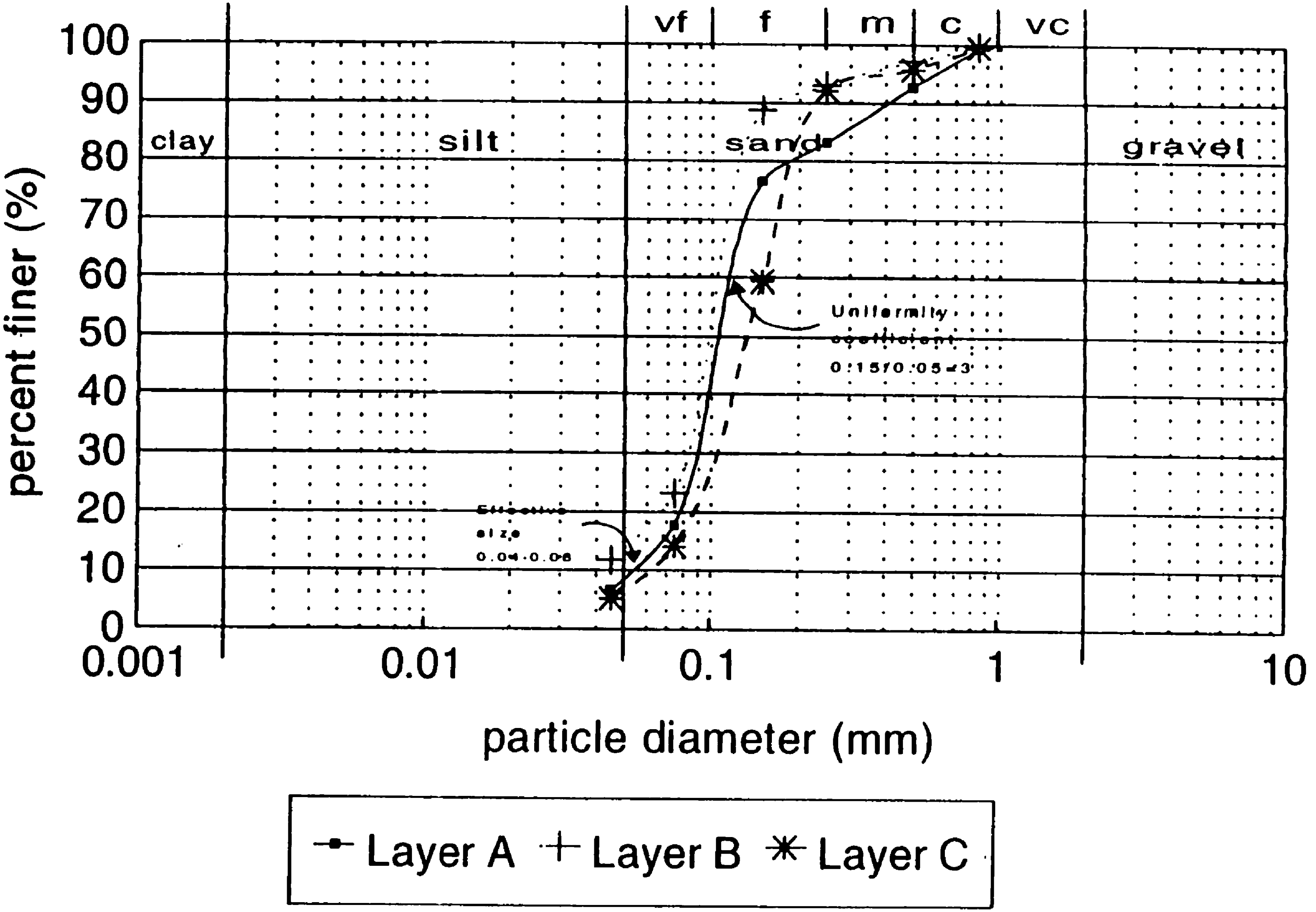
Figure A-1: Moisture characteristic for the Lamoureux soils a) site 1, b) site 2 c) site 3, d) site 4, e) site 5

Figure A-2 Grain Size Distribution (Site 1)



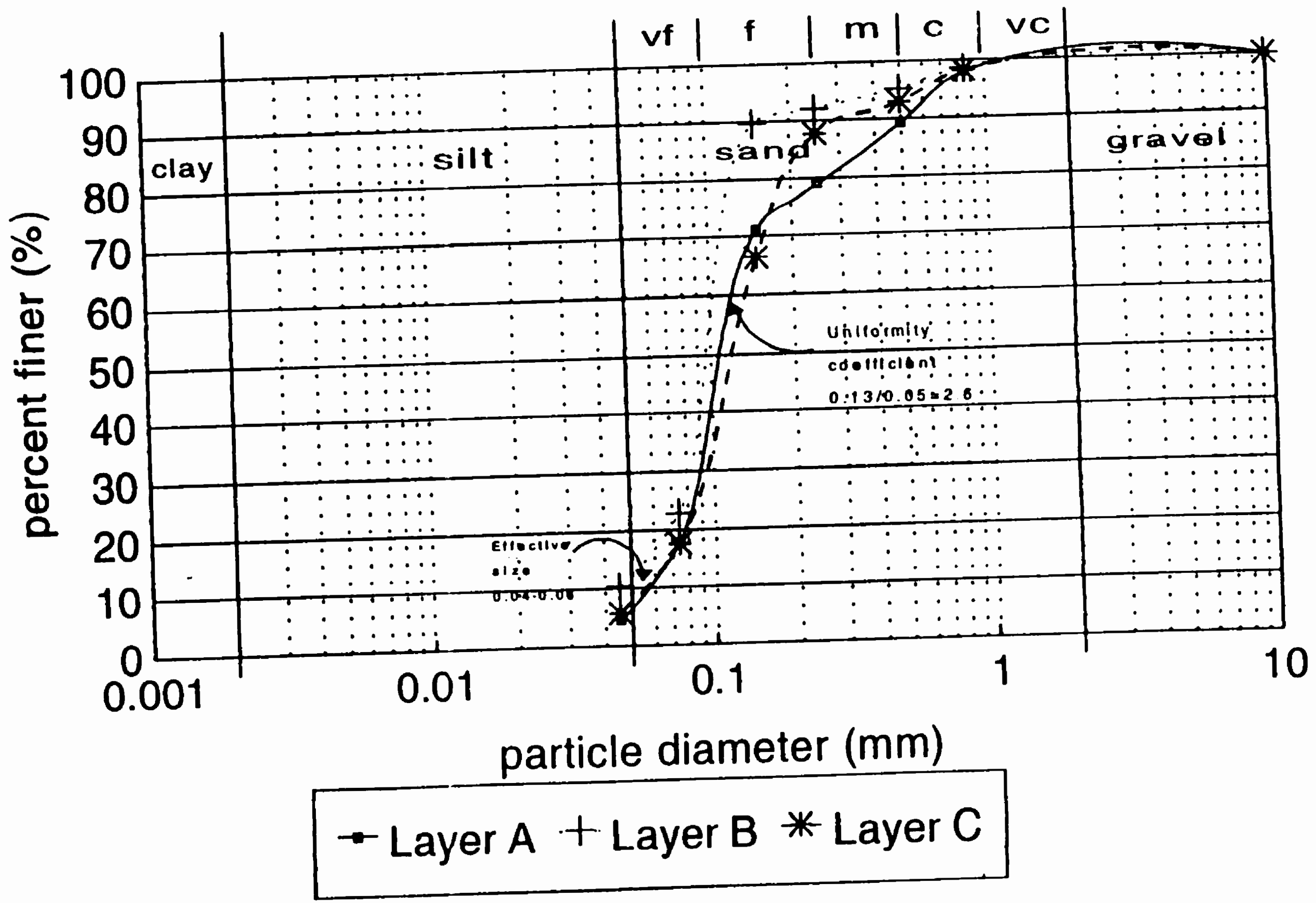
Samples taken in July 1996

Figure A-3 Grain Size Distribution (Site 2)



