AN EVALUATION OF THE FIRST PRODUCTION-SCALE SUBSURFACE DRAINAGE SYSTEM IN TRINIDAD AND TOBAGO

by

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ABSTRACT

M.Sc. Patrick Cambridge Agricultural Engineering

An Evaluation of the First Production-Scale Subsurface Drainage System in Trinidad and Tobago

Some physical, biological and chemical parameters associated with the drainage system were investigated. In two sugarcane fields, the drains were in their second year of operation. In the third field, there was no cultivation and the drains were operating in their first year.

In the subsurface drained areas, the water table was lowered by about 30 cm during the first 24 hours after heavy rainfall compared with about 5 cm in an adjacent non-subsurface drained field. Drain outflow rates responded quickly to rainfall and receded rapidly after rainfall. A curvilinear relationship was obtained between drainage rate and mid-spacing water table height.

Mean dry matter millable sugarcane stalk yield from 8 plots on a subsurface drained field was 52 per cent greater than from an adjacent non-subsurface drained field.

Negligible quantities of chemicals emanated from the subsurface drains. Generally there was little difference in the water chemistry between the cultivated and non-cultivated areas.

RESUME

M.Sc. Patrick Cambridge Génie rural

Evaluation du premier système de drainage souterrain à grande échelle à Trinidad et Tobago

Certains paramètres physiques, biologiques et chimiques associés à l'implantation du système de drainage, furent l'objet d'une étude. Dans deux champs plantés en canne à sucre, un système de drainage souterrain fonctionnait depuis deux ans. Dans un troisième champ en jachère, un système de drainage souterrain n'avait été installé que depuis un an.

Dans les parties drainées souterrainement, le niveau de la nappe phréatique baissent d'environ 30 cm durant les premières 24 heures suivant une pluie intense. Par contre, dans un champ adjacent, sans drainage souterrain, le rabattement de la nappe ne fut que d'environ 5 cm. Le débit des drains augmentait rapidement lors d'une pluie pour diminuer très vite après la fin de celle-ci. Une relation curviligne fut obtenue entre le taux de drainage et la hauteur de la nappe phréatique au demi-espacement des drains.

Le rendement en matière sèche raffinable moyen obtenu sur 8 parcelles établies sur un terrain drainé souterrainement dépassait de 52% celui du champ adjacent non drainé souterrainement.

La quantité de substances chimiques émanant des drains souterrains était négligeable. Cependant, on peut affirmer qu'en général la composition chimique des eaux était peu différente entre champs cultivés et non cultivés.

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CHAPTER I

INTRODUCTION

Subsurface drainage is the removal and disposal of water which will seep out of the root zone due to gravity. This is contrasted to surface drainage which is the removal of excess water from the surface of the land.

In Trinidad and Tobago, like other tropical regions, there is a period during the year when rainfall greatly exceeds potential evaporation and infiltration rates. Thus in flat areas, where natural drainage is slow, supplemental drainage is desired. Traditionally most of this drainage in Trinidad and Tobago has been provided by surface methods of bedding, ditches and land grading.

The concept of subsurface drainage is not entirely new to Trinidad and Tobago. The cambered bed system, which has been used extensively in the sugarcane and other agricultural industries, is technically a partial subsurface system since water not only drains off the surface but also seeps through the soil profile to the dead furrows. This system encourages the persistence of wet stripes adjacent to the furrows. It also effectively reduces the area of land under cultivation because of the large space taken up by the furrows and collector ditches. Mole drains and subsoilers have also been used to break up hard subsoils and encourage subsurface drainage. These methods only provide temporary benefits and have to be repeated after a few years. Clay tiles or plastic subsurface drainage tubes can provide the benefits of permanence, reasonably rapid drainage and efficiency of land utilisation.

In the past, plastic drainage tubes have been installed on small experimental plots at the Field Station of the University of the West Indies and other locations. The subsurface system that has been installed at the Sugarcane Feeds Centre (SFC) in Trinidad is the prototype of a production scale system in Trinidad and Tobago and possibly the entire Caribbean.

Subsurface drains were installed at the SFC in an attempt to boost yields of sugarcane and other feed crops on the poor soils in the area. The performance of the system will be important to crops other than sugarcane in Trinidad and Tobago. Many ideas are presently being expressed for the diversification of agriculture in the nation. Most of these plans call for the production of crops that are less tolerant to inundation than sugarcane. Thus one can reasonably expect that if there are benefits to sugarcane production that there will also be benefits to other crops.

From an agricultural engineering viewpoint, evaluation of this first system is of great importance. Performance of this system will influence future decisions on the installation of similar systems in other areas of Trinidad and Tobago. Drainage system designers wish to know to what extent, if any, that established design methods must be modified when designing new drainage systems in Trinidad and Tobago.

The ultimate aim of subsurface drainage is to help improve the overall efficiency of crop production. Thus the agricultural engineer, especially on pioneering projects like these, shares the Agronomist and Economist's concern for higher yields and better field utilisation in order to offset additional cost; the manager's concern for timeliness of operations; the soil physicist's concern for modification of soil characteristics and extent of root penetration and distribution; and the soil chemist's concern about the quality and quantity of nutrients that are leached from the soils. The agricultural engineer's evaluation should therefore include investigations into all of the above factors since they all should be taken into consideration when making future decisions and designs. These factors were all considered in this evaluation.

The system at the SFC was designed primarily as a production system. This evaluation was conceptualised after the drains were laid. As a result the evaluation was carried out under production conditions. Thus the measurements were designed to suit these conditions. This meant that the data collected and its subsequent analysis was not as statistically rigorous as if the drains were laid specifically for a scientific experiment. However, any assumptions made were conservative. Therefore the designs used should produce results which would give a good indication of the performance of the subsurface drainage system.

Objectives

The objectives of the study were:

1. To monitor the rates of flow of water from the subsurface drainage system after significant rainfall events.
2. To determine the rates of fall of water table on fields that are subsurface drained and compare them with the rates on undrained fields.
3. To investigate the nature of the phreatic surface between drains and compare with theoretical predictions.

4. To use the data obtained in 1, 2 and 3 to calculate drainable porosities and to compare the results with those obtained by laboratory methods.
5. To measure hydraulic conductivities of the soils in the area and to relate them to data obtained in 1, 2 and 3.
6. To compare sugarcane root distributions in subsurface drained areas with those in land without subsurface drains.
7. To compare yields of sugarcane from subsurface drained and non-subsurface drained areas.
8. To compare the quality and quantity of nutrients emanating from subsurface drains in fertilised areas and non-fertilised areas.
9. To make qualitative observations of the drains and drainage areas before, during and after rainfall events.
10. To use all the observations and data obtained above to perform an overall evaluation of the drainage systems and to make recommendations with respect to the design of subsurface drainage systems for Trinidad and Tobago conditions.

Scope

The results obtained from this work apply only to the soils and drains located in the areas studied. The series to which these soils belong are noted for their wide variation of physical characteristics. Thus drains located in other areas within the same soil series may perform differently. Similarly, performance on other flatland soils in Trinidad and Tobago may vary. If, however, adequate soil data are obtained for other specific areas, the performance of this drainage system should serve as a useful aid in future subsurface drainage design in Trinidad and Tobago.

CHAPTER II

REVIEW OF LITERATURE

Agronomic Benefits of Drainage

The growth of most agricultural crops is sharply affected by continued saturation of any substantial part of the root zone (U.S. Soil Conservation Service 1973). The agronomic benefits of drainage have been well documented by Bernstein (1974), Broughton (1972), Irwin (1979b), Reeve and Fausey (1974), Wesseling (1974) and others. Some of the benefits that are seen repeatedly in the literature are:

(a) air diffusion is increased. This encourages biological activity in the root zone. Thus, more beneficial bacterial activity and deeper root penetration is encouraged,

(b) some plant diseases and parasites are discouraged,

(c) soil structure is improved,

(d) salts and alkali, if present in the soil or ground water, tend to be leached away from the root zone and soil surface,

(e) farm operations can be more timely and more uniform cultivation and planting is possible. Therefore, there is more efficient use of machinery,

(f) a wider range of crops and varieties may be grown on well-drained soil than on poorly drained soil,

(g) better crop quality is achieved, and

(h) greater overall yields are obtained.

Several reports in the literature have indicated that subsurface drainage is beneficial to sugarcane production. Barnes (1974) stated that although sugarcane will withstand flooding for periods up to three weeks in some conditions, a well-drained soil is essential for the production of the crop. Carter and Floyde (1973) also reported that drained, yet moist soil conditions created by water management treatments are very favourable for sugarcane production. They found in areas that were subsurface drained, yields were from 24 to 62 per cent higher than check plots. Maclean (1977) concluded that poor yields are more closely related to frequent high water tables than are good yields to low water tables, and that yield differences of at least 30 tonnes per hectare can occur in the same area as a result of differences in water table height. He also said that short-term fluctuating high water tables where aerated water is involved have less adverse effect on cane than static high water tables with stagnant water. Ridge (1978) reported that yields under subsurface drainage for three cane varieties were increased by 32.2, 22.3 and 19.0 tonnes per hectare above the yields of 70.5, 76.8 and 82.2 tonnes per hectare which were obtained on nearby plots without subsurface drains.

The increased yields reported may have been due to the occurrence of more healthy and extensive root systems in subsurface drained areas. Barnes (1974) stated that prolonged wetness of the soil in the root zone of sugarcane favours the attack by root-destroying organisms. Nickel (1977) stated that the cane plant is highly aerobic. He found that there were much reduced sugarcane root systems when the crop was grown in nutrient culture without air compared to those with air bubbled through continuously. Yang et al (1977) concluded that the improved aeration in the root zone resulting from subsurface drainage promoted root growth and increased cane yield.

Flow to Drains

Theories to describe the flow of water to drains have been developed by several authors. Excellent reviews of these theories have been made by King (1974), Wesseling (1973), Kirkham et al (1974), Van Schilfgaarde et al (1957 and 1974) and others. There will be no attempt to duplicate the details of mathematical developments made in all of the theories. Rather the major underlying principles behind the theories will be investigated. Pertinent mathematical equations will be quoted whenever required in the body of the thesis.

Both steady state and non-steady state drainage formulae have been developed. Steady state formulae assume that the recharge intensity equals the drain discharge and consequently that the water table remains in position. The non-steady state formulae consider the fluctuations of the water table with time under the influence of a non-steady recharge (Wesseling 1974). Most of the equations used in describing the flow of water to drains are based on one or a combination of the Dupuit-Forchheimer (D-F) assumptions, Darcy's law, Potential theory and the equation of continuity (Kirkham et al 1974).