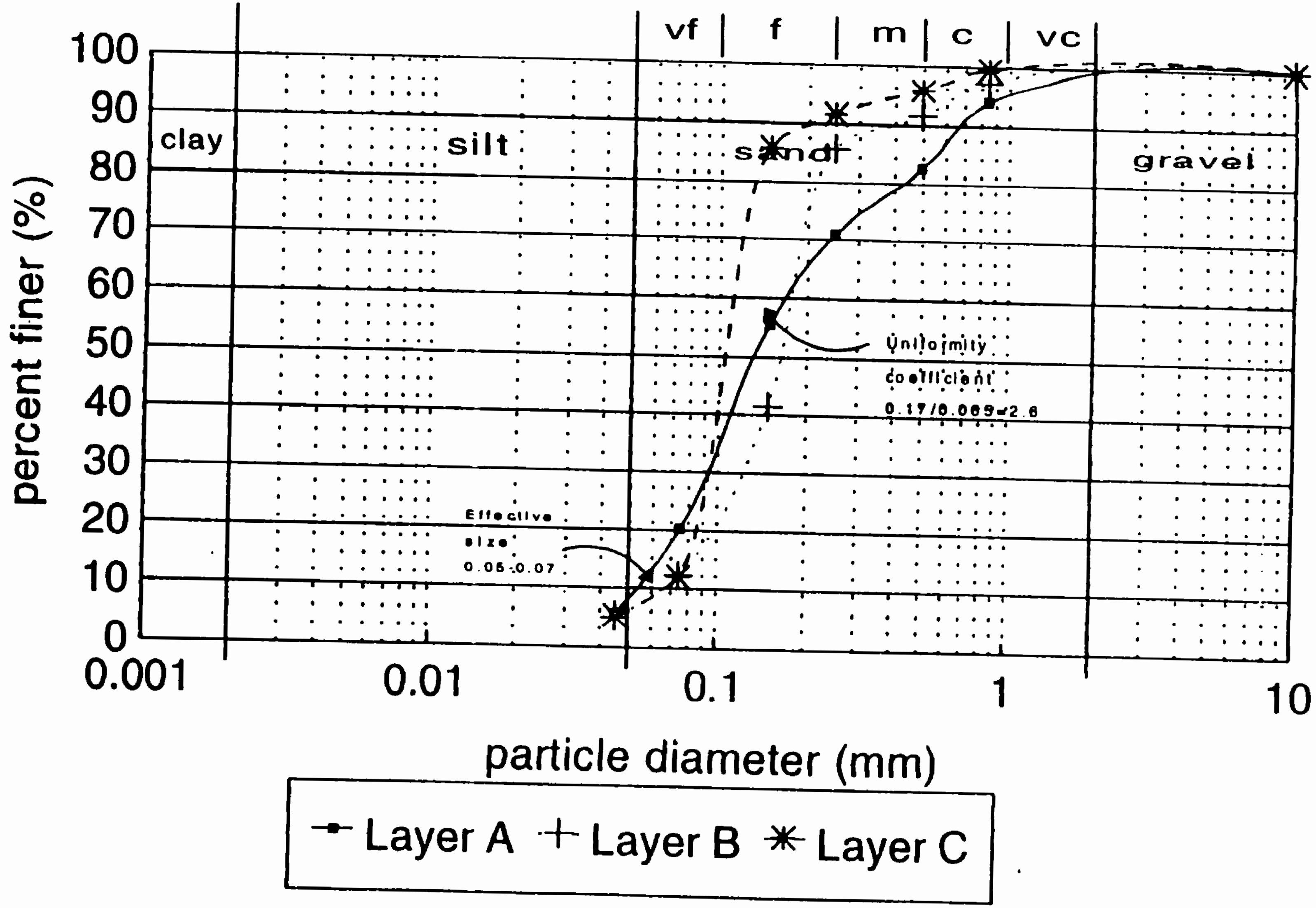
Samples taken in July 1996

Figure A-4 Grain Size Distribution (Site 3)



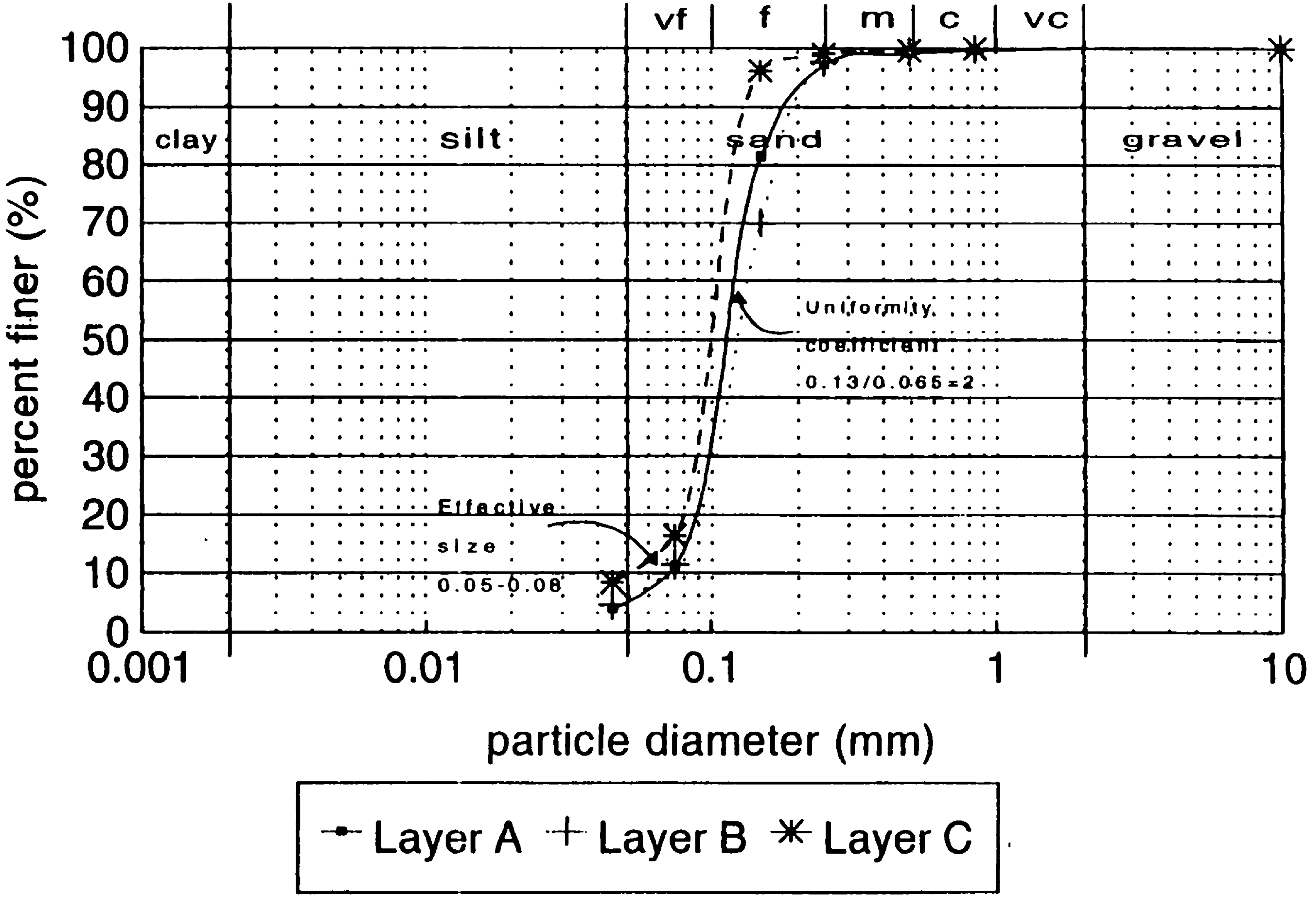
Samples taken in July 1996

Figure A-5 Grain Size Distribution (Site 4)



Samples taken in July 1996

Figure A-6 Grain Size Distribution (Site 5)



Samples taken in July 1996

Appendix B

Table B-1	Daily rainfall data.
Table B-2	Daily evapotranspiration data.
Table B-3	Available water and tension readings.
Table B-4	Daily mean air temperature.

Table B-1 Rain gauge (mm), Summer 1996

Date	Field data (mm)				CDA station (mm)			
	June	July	Aug.	Sept.	June	July	Aug.	Sept
01	0.0	0.0	17.6	0.0	0.0	0.0	3.8	0.0
02	0.0	0.0	0.0	0.0	0.0	2.4	0.0	0.0
03	0.0	8.0	0.0	0.0	0.0	13.8	0.2	0.0
04	0.0	9.5	0.0	0.0	4.8	0.0	0.0	0.0
05	21.5	0.0	0.0	0.0	9.6	0.2	0.0	0.0
06	6.0	0.0	0.0	0.0	13.2	0.0	0.0	0.0
07	12.0	1.0	0.0	0.0	2.6	0.8	0.0	20.6
08	6.5	0.0	35.0	10.0	1.4	1.2	74.8	18.0
09	0.0	0.0	0.0	15.1	9.2	0.0	0.0	0.2
10	6.5	0.0	0.0	0.5	1.2	0.0	0.0	0.0
11	0.4	0.0	0.0	0.0	0.0	0.0	0.0	24.0
12	0.0	0.0	0.0	9.0	0.0	0.4	0.0	7.6
13	1.0	4.9	0.0	12.5	11.4	2.2	0.0	10.0
14	0.0	5.0	0.0	4.5	0.0	0.4	0.0	5.4
15	0.0	35.0	0.0	5.9	0.0	9.4	3.2	3.6
16	0.0	18.0	15.0	5.0	0.0	0.2	0.0	0.0
17	0.0	0.5	0.0	1.5	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	32.8	0.4	0.0
19	0.0	3.9	0.0	0.0	0.0	3.6	0.0	0.0
20	0.0	0.4	0.0	0.0	0.0	0.0	2.4	0.0
21	0.0	0.0	4.0	0.0	4.8	0.0	0.0	0.0
22	4.0	0.0	0.0	0.0	9.0	0.0	1.2	0.0
23	0.5	27.5	0.0	0.0	0.0	36.0	0.0	0.0
24	0.0	0.0	0.8	0.0	2.0	0.0	0.0	2.8
25	3.0	8.5	0.0	2.0	2.0	6.6	0.2	0.0
26	0.0	0.0	0.0	0.2	0.0	0.0	0.6	0.4
27	7.0	0.0	0.2	0.0	6.2	0.0	0.0	8.0
28		0.0	0.0	16.5	0.4	0.2	0.0	17.8
29	5.0	0.0	0.0	15.0	4.2	0.8	0.0	6.0
30	5.0	14.5	0.0	9.4	7.2	10.5	0.0	0.0
31		15	0.0			27.8	0.0	
Tot.	78.4	151.7	72.6	107.1	89.2	149.3	86.8	124.4
Mean	2.6	4.9	2.34	3.57	3.0	4.8	2.8	4.1