The D-F assumptions and potential theory have been most used in developing formulae for flow to drains. Differing views have been expressed on the question of whether the D-F assumptions or the potential theory give more accurate results. Wesseling (1973) reported that although equations based on the D-F assumptions give approximate solutions, they are generally accepted as having such a high degree of accuracy that their application in practice is completely justified. However, Kirkham et al (1974) stated that for tile drainage D-F theory should not be used for spacing design; potential theory should be used since D-F theory gives a spacing wider than it should be. Van Schilfgaarde (1974) who compared several non-steady state equations concluded that equations derived from the D-F theory will yield substantially the same results as those derived from potential theory.

Theorists and field researchers have ascribed different shapes to the water table between parallel drains. Glover and Dumm (Dumm 1964) assumed an initial flat water table, Moody (1966) assumed a parabolic shape while Van Schilfgaarde (1965) assumed an elliptic shape and also suggested that field experience could be used to make appropriate, minor corrections to account for the initial conditions. In the field, Skaggs et al (1973) found that the water table was relatively flat and had essentially a constant shape during the entire period of drawdown observation. Dumm (1964) reported that field observations were most nearly approximated by a fourth degree parabola. Kirkham and De Zeeuw (1952), Broughton (1972) and Gibson (1978) all observed elliptical shapes.

The maximum water table height between a pair of tubes or ditch drains will generally be of more importance than the water table elsewhere (Kirkham et al 1974). In all the shapes mentioned above the water table is closest to the surface at approximately midway between parallel drains. As a result, the relationship between the mid-plane water table and the drain flow rate have been the subject of many field investigations. Goins and Taylor (1959) stated that under field conditions, the mid-plane water-table heights varied almost linearly with the drain flow. They also found that when the water table was less than 15 cm above the drains the relationship was no longer linear. Similar results were obtained by Luthin and Worstell (1959). Hoffman and Schwab (1964), however, reported that a non-linear relationship was found to exist between the mid-plane water table height and the tile flow for a stratified, anisotropic soil. Van Horn (1973) used a series of examples to illustrate that the relationship between water-table height and drain discharge may vary from curvilinear to rectilinear at high and low discharges depending on the soil physical properties and the layering of the profile.

Van Schilfgaarde (1974), commenting on the "present" situation as regards 'Flow to drains' investigations, said that it would be comforting if more extensive field data were available for evaluation of theory. He also stated that it appeared that little was to be gained from further improvements in flow theory, since many of the equations that had been developed were far more accurate than needed in view of the uncertainties in the evaluation of the necessary parameters. He saw the need for further research to be threefold:

(1) Better methods must be developed to characterise the pertinent soil parameters.

(2) Quantitative criteria must be developed, especially for humid areas, to describe requirements.

(3) Methodology must be developed to incorporate climatological data and drainage theory into workable design schemes.

Drainage Requirements

Drainage Requirements (or Drainage Criteria) express the total desired drainage intensity for a given field or region. They should be distinguished from the design requirements (or design criteria). The design requirement expresses the drainage deficiency of a field to be absorbed by the drainage system. Drainage criteria can be evaluated for a steady-state condition, a falling water table, a fluctuating water table, salinity control, or trafficability of the soil, depending on the main function of the drainage system (Bouwer 1974). Kessler (1973) stated that the appropriate choice of drainage criterion will depend on the hydrological, agronomic, soil and economic conditions.

Broughton (1972), Bouwer (1974) and Kessler (1973) have made extensive reviews about the drainage criteria that are frequently used in various parts of the world. Some of these criteria will be examined later in the text (Chapters V and VI).

Broughton (1972) states that from the standpoint of determining the required rates of removal of excess water, it would be good if agronomic requirements could be stated as the number of hours of root zone saturation a crop can stand, or the number of millimeters of root zone depth that should never be saturated and the number of millimeters per day of additional root zone depth that should be drained below the saturation water content after a precipitation event. From an economic standpoint, Bouwer (1974) states that the design requirement should express the "optimum" intensity of the drainage system whereby the difference between the increase in financial returns due to drainage and the cost of the drainage system is maximum.

Bouwer (1974) suggests that it may be advantageous to express all drainage criteria in terms of one equivalent criterion regardless of the primary purpose of the drainage system. The steady-state criterion is one possible base since it is the simplest criterion to use. For example, Van Schilfgaarde (1965) showed that if the steady-state criterion is known for a soil of a certain porosity (soil A), it can be evaluated for a soil of different porosity (soil B) by calculating the frequency of high water table positions for both soils using analog or digital models. The drainage criterion for soil B is then selected as that yielding the same frequency of high water table positions as the known criterion for soil A.

Adequate information about drainage design criteria is lacking in many places of the world (Bouwer 1974). Thus the drainage criterion should be adjusted to natural drainage intensity since fields within the same soil or climatic region may have different degrees of natural drainage.

Schwab et al (1966) states that the selection of a drainage coefficient is based primarily on experience and judgement. They recommended drainage coefficients for tile drains in humid regions which are reproduced in Table B5 in the Appendix. A summary of some suggested drainage criteria in humid areas based on depth and rate of drop of the water table is presented in Table B6 of the Appendix. The above criteria were all based on North American and European conditions, thus they may not be applicable to the Trinidad and Tobago situation. Archer (1976) reporting on investigations done on a clay soil in Trinidad (Ecclesville Clay) concluded that peak subsurface drainage rates of 12 to 18 mm per day would be needed to maintain the water table at a level which would permit satisfactory crop growth in the wet season. Peak drainage rates would occur when the water table is at or above the soil surface. Drainage rates will decrease as the water table drops below the soil surface. Archer (1976) arrived at his recommendations by making day by day calculations of expected water table heights using a water balance model which took into account the daily precipitation, evapotranspiration, subsurface drainage outflow and water held in temporary storage in the drainable pore space.

Soil Properties and Their Effects on Flow to Drains

Soil texture can play an important part in the design of drainage systems since, in some areas, it is possible to relate texture to soil permeability (Luthin 1973). It is also known that soil structure has a significant effect on drainability. The two soil properties required for most of the depth and spacing equations are the saturated hydraulic conductivity K and the drainable porosity f (Broughton 1972). Hence these properties will be concentrated on in this review.

Saturated Hydraulic Conductivity

The term hydraulic conductivity is generally defined as the coefficient K in Darcy's Law $V = Ki$, where V is the velocity of seepage through the soil and i is the hydraulic gradient. Techniques for measuring hydraulic conductivity may be divided into those where the soil is tested "in place" and those where soil samples are transported to the laboratory to be tested. Tests made "in place" (field tests) are generally considered to be superior as it is almost impossible to obtain samples and transport them to the laboratory without disturbing them to some degree, thereby altering their permeability (U.S. Soil Conservation Service 1973, Hoffman and Schwab 1964).

Field determinations of hydraulic conductivity can be divided into those which measure hydraulic conductivity below a water table and those which measure it above a water table (Boersma 1965). Below water table methods include the Auger hole method, the Piezometer method and the drain line method. Above water table methods include, the Double-Tube Method, the Shallow-Well Pump-In Method and the Permeameter method. The auger hole and the drain line methods were used in this study and are examined below.

The Auger hole method is the simplest of all methods in conception and in field practice (Van Schilfgaarde et al 1962). It utilizes the principle that the rate of rise of water in an emptied auger hole, from a surrounding saturated soil, is proportional to the hydraulic conductivity. Historical reviews of the method are given by Boersma (1965) and Bouwer and Jackson (1974). Today the equation most used with the method is

$$K = C\ (\Delta y / \Delta t)$$

Where, Δy is the change of the water level in the hole during the given time (Δt). C is a function of the level of y, the depth of the hole below ground water level, the radius of the hole and the distance to the impermeable layer. A thorough description of the method is given by Van Beers (1976). Handy nomographs from which C can be obtained are also presented in Van Beers' bulletin. Good descriptions are also presented in Boersma (1965), Bouwer and Jackson (1977), U.S. Soil Conservation Service (1973) and Van Schilfgaarde et al (1962).

K values as determined by the Auger hole method may differ by as much as one hundred per cent between holes only a few feet apart in soil classified as a single type (Boersma 1965). Similar variations, tens of percents (Van Beers 1976), sixfold in magnitude (De Boer 1979), have also been reported. Because of the great difference among holes, approximate values on a number of holes are more valuable for practical drainage problems than are precise measurements on one or two holes (Boersma 1965, Van Beers 1976).

Van Schilfgaarde (1962) states that the Auger hole method cannot be used effectively in layered soils unless the layers have nearly equal values of K. However, Van Beers suggests that if there are appreciable differences in hydraulic conductivities, the K-value of each layer can be determined by working with holes of different depth.

Broughton (1972) suggests that more realistic values for field scale hydraulic conductivity for use in design of drainage systems should be obtained by measurement of water table positions at successive times on some fields in which drainage systems are established. Hoffman and Schwab (1964) used Van Schilfgaarde's falling water table drain spacing equation to calculate hydraulic conductivities. They concluded that hydraulic conductivity as computed from drain outflow is a better estimate for drainage design than that determined from core and auger-hole measurements. However, Johnston et al (1963) reported that the auger-hole hydraulic conductivity values compare favourably, from a practical viewpoint, with the hydraulic conductivity values determined from design theory applied to tile drainage systems outflows. They used Kirkham's ponded water theory in their investigations. Perrier et al (1972) reported that the values of hydraulic conductivity obtained by either the steady-state equation (Hooghoudt's) or the unsteady-state equation (Van Schilfgaarde's) are approximately the same.

Van Horn (1973) used graphs of the ratio of drainage rates to observed water table heights against observed water table heights to calculate hydraulic conductivities. Examples for different layering conditions were worked out. He suggested that each location should be analysed separately and that general conclusions based on these analyses should be avoided.

Drainable Porosity

The drainable porosity, also called drainable pore space or specific yield, f, is defined by Bouwer and Jackson (1974) as the volume of water that will be released per unit volume of soil by lowering the water table. It is an essential factor for the use of falling water table equations to estimate required drain spacings (Broughton 1972).

Several laboratory methods for determining drainable porosity are described by Childs (1957), Avery and Bascomb (1974) and Vomocil (1965). All of these laboratory methods entail the measuring of moisture retention characteristics of "undisturbed" soil samples. Field estimates may be obtained by: (1) measuring the water content of the soil in the field when the soil is saturated, then again one or two days later when the water table has fallen (Broughton 1972) or (2) measuring the volume of outflow from a subsurface drainage system for a measured water table drop (Hoffman and Schwab 1964, Dos Santos and Youngs 1969). Field values of drainable porosity are generally lower than those measured in the laboratory (Bhattacharya 1977, Legacé 1977).

Taylor (1960) and Broughton (1972) both stated that the drainable porosity in a soil profile may vary with depth. Hence the assumption of a constant drainable porosity may lead to significant errors in estimating drain spacing. However, Skaggs (1973) reported that the concept of a constant drainable porosity can be used to predict water table drawdown with an accuracy which is probably sufficient for design purposes.

Chemical Analysis of Subsurface Drainage Water

MacKenzie and Viets (1974) stated that agricultural drainage water, whether surface or subsurface, sometimes contains nutrients and chemicals in sufficient concentrations to be of significance to subsequent users of the water or to the aquatic environment. Drainage waters in humid climates characteristically have low salt concentrations and cause few problems as compared to those in arid climates (Bower 1974).