Table B-2 Evapotranspiration (mm), Summer 1996

Date	Field data (mm) *				CDA station (mm) **			
	June	July	Aug.	Sept.	June	July	Aug.	Sept
01	2.0	5.8	1.0	2.6	5.3	4.8	3.5	4.7
02	2.0	4.8	3.0	3.5	6.1	4.9	3.8	4.9
03	2.0	4.8	5.0	3.5	3.3	3.2	4.8	4.0
04	3.0	1.5	5.0	3.2	4.1	3.4	5.1	4.4
05	2.0	2.4	5.0	3.4	3.2	4.5	5.3	4.3
06	4.0	7.2	4.0	2.4	3.8	3.3	5.5	4.1
07	2.0	2.4	5.0	4.7	1.9	3.8	5.3	3.3
08	4.0	3.1	2.0	4.0	2.5	4.3	4.3	1.2
09	4.0	4.8	4.0	0.0	3.8	3.5	3.7	1.7
10	2.0	3.6	5.0	1.1	4.9	3.5	3.0	2.3
11	3.0	4.8	5.0	2.5	4.8	5.2	3.8	3.1
12	4.0	3.4	5.0	3.8	4.8	5.0	4.3	1.4
13	3.0	2.9	6.0	2.3	3.7	3.9	3.9	1.5
14	4.0	3.9	2.8	2.1	4.7	4.8	3.7	1.5
15	5.0	1.0	3.6	1.1	3.9	3.0	4.9	0.3
16	4.0	2.8	5.2	2.2	4.5	4.2	3.2	0.5
17	3.0	3.7	3.4	0.0	5.0	4.8	3.6	2.2
18	4.0	3.0	3.3	2.6	4.1	5.3	3.7	2.7
19	3.0	1.6	3.6	5.0	4.5	3.3	4.3	2.5
20	3.0	7.4	3.4	4.8	3.5	4.1	4.0	2.5
21	3.0	7.2	1.0	4.7	4.2	4.5	3.3	2.7
22	3.0	3.5	4.0	2.2	2.0	5.3	4.6	0.[illegible]
23	3.0	7.1	3.0	2.1	3.1	4.5	3.5	1.3
24	3.0	0.8	3.2	4.2	3.5	5.1	3.9	1.4
25	4.0	4.3	3.0	0.0	3.5	4.3	5.1	1.0
26	4.0	3.4	4.6	3.0	4.2	4.1	1.8	2.5
27	4.0	3.5	1.2	0.0	2.2	3.7	3.2	1.6
28	4.0	4.7	2.9	1.0	4.5	4.1	3.8	1.0
29	4.0	4.2	2.6	3.2	4.0	4.7	3.8	1.0
30	4.0	1.5	4.7	4.4	5.5	1.8	3.4	0.5
31		0.5	3.6			3.4	4.5	
Tot.	99.0	115.6	114.1	79.6	119.1	128.3	124.6	66.5
Mean	3.3	3.7	3.7	2.6	4.0	4.1	4.0	2.2

* From screened evaporation pan at Lamoureux Farm; ** Calculated by CDA from meteorological observations.

Table B-3 Remaining available water* and tension readings (Site 1)

Date	M.C. (mm)			Tension (centibars)			Total depth of available water from surface to soil depth indicated		
Layers	A	B	C	A	B	C	300 mm	400 mm	600 mm
July 18	23.2	22.6	17.5	6.0	10.0	5.0	34.5	45.8	63.4
23	38.7	20.0	18.7	15.0	14.0	7.0	48.7	58.7	77.3
29	33.8	14.6	21.8	10.5	11.5	4.0	41.1	48.4	70.2
August 07	40.0	14.8	18.9	19.3	12.8	7.8	47.4	54.8	73.7
13	33.8	13.4	20.8	18.0	14.5	9.5	40.5	47.2	68.0
15	28.4	21.3	20.0	27.0	14.0	9.0	39.1	49.7	69.7
19	35.7	18.3	16.3	25.8	14.7	9.9	44.8	54.0	70.3
22	30.9	16.3	12.6	44.0	18.5	11.3	39.1	47.3	59.8
25	32.3	3.0	5.6	62.5	32.5	21.5	47.3	35.3	54.9
29	17.2	3.8	8.4	76.0	59.0	50.5	19.1	21.0	29.4
31	10.8	9.6	12.6	76.0	62.0	55.0	25.6	20.4	42.9
September 02	15.8	7.3	10.0	77.3	65.1	61.5	26.9	18.1	43.0
06	---	---	---	---	---	---	---	---	---
17	38.3	19.5	10.6	25.0	15.0	44.2	40.1	57.8	68.4
October 13	42.6	18.3	22.1	18.0	25.0	5.0	51.8	60.9	83.0

* The remaining available water numbers in this table are obtained from the total water content in the soil samples on date of measurements minus the wilting point value for the site.

Table B-3 cont. Remaining available water* and tension readings (Site 3)

Date	M.C. (mm)			Tension (centibars)			Total depth of available water from surface to soil depth indicated		
Layers	A	B	C	A	B	C	300 mm	400 mm	600 mm
July 18	56.6	54.7	51.0	18.5	15.5	36.0	84.0	111.3	162.3
23	61.1	43.7	47.3	24.0	20.0	20.0	83.0	104.8	152.1
29	65.1	50.4	54.3	23.3	16.0	17.5	90.3	115.6	169.8
August 07	62.4	48.1	52.7	22.5	18.0	17.5	86.5	110.5	163.3
13	61.6	54.8	54.5	20.0	15.5	16.8	89.0	116.4	170.9
15	55.0	54.9	45.5	26.0	20.3	21.5	82.4	109.9	155.3
19	53.2	49.5	52.3	24.0	18.1	18.0	77.9	102.7	155.0
22	59.0	44.6	45.1	25.0	20.0	20.0	81.3	103.5	148.7
25	54.6	45.8	37.9	31.0	24.0	22.0	77.5	100.4	138.3
29	55.2	39.8	36.6	34.4	25.0	29.5	75.1	95.0	131.6
31	55.1	30.7	41.7	36.5	27.0	24.6	70.5	85.8	127.5
September 02	50.9	31.8	30.8	38.0	29.5	27.1	66.8	82.7	113.5
06	48.1	31.1	17.8	33.0	32.0	28.5	63.6	79.2	97.0
17	63.7	53.3	51.3	17.5	14.5	17.0	90.3	117.0	168.3
October 13	63.0	54.2	46.4	14.5	11.0	12.5	90.1	117.2	163.6

* The remaining available water numbers in this table are obtained from the total water content in the soil sample on date of measurement minus the wilting point value for that site.

Table B-3 cont. Remaining available water* and tension readings (Site 5)

Date	M.C. (mm)			Tension (centibars)			Total depth of available water from surface to soil depth indicated		
Layers	A	B	C	A	B	C	300 mm	400 mm	600 mm
July 18	42.9	40.7	24.6	16.0	14.5	12.5	78.3	83.7	108.2
23	45.1	38.0	15.4	21.5	16.5	15.3	64.1	83.1	98.5
29	43.4	34.8	16.6	19.5	15.0	13.0	60.8	78.2	94.8
August 07	42.7	34.6	21.4	21.0	16.0	15.3	59.9	77.2	98.6
13	44.2	36.3	16.0	20.5	17.0	15.0	62.4	80.5	96.5
15	42.2	32.6	20.1	28.5	18.0	17.5	58.5	74.8	94.8
19	32.2	24.6	29.4	24.5	18.0	18.0	44.5	56.8	86.2
22	32.2	27.3	9.8	29.5	17.1	21.5	45.9	59.5	69.3
25	33.8	23.2	13.4	43.1	25.0	26.5	45.4	57.0	70.4
29	22.9	24.6	8.5	66.0	37.0	46.5	35.2	47.5	55.9
31	21.4	24.1	11.6	74.1	47.5	49.0	38.4	45.5	62.0
September 02	18.3	14.2	8.0	75.5	54.5	50.0	25.4	32.4	40.5
06	12.6	13.4	3.9	80.0	67.0	54.0	19.3	26.0	29.9
17	40.4	28.0	4.8	14.0	14.0	46.1	54.4	68.4	73.3
October 13	37.3	31.6	16.5	11.0	12.0	8.5	53.0	68.8	85.3

* The remaining available water numbers in this table are obtained from the total water content in the soil sample on date of measurement minus the wilting point value for that site.