Runoff waters even in irrigated areas always have lower solute contents than percolated waters (Bower 1974). However, Nicholls & Maccrimon (1974) concluded that the contribution of nutrients to downstream main channels by the base flow of subsurface water, from fertilised and cultivated areas, is considered negligible during the growing season.

MacKenzie et al (1971) stated that nutrient movement in the soil profile should involve mainly inorganic nitrogen. Phosphorous moves to a very limited extent in soils. Fertiliser Calcium and Magnesium may move into the soil profile, but these movements are masked by the large amounts present in most soils.

Bolton et al (1970) reported a relative order of nutrient losses measured in tile drainage to be Ca > Mg > N > K > P. They stated that nutrient loss was influenced predominantly by the amount of water that flowed through the soil on a particular cropping treatment. Kowalenko (1978) reported that movement of fertiliser Nitrogen was greatest in periods of high precipitation and low evaporation.

Soil properties have a definite effect on nutrient leaching losses according to Brady (1974). Hanway & La Fleur (1974) in experiments with tile outlets found that there was no relation between the amounts of fertiliser applied and plant nutrient losses or concentrations in drainage water.

Iron Ochre in Subsurface Drains

Ford (1978) defined Ochre as a red to yellow, filamentous, gelatinous, amorphous, sticky mass of ferric hydroxide plus an organic matrix that can clog drain wall openings and drain envelopes. The red sludge in drain lines is often called iron deposits. In another paper Ford (1979a) added that ochre formation is more complicated than simple iron deposition. Bacteria are necessary for copious quantities of ochre that form rapidly and stick tenaciously to drain lines. The ochre problem is more pronounced on poorly drained sandy soils than on clay soils (Irwin 1979b, Ford 1979a).

Two main types of Ochre have been identified (Irwin 1979b, Ford 1979a). These are referred to as 1. bacterial clogging and 2. chemical clogging. These two types often occur simultaneously. Chemical clogging is more evident in soils with substantial iron and filamentous red ochre deposits. These soils will continue to form iron clogging indefinitely. Where the pH is above 5.5 the ochre problem is likely to abate some time after the drains have been installed particularly in sandy and loam soils. This iron ochre is due to bacterial origin.

Invarson and Sojak (1978) state that the crystallisation of the amorphous ferric oxyhydroxide (ochre formation) is inhibited by the paucity of dissolved ferrous and ferric iron, the presence of organic matter and adsorbed anions.

Ochre may be deposited when concentrations of reduced soluble iron are as low as 0.2 ppm (Ford 1978). Hundal et al (1977) reported that iron sludge accumulation in drains would be greater during prolonged periods of low flow rates. They also stated that the problem will be more serious if a period of low flow is followed by a long period without flow. In this situation the sludges may dry irreversibly thus permanently blocking drain tube openings and filters.

Several methods have been tried to combat the ochre problem. These include (Ford 1978), promoting oxidation and precipitation of iron in the soil before it reaches the drain line, surface liming, liming of drain trenches, copper placed in filter envelopes and attempting to retard clogging within drains by physical and chemical means. None of these methods have proven to be effective economical propositions. Irwin (1979b)summarised the problem by stating that 'on present knowledge, there are no obvious comprehensive solutions worthy of field trial. The problem may be insolvable in terms of being both economically viable and compatible with farming the land.'

CHAPTER III

THE EXPERIMENTAL SITE

All of the field work for this study was performed at the Sugarcane Feeds Centre, near Longdenville, Trinidad.

The Sugarcane Feeds Centre

The Sugarcane Feeds Centre (SFC) is a joint venture between the University of the West Indies and McGill University. It was established in 1976 with funding from the Canadian International Development Agency (CIDA). The centre is a research, demonstration and training unit. It is involved mainly in the investigation of the use of sugarcane as a major feed ingredient in the production of beef and dairy cattle.

Location

The SFC is situated on 61 hectares of land in the Longdenville district of Trinidad. Trinidad is the larger of the twin island nation of Trinidad and Tobago. Trinidad is approximately 4,547 square kilometers in area. Its geographic centre is located at 10° 31' north latitude and 61° 15' west longitude (Figure 1). The southern and western coast of Trinidad is about 10 miles from the South American coastline. It is the southernmost of the West Indian islands.

Longdenville is a rural village in the central region of Trinidad. The village is approximately 32 kilometers from the capital city of Port-of-Spain and 16 kilometers from Piarco International Airport (Figure 2). Access is gained to the village by a modern road system.

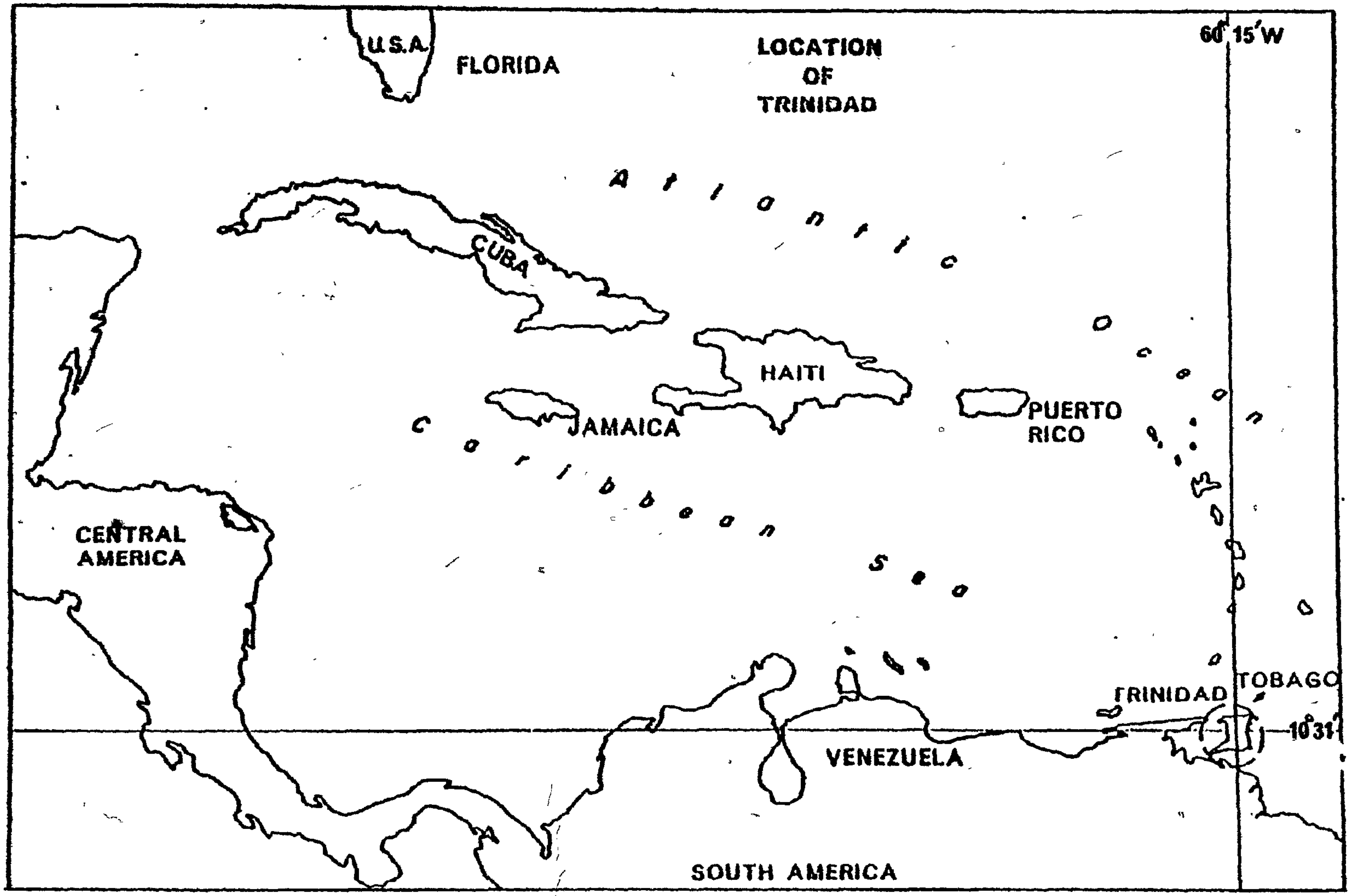

Figure 1. Sketch map of the Caribbean region showing the location of Trinidad.