Table B-4 Mean air temperature (°C). Summer 1996 *

Date	Field measurement				CDA weather station			
	June	July	Aug.	Sept.	June	July	Aug.	Sept
01		23	18	17.5	17	22.4	18.5	20.9
02		22.5	18.5	19	22.3	22.4	18.3	23.3
03		21	19	20	19	18.8	20.7	21.7
04		21		21.5	19	18.2	22.3	22.1
05		20.5		22.5	15.7	21.2	22.6	22.4
06		21.5		20.5	17.9	17.8	24.1	22.9
07		16.5		22	14.9	18.8	26.9	21.1
08		20		21	15.3	20.1	23.8	17.2
09		19.5		17	18.1	17.4	20.1	19.6
10		14.5		19	22.4	16.7	14.8	18.2
11		18.5		16.5	22.9	20.6	16.2	20.5
12		19.5		19	23.4	22.3	20.4	17.9
13		22	17.5	17	21	20.8	20.6	16.1
14		21.5	17	16	21.5	22.6	18.8	15.6
15	22.5	20.5	17.5	14.5	17.1	18.8	22.7	13.1
16	19.5	20.5	21	12.5	18.7	21.3	20.4	13.6
17	180	22	20	11	21.7	22.6	20.7	16.3
18	20.5	23.5	19	15	20.4	24.7	18.5	16.6
19	20	23.5	17	16	21.7	18.1	19.3	16.6
20	21	16.5	16.5	16.5	21.8	18.9	21	17.4
21	23.5	18	20	16	21.7	19.2	20.3	17.5
22	21	18	18.5	16	16.3	20.6	24.2	10.6
23	16.5	18.5	23	12	17.2	19.1	21	9.2
24	16.5	18.5	19	6.5	17.6	21.7	19.7	10
25	17.5	18.5	19	10	15.6	20.3	22.1	8.2
26	16	18.5	21	7.5	17.6	20	15.1	12.6
27	16.5	18.5	13.5	11	14.5	18	16.6	14.2
28		17.5	14	15	20.1	17.7	18.5	14
29		17	16.5	13.5	21.3	22	17.1	11.3
30	21	19	15	10.5	24.7	17.8	16.8	9.7
31		19	15			19.6	19.8	
Tot.l	270	609	395.5	472	577.7	619.8	621.1	489.8
Mean	19.3	19.6	18	15.7	19.3	20	20	16.3

* Mean air temp. is the arith. avrg. of the Max and Min temp. reading ending at 8 AM the day after the date shown.

Appendix C

Tables C-1 to C-3	Suggested irrigation scheduling. Sites 1, 3 and 5, data for summer 1974.
Figures C-1 to C-5	Suggested irrigation scheduling graphs. Sites 1, 3 and 5, root zone 300 mm deep.

Table C-1 Suggested irrigation scheduling, Site 1, 400 mm of root zone depth (Base on monthly weather data for June 1974)*

DATE	RAIN	ET	A.W.	Irrigation	Drainage
01	0.0	4	49.6 FC		
02	0.0	3	46.6		
03	0.0	3	43.6		
04	0.0	4	39.6		
05	8.4	1	47.0		
06	3.0	3	47.0		
07	6.4	1	52.4		
08	2.0	1	53.4		
09	0.0	2	49.6 FC		1.8
10	3.0	2	50.6		
11	2.0	3	49.6 FC		
12	0.0	4	45.6		
13	0.5	2	44.1		
14	0.0	4	40.1		
15	0.0	8	32.1		
16	0.0	4	28.1		
17	0.0	6	47.1	25	
18	0.0	4	43.1		
19	0.0	4	39.1		
20	0.0	2	37.1		
21	0.0	6	31.1		
22	2.0	4	29.1		
23	1.0	8	47.1	25	
24	0.0	2	45.1		
25	2.0	6	41.1		
26	0.0	6	35.1		
27	3.4	1.4	37.1		
28	0.0	5	32.1		
29	3.4	1	34.5		
30	2.5	2	35.0		
Tot.	39.6	103.4		50	1.8

* Monthly total values are from a summary of weather data. Daily values have been estimated and distributed to give the monthly totals. All the values are in mm of water.

Table C-1 cont. **Suggested irrigation scheduling, Site 1, 400 mm of root zone depth (Based on monthly weather data for July 1974)***

DATE	RAIN	ET	A.W.	Irrigation	Drainage
01	0.0	7.0	28.0		
02	0.0	4.0	24.0		
03	4.0	1.0	27.0		
04	4.0	1.0	30.0		
05	0.0	2.0	28.0		
06	0.0	5.0	48.0	25	
07	0.5	5.0	43.5		
08	0.0	3.0	40.5		
09	0.0	5.0	35.5		
10	0.0	4.0	31.5		
11	0.0	3.0	28.5		
12	0.0	5.0	23.5		
13	4.0	1.0	26.5		
14	3.1	2.0	27.6		
15	15.0	1.0	41.6		
16	8.0	1.0	48.6		
17	1.0	7.0	42.6		
18	0.0	5.0	37.6		
19	3.0	3.0	37.6		
20	0.0	8.0	29.6		
21	0.0	6.0	23.6		
22	0.0	3.0	20.6		
23	13.0	1.0	32.6		
24	0.0	5.0	27.6		
25	5.0	2.0	30.6		
26	0.0	5.0	25.6		
27	0.0	4.0	46.6	25	
28	0.0	5.0	41.6		
29	0.0	4.0	37.6		
30	7.0	1.0	43.6		
31	5.0	2.0	46.6		
Tot	72.6	112.0		50	0.0

* Monthly total values are from a summary of weather data. Daily values have been estimated and distributed to give the monthly totals. All the values are in mm of water.

Table C-1 cont. **Suggested irrigation scheduling, Site 1, 400 mm of root zone depth (Based on monthly data for August 1974)***

DATE	RAIN	ET	A.W.	Irrigation	Drainage
01	12.0	2.0	56.6		
02	0.0	4.0	52.6		
03	0.0	6.0	46.6		
04	0.0	6.0	40.6		
05	0.0	3.0	37.6		
06	0.0	7.0	30.6		
07	0.0	2.0	28.6		
08	20.0	1.0	47.6		
09	0.0	6.0	41.6		
10	0.0	4.0	37.6		
11	0.0	2.0	35.6		
12	0.0	3.0	32.6		
13	0.0	3.0	29.6		
14	0.0	3.0	26.6		
15	0.0	2.0	24.6		
16	10.0	1.0	33.6		
17	0.0	1.0	32.6		
18	0.0	5.0	27.6		
19	0.0	4.0	23.6		
20	0.0	4.0	44.6	25	
21	2.5	1.0	46.1		
22	0.0	3.0	43.1		
23	0.0	4.0	39.1		
24	0.5	1.0	38.6		
25	0.0	3.0	35.6		
26	0.0	1.0	34.6		
27	0.5	1.0	34.1		
28	0.0	3.0	31.1		
29	0.0	3.0	28.1		
30	0.0	5.0	23.1		
31	0.0	3.0	45.1	25	
Tot	45.5	97.0		50	0.0

* Monthly total values are from a summary of weather data. Daily values have been estimated and distributed to give the monthly totals. All the values are in mm of water.

Table C-1 cont. **Suggested irrigation scheduling, Site 1, 400 mm of root zone depth (Based on monthly data for September 1974)***

DATE	RAIN	ET	A.W.	Irrigation	Drainage
01	0.0	1.0	44.1		
02	0.0	3.0	41.1		
03	0.0	3.0	38.1		
04	0.0	3.0	35.1		
05	0.0	2.0	33.1		
06	0.0	1.0	32.1		
07	0.0	5.0	27.1		
08	5.0	1.0	31.1		
09	7.0	0.5	37.6		
10	0.5	3.0	35.1		
11	0.0	5.0	30.1		
12	4.0	1.0	33.1		
13	5.0	1.0	37.1		
14	2.0	0.5	38.6		
15	3.0	0.1	41.5		
16	2.0	1.0	42.5		
17	0.5	4.0	39.0		
18	0.0	3.0	36.0		
19	0.0	3.0	33.0		
20	0.0	3.0	30.0		
21	0.0	1.0	29.0		
22	0.0	2.0	27.0		
23	0.0	1.0	26.0		
24	0.0	1.0	25.0		
25	1.0	2.0	24.0		
26	0.2	0.5	23.7		
27	0.0	0.5	23.2		
28	5.0	1.0	27.2		
29	5.0	2.0	30.2		
30	4.0	1.0	33.2		
Tot	44.2	56.1		0.0	0.0

* Monthly total values are from a summary of weather data. Daily values have been estimated and distributed to give the monthly totals. All the values are in mm of water.

Table C-2 **Suggested irrigation scheduling, Site 3, 400 mm of root depth (Based on monthly weather data for June 1974)***

DATE	RAIN	ET	A.W.	Irrigation	Drainage
01	0.0	4	114.2 FC		
02	0.0	3	111.2		
03	0.0	3	108.2		
04	0.0	4	104.2		
05	8.4	1	111.6		
06	3.0	3	111.6		
07	6.4	1	117.0		
08	2.0	1	118.0		
09	0.0	2	114.2 FC		1.8
10	3.0	2	115.2		
11	2.0	3	114.2 FC		
12	0.0	4	110.2		
13	0.5	2	108.7		
14	0.0	4	104.7		
15	0.0	8	96.7		
16	0.0	4	92.7		
17	0.0	6	86.7		
18	0.0	4	82.7		
19	0.0	4	78.7		
20	0.0	2	76.7		
21	0.0	6	70.7		
22	2.0	4	68.7		
23	1.0	8	61.7		
24	0.0	2	59.7		
25	2.0	6	55.7		
26	0.0	6	74.7	25	
27	3.4	1.4	76.7		
28	0.0	5	71.7		
29	3.4	1	74.1		
30	2.5	2	74.6		
Tot.	39.6	103.4		25	1.8

* **Monthly total values are from a summary of weather data. Daily values have been estimated and distributed to give the monthly totals. All the values are in mm of water.**

Table C-2 cont. **Suggested irrigation scheduling, Site 3, 400 mm of root zone depth (Based on monthly weather data for July 1974)***

DATE	RAIN	ET	A.W.	Irrigation	Drainage
01	0.0	7.0	67.6		
02	0.0	4.0	63.6		
03	4.0	1.0	66.6		
04	4.0	1.0	69.6		
05	0.0	2.0	67.6		
06	0.0	5.0	62.6		
07	0.5	5.0	58.1		
08	0.0	3.0	55.1		
09	0.0	5.0	75.1	25	
10	0.0	4.0	71.1		
11	0.0	3.0	68.1		
12	0.0	5.0	63.1		
13	4.0	1.0	66.1		
14	3.1	2.0	67.2		
15	15.0	1.0	81.2		
16	8.0	1.0	88.2		
17	1.0	7.0	82.2		
18	0.0	5.0	77.2		
19	3.0	3.0	77.2		
20	0.0	8.0	69.2		
21	0.0	6.0	63.2		
22	0.0	3.0	60.2		
23	13.0	1.0	72.2		
24	0.0	5.0	67.2		
25	5.0	2.0	70.2		
26	0.0	5.0	65.2		
27	0.0	4.0	61.2		
28	0.0	5.0	56.2		
29	0.0	4.0	77.2	25	
30	7.0	1.0	83.2		
31	5.0	2.0	86.2		
Tot	72.6	112.0		50	0.0

*** Monthly total values are from a summary of weather data. Daily values have been estimated and distributed to give the monthly totals. All the values are in mm of water.**

Table C-2 cont. **Suggested irrigation scheduling, Site 3, 400 mm of root zone depth (Based on monthly data for August 1974)***

DATE	RAIN	ET	A.W.	Irrigation	Drainage
01	12.0	2.0	96.2		
02	0.0	4.0	92.2		
03	0.0	6.0	86.2		
04	0.0	6.0	80.2		
05	0.0	3.0	77.2		
06	0.0	7.0	70.2		
07	0.0	2.0	68.2		
08	20.0	1.0	87.2		
09	0.0	6.0	81.2		
10	0.0	4.0	77.2		
11	0.0	2.0	75.2		
12	0.0	3.0	72.2		
13	0.0	3.0	69.2		
14	0.0	3.0	66.2		
15	0.0	2.0	64.2		
16	10.0	1.0	73.2		
17	0.0	1.0	72.2		
18	0.0	5.0	67.2		
19	0.0	4.0	63.2		
20	0.0	4.0	59.2		
21	2.5	1.0	60.7		
22	0.0	3.0	57.7		
23	0.0	4.0	78.7	25	
24	0.5	1.0	78.2		
25	0.0	3.0	75.2		
26	0.0	1.0	74.2		
27	0.5	1.0	73.7		
28	0.0	3.0	70.7		
29	0.0	3.0	67.7		
30	0.0	5.0	62.7		
31	0.0	3.0	59.7		
Tot.	45.5	97.0		25	0.0

* Monthly total values are from a summary of weather data. Daily values have been estimated and distributed to give the monthly totals. All the values are in mm of water.

Table C-2 cont. **Suggested irrigation scheduling, Site 3, 400 mm of root zone depth (Based on monthly data for September 1974)***

DATE	RAIN	ET	A.W.	Irrigation	Drainage
01	0.0	1.0	58.7		
02	0.0	3.0	55.7		
03	0.0	3.0	77.7	25	
04	0.0	3.0	74.7		
05	0.0	2.0	72.7		
06	0.0	1.0	71.7		
07	0.0	5.0	66.7		
08	5.0	1.0	70.7		
09	7.0	0.5	77.2		
10	0.5	3.0	74.7		
11	0.0	5.0	69.7		
12	4.0	1.0	72.7		
13	5.0	1.0	76.7		
14	2.0	0.5	78.2		
15	3.0	0.1	81.1		
16	2.0	1.0	82.1		
17	0.5	4.0	78.6		
18	0.0	3.0	75.6		
19	0.0	3.0	72.6		
20	0.0	3.0	69.6		
21	0.0	1.0	68.6		
22	0.0	2.0	66.6		
23	0.0	1.0	65.6		
24	0.0	1.0	64.6		
25	1.0	2.0	63.6		
26	0.2	0.5	63.3		
27	0.0	0.5	62.8		
28	5.0	1.0	66.8		
29	5.0	2.0	69.8		
30	4.0	1.0	72.8		
Tot	44.2	56.1		25	0.0

* Monthly total values are from a summary of weather data. Daily values have been estimated and distributed to give the monthly totals. All the values are in mm of water.

Table C-3 Suggested irrigation scheduling, Site 5, 400 mm of root zone depth (Based on monthly weather data for June 1974)*

DATE	RAIN	ET	A.W.	Irrigation	Drainage
01	0.0	4	75.7		
02	0.0	3	72.7		
03	0.0	3	69.7		
04	0.0	4	65.7		
05	8.4	1	73.1		
06	3.0	3	73.1		
07	6.4	1	78.5		
08	2.0	1	79.5		
09	0.0	2	77.5		
10	3.0	2	78.5		
11	2.0	3	77.5		
12	0.0	4	73.5		
13	0.5	2	72.0		
14	0.0	4	68.0		
15	0.0	8	60.0		
16	0.0	4	56.0		
17	0.0	6	50.0		
18	0.0	4	46.0		
19	0.0	4	42.0		
20	0.0	2	40.0		
21	0.0	6	59.0	25	
22	2.0	4	57.0		
23	1.0	8	50.0		
24	0.0	2	48.0		
25	2.0	6	44.0		
26	0.0	6	38.0		
27	3.4	1.4	40.0		
28	0.0	5	60.0	25	
29	3.4	1	62.4		
30	2.5	2	62.9		
Tot	39.6	103.4		50	0.0

* Monthly total values are from a summary of weather data. Daily values have been estimated and distributed to give the monthly totals. All the values are in mm of water.

Table C-3 cont. Suggested irrigation scheduling, Site 5, 400 mm of root zone depth (Based on monthly weather data for July 1974)*

DATE	RAIN	ET	A.W.	Irrigation	Drainage
01	0.0	7.0	55.9		
02	0.0	4.0	51.9		
03	4.0	1.0	54.9		
04	4.0	1.0	57.9		
05	0.0	2.0	55.9		
06	0.0	5.0	50.9		
07	0.5	5.0	46.4		
08	0.0	3.0	43.4		
09	0.0	5.0	38.4		
10	0.0	4.0	59.4	25	
11	0.0	3.0	56.4		
12	0.0	5.0	51.4		
13	4.0	1.0	54.4		
14	3.1	2.0	55.5		
15	15.0	1.0	69.5		
16	8.0	1.0	76.5		
17	1.0	7.0	70.5		
18	0.0	5.0	65.5		
19	3.0	3.0	65.5		
20	0.0	8.0	57.5		
21	0.0	6.0	51.5		
22	0.0	3.0	48.5		
23	13.0	1.0	60.5		
24	0.0	5.0	55.5		
25	5.0	2.0	58.5		
26	0.0	5.0	53.5		
27	0.0	4.0	49.5		
28	0.0	5.0	44.5		
29	0.0	4.0	40.5		
30	7.0	1.0	46.5		
31	5.0	2.0	49.5		
Tot	72.6	112.0		25	0.0

* Monthly total values are from a summary of weather data. Daily values have been estimated and distributed to give the monthly totals. All the values are in mm of water.