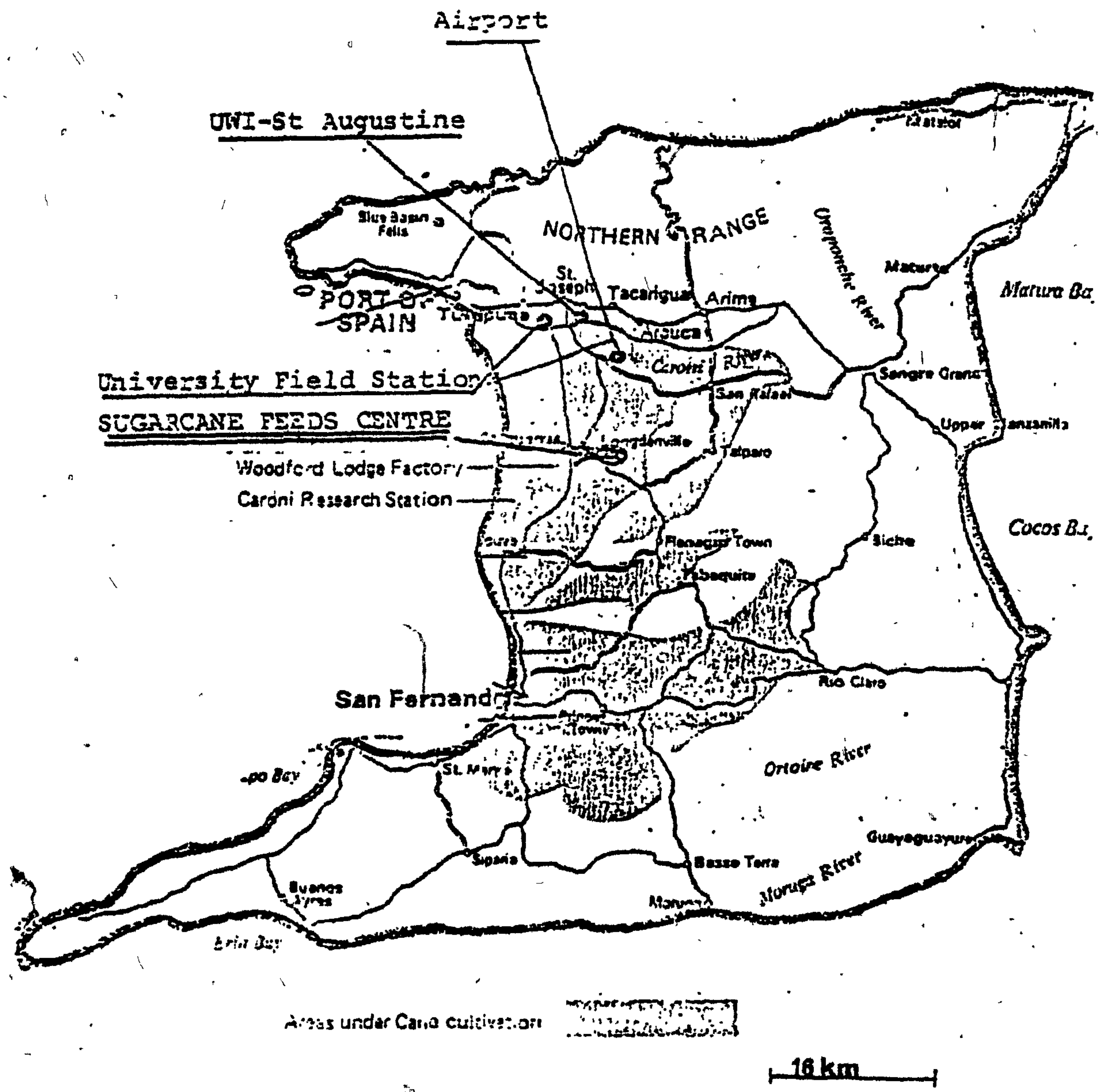

Figure 2. Map of Trinidad showing the location of the UWI-McGill Sugarcane Feeds Centre.

Climate

Trinidad has a tropical climate. There are two main seasons; the dry season and the rainy season. The dry season typically lasts from January through May and the rainy season from June through December. There is, however, no clear cut division between the seasons. There is some variability from year to year and month to month. Thus there may be one or more dry spells during the rainy season and a few showery days in the dry season. The annual rainfall in the Longdenville district is about 1780 millimeters. Usually precipitation is in excess of evaporation in the rainy season, but there is moisture deficiency in the dry season. A table of monthly rainfalls (Table B7) for the past 11 years is given in the Appendix. Estimates of mean monthly potential evaporation are given in the Appendix also (Table B7).

In central Trinidad the hottest months are usually May and September with the monthly mean of daily maximum temperatures being about 30°C. The monthly mean of daily minimum temperatures for the coldest month is about 20°C and occurs in January. The range of mean monthly temperatures is from 25°C in the early part of the dry season (January) to 27.2°C in the early part of the wet season (June).

Relief and Soils

The topography of the area in which the SFC is located is generally flat with less than a 5 per cent slope for 36 of the 61 hectares. There are 4 steep-sided valleys in the other 25 hectares.

The soils show some variability. In general, however, they are characterized by high acidities, high bulk densities, small drainable pore space and low to moderate water holding capacities. Ahmad and Gumbs (1978) identified Piarco fine sand (Aquiox Tropudult-(Ultisol)) and the Las Lomas fine sandy loam (Orthoxic Tropudult-(Ultisol)) as the soils covering most of the SFC property. The Cunupia fine sandy clay (Aquic Eutropept-(Inceptisol)) was also identified in an area of about 2 ha.

The Piarco fine sand is essentially structureless, in the agricultural sense, at all depths. The surface fine sandy to silty material is densely packed and a very compact layer results. The clay subsoil is also very compact. These factors are associated with very low permeability and infiltrability.

The Las Lomas fine sandy loam has a fine sandy loam texture throughout the profile. The profile is not very compact and has relatively better permeability than the Piarco fine sand.

The Cunupia fine sandy clay may vary from loams to clay loams but the profile always gets finer textured with depth. At depths of greater than 45 cm the soil material is essentially structureless, sticky, plastic and compact (Ahmad and Gumbs 1978).

The Experimental Fields

Figure 3 shows the general layout of the SFC. The areas labelled as Field 1 (subsurface drained and non-subsurface drained) Field 2 and Field 3 were used in the study. The complete plan of subsurface drains and buried irrigation pipe for the entire farm is given in Drawing 1 which is enclosed in the pocket of this thesis.

Most of the area under study had been cleared for shifting agriculture and abandoned, after soil productivity became too low,