Table C-3 cont. Suggested irrigation scheduling, Site 5, 400 mm of root zone depth (Based on monthly data for August 1974)*

DATE	RAIN	ET	A.W.	Irrigation	Drainage
01	12.0	2.0	59.5		
02	0.0	4.0	55.5		
03	0.0	6.0	49.5		
04	0.0	6.0	43.5		
05	0.0	3.0	40.5		
06	0.0	7.0	58.5	25	
07	0.0	2.0	56.5		
08	20.0	1.0	75.5		
09	0.0	6.0	69.5		
10	0.0	4.0	65.5		
11	0.0	2.0	63.5		
12	0.0	3.0	60.5		
13	0.0	3.0	57.5		
14	0.0	3.0	54.5		
15	0.0	2.0	52.5		
16	10.0	1.0	61.5		
17	0.0	1.0	60.5		
18	0.0	5.0	55.5		
19	0.0	4.0	51.5		
20	0.0	4.0	47.5		
21	2.5	1.0	49.0		
22	0.0	3.0	46.0		
23	0.0	4.0	42.0		
24	0.5	1.0	41.5		
25	0.0	3.0	38.5		
26	0.0	1.0	37.5		
27	0.5	1.0	37.0		
28	0.0	3.0	59.0	25	
29	0.0	3.0	56.0		
30	0.0	5.0	51.0		
31	0.0	3.0	48.0		
Tot.	45.5	97.0		50	0.0

* Monthly total values are from a summary of weather data. Daily values have been estimated and distributed to give the monthly totals. All the values are in mm of water.

Table C-3 cont. **Suggested irrigation scheduling, Site 5, 400 mm of root zone depth (Based on monthly data for September 1974)***

DATE	RAIN	ET	A.W.	Irrigation	Drainage
01	0.0	1.0	47.0		
02	0.0	3.0	44.0		
03	0.0	3.0	41.0		
04	0.0	3.0	38.0		
05	0.0	2.0	61.0	25	
06	0.0	1.0	60.0		
07	0.0	5.0	55.0		
08	5.0	1.0	59.0		
09	7.0	0.5	65.5		
10	0.5	3.0	63.0		
11	0.0	5.0	58.0		
12	4.0	1.0	61.0		
13	5.0	1.0	65.0		
14	2.0	0.5	66.5		
15	3.0	0.1	69.4		
16	2.0	1.0	70.4		
17	0.5	4.0	66.9		
18	0.0	3.0	63.9		
19	0.0	3.0	60.9		
20	0.0	3.0	57.9		
21	0.0	1.0	56.9		
22	0.0	2.0	54.9		
23	0.0	1.0	53.9		
24	0.0	1.0	52.9		
25	1.0	2.0	51.9		
26	0.2	0.5	51.6		
27	0.0	0.5	51.1		
28	5.0	1.0	55.1		
29	5.0	2.0	58.1		
30	4.0	1.0	61.1		
Tot	44.2	56.1		25	0.0

* Monthly total values are from a summary of weather data. Daily values have been estimated and distributed to give the monthly totals. All the values are in mm of water.

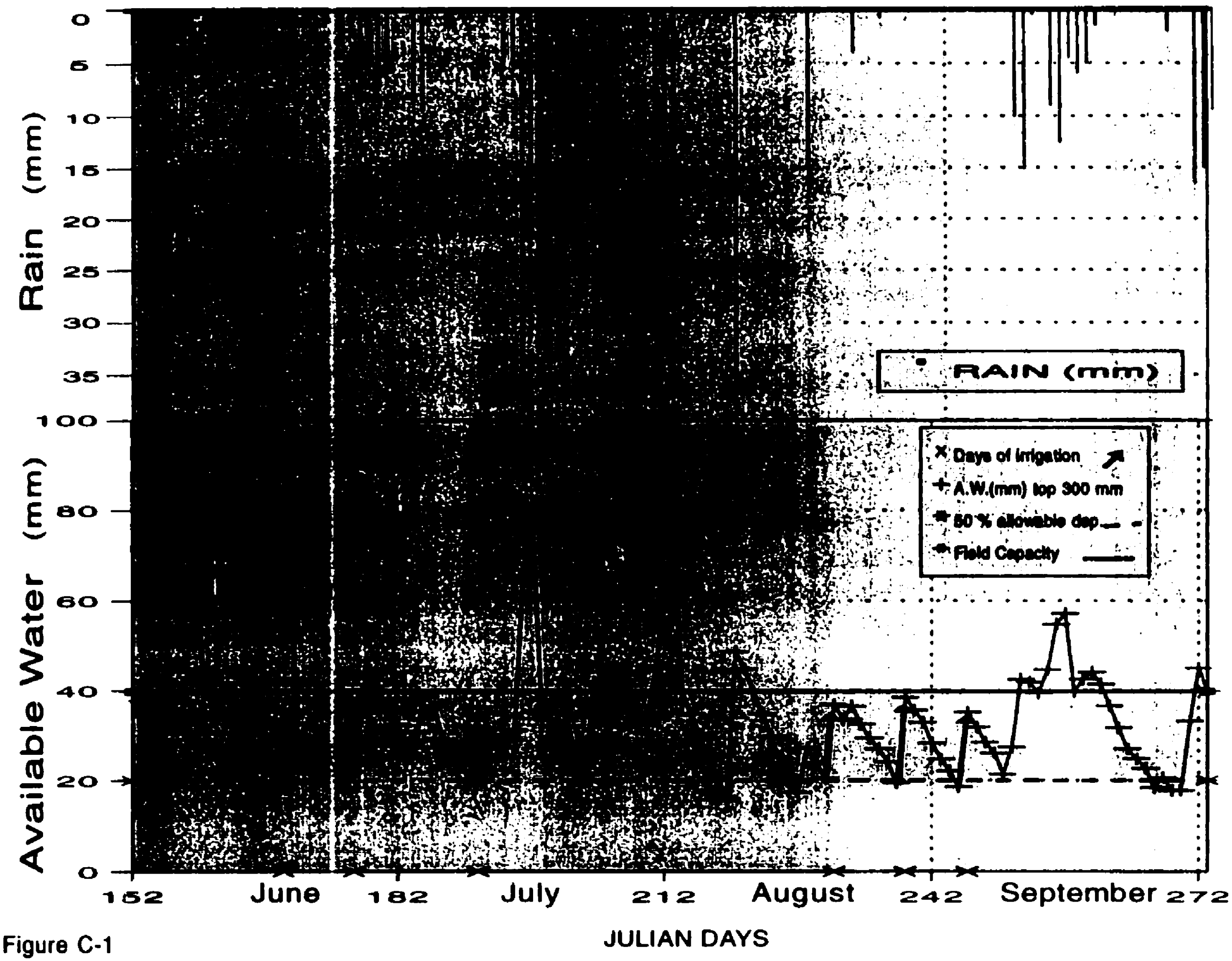


Figure C-1

SUGGESTED IRRIGATION SCHEDULING FOR RAIN DISTRIBUTION OF 1996, SITE No.1 (ROOT ZONE 300 mm DEEP)

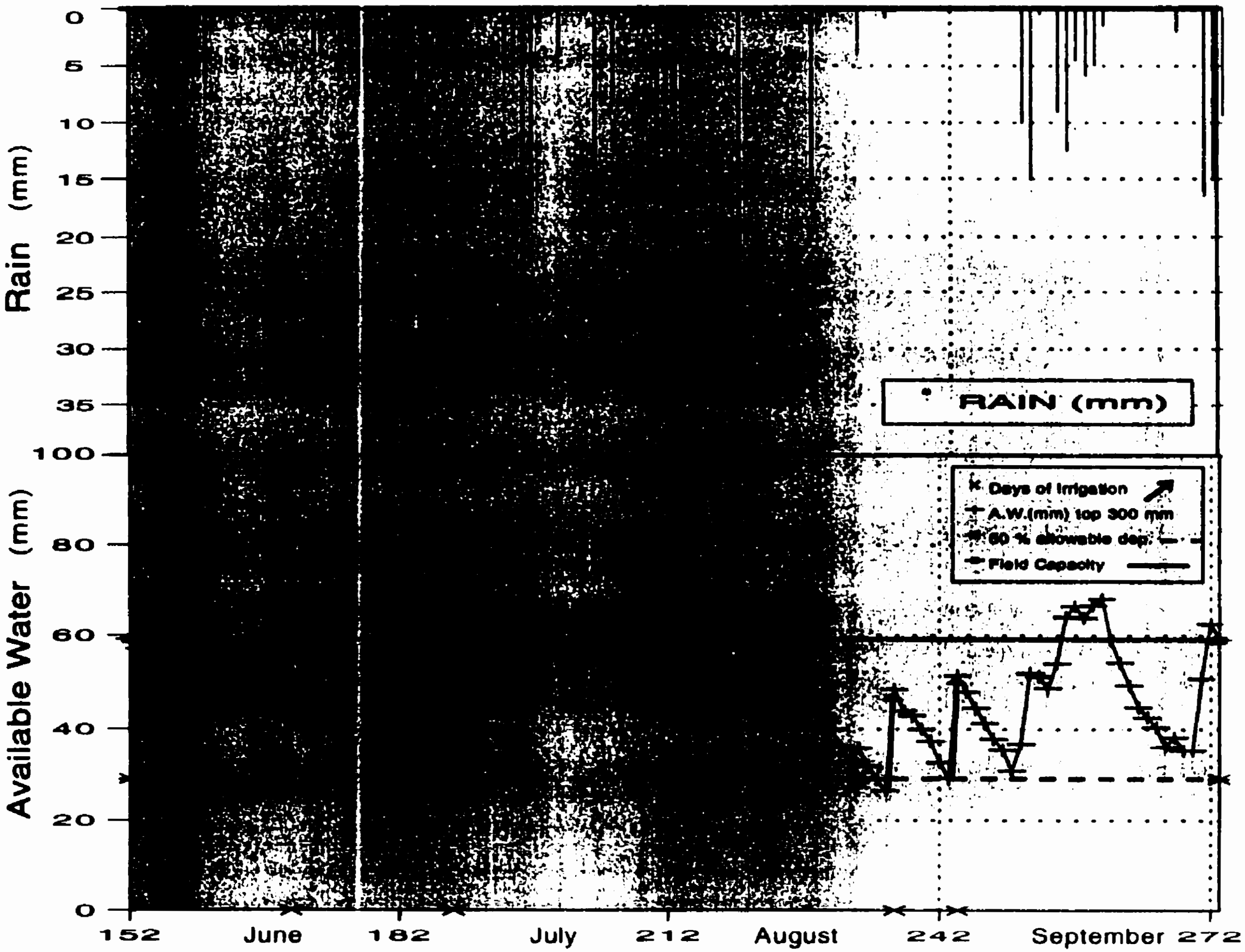


Figure C-2

SUGGESTED IRRIGATION SCHEDULING FOR RAIN DISTRIBUTION OF 1996, SITE 5 (ROOT ZONE 300 mm DEEP)

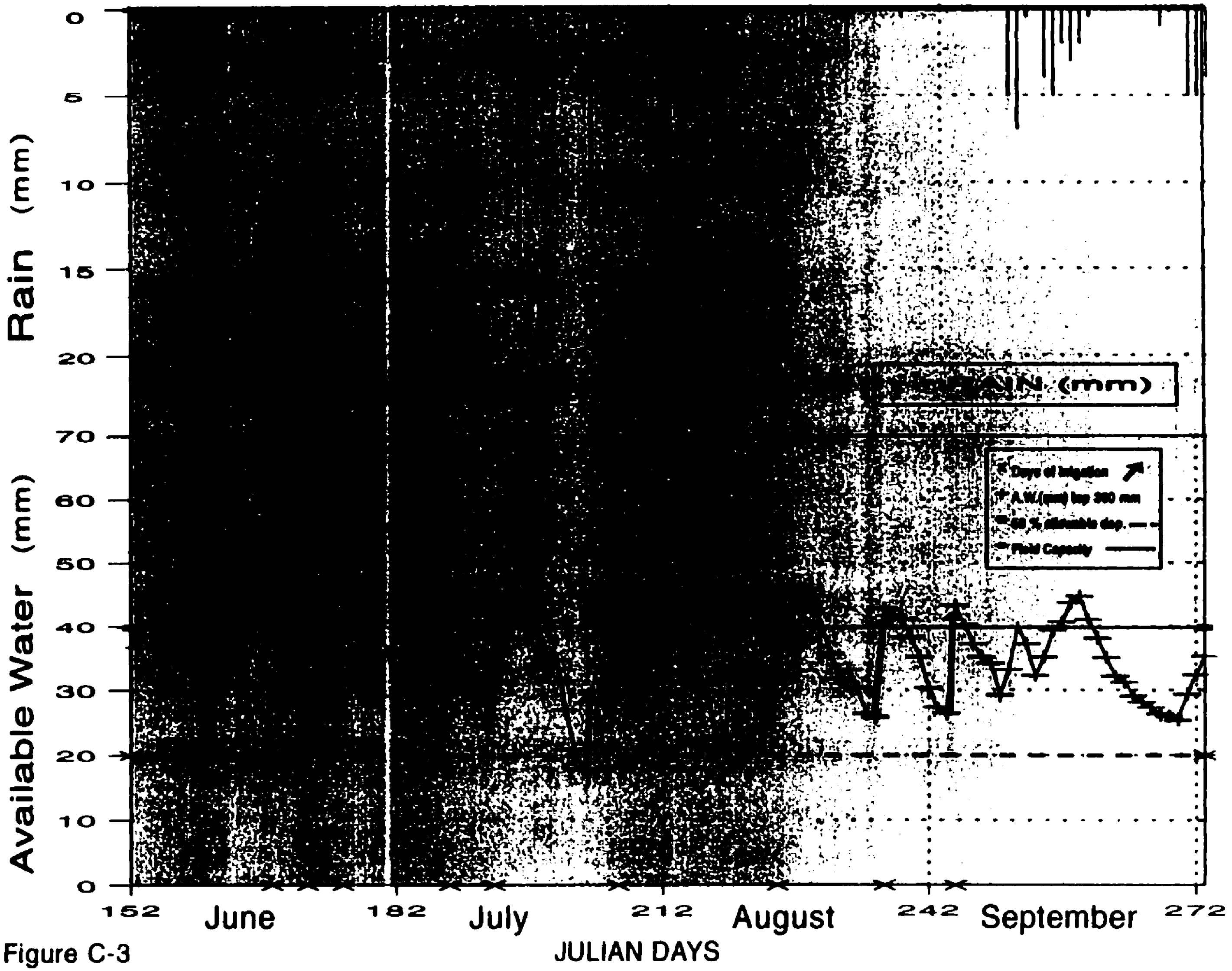


Figure C-3

SUGGESTED IRRIGATION SCHEDULING FOR RAIN DISTRIBUTION OF 1974, SITE 1 (ROOT ZONE 300 mm DEEP)

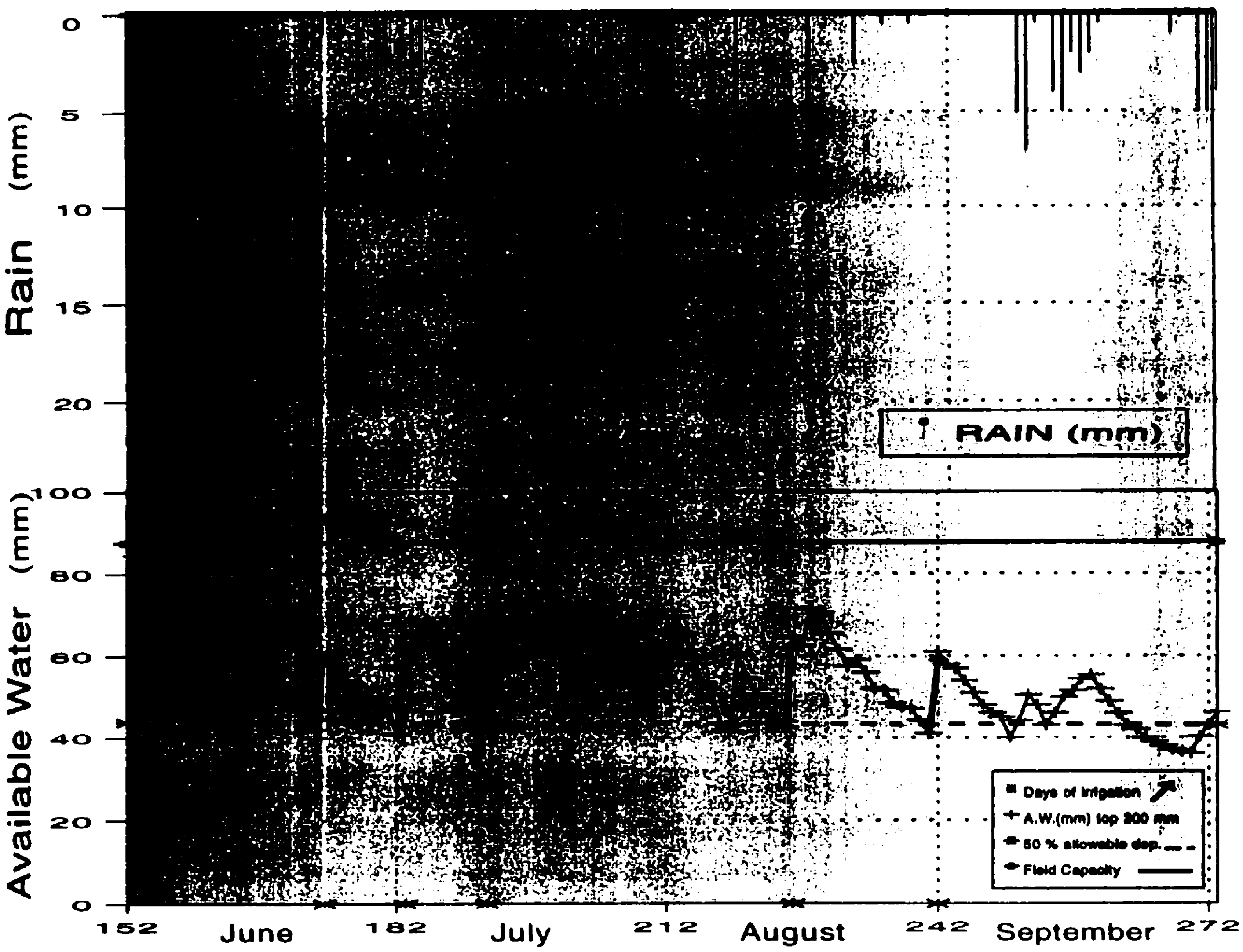


Figure C-4

SUGGESTED IRRIGATION SCHEDULING FOR RAIN DISTRIBUTION OF 1974, SITE 3 (ROOT ZONE 300 mm DEEP)

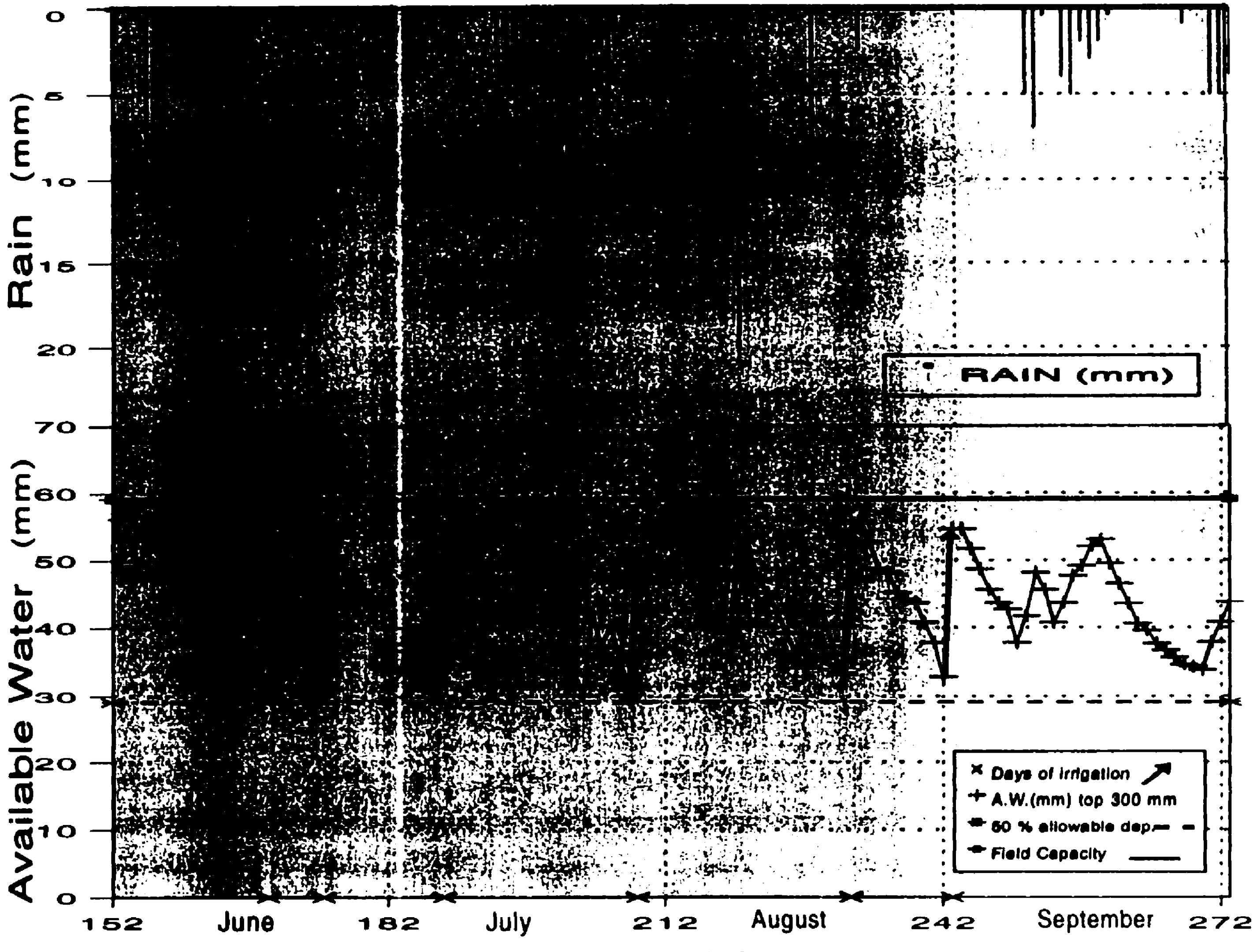
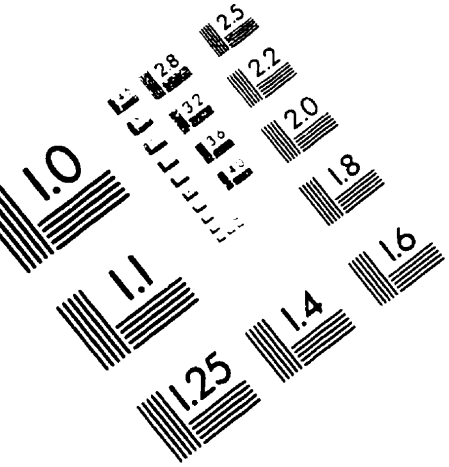
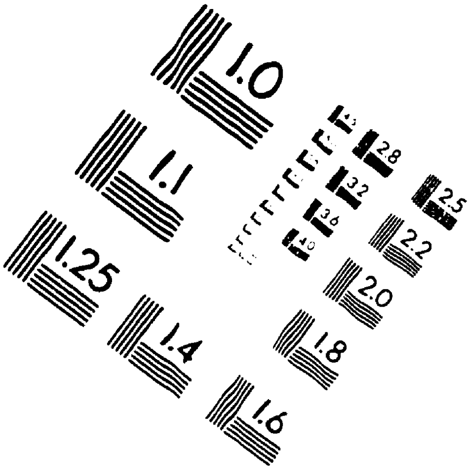


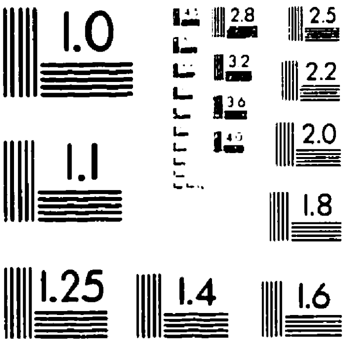
Figure C-5

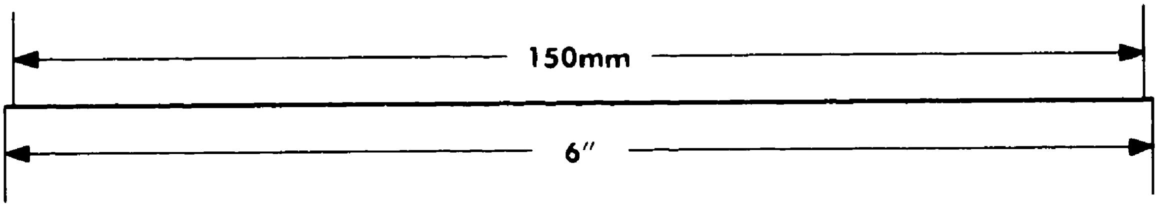
SUGGESTED IRRIGATION SCHEDULING FOR RAIN DISTRIBUTION OF 1974, SITE 5 (ROOT ZONE 300 mm DEEP)

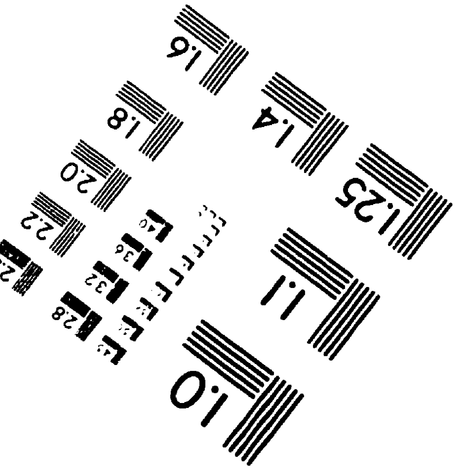
IMAGE EVALUATION TEST TARGET (QA-3)

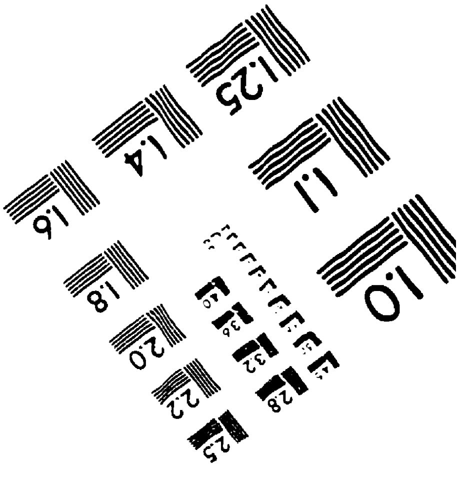












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