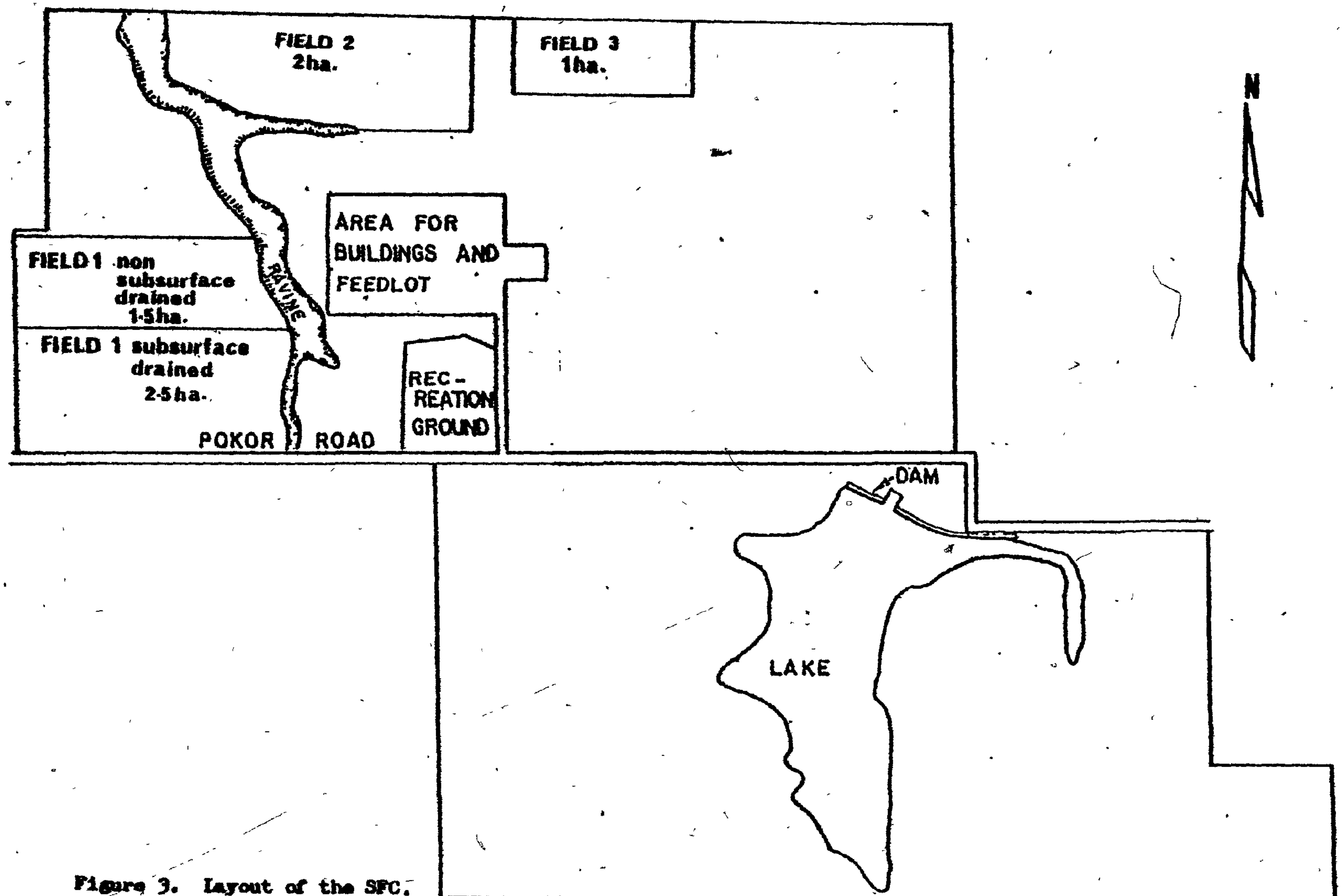

Figure 3. Layout of the SFC.

sometime before the establishment of the SFC. Further land clearing (where necessary) was carried out by SFC staff and contractors.

Subsurface drains were installed in fields 1 and 2 during the dry season of 1978 in accordance with the attached drainage plan. The drains in field 3 were installed in June, 1979. The spacings for the different fields were based on the measured hydraulic conductivities. Corrugated polyethylene drain tubes, wrapped with a knitted polyester filter material, were used at all locations. They were installed with a chain type "Drainmaster" trenching machine under the guidance of Professor R. Broughton of McGill University.

During the period of field work for this thesis (June, 1979 to January, 1980), fields 1 and 2 were under sugarcane production. The canes were planted in November, 1978. The crops were planted on row ridges rather than cambered beds. Row ridges were preferred because they facilitate easier mechanisation of field operations and also because a higher plant density can be achieved. Ground limestone was applied to both fields before final cultivation operations at a rate of 5 metric tons per hectare, in order to raise the pH of the soils. The plants were fertilised at planting and at 6 months with 15:5:10 fertiliser. Rates at planting and 6 months were 1.12 and 0.45 metric tons per hectare respectively. Two applications (23 millimeters per application) of liquid manure were made on both fields between the months of July and September using a travelling gun irrigation system.

No crops were planted in field 3. Vegetation was limited to low grasses, sedges and shrubs. There were several bare patches on the terrain. No limestone, inorganic fertiliser or liquid manure was applied to this field.

CHAPTER IV

QUALITATIVE OBSERVATIONS

Qualitative observations were made on the entire area under study throughout the period of field work. These observations were meant to supplement the quantitative data in the evaluation of the subsurface drainage system. The more relevant of these observations are reported below.

Soil Water Regime

The soils at the Sugarcane Feeds Centre had a tendency to form a hard crust on drying. This crusting was more evident amid the sparse grass in field 3 but it was observed even on some of the cane ridges of fields 1 and 2. Generally, however, the cultivated areas of fields 1 and 2 tended to be characterised by good soil structure with fairly large aggregates being observed. Aggregation was less evident in field 3.

There were several small depressions in the predominantly flat field 3, especially in the area between the upstream end of the drains and about 50 m downdrain. In this area there was more vegetation, primarily low sedges and grasses. These formed a very thick mat of roots that was concentrated within the first few centimeters from the surface. The combination of roots and crust was almost inpenetrable when dry. During the installation of the water table pipes a crow-bar had to be used to start the holes because the augers could not penetrate the surface. Observations during the rainy season of 1978 had revealed that this area had remained waterlogged for most of the period between June and August. Therefore it was very likely that this mat was formed over a period of time because of the presence of a persistently high water table. Another indication of prolonged wetness, in this area, in the past was the heavy iron mottling that was observed in the profile, especially between the depths of 20 and 60 cm. These observations were made while obtaining soil samples from pits which were about 60 cm deep. Mottling was also observed in the 30 to 60 cm zones of the eastern half of field 3 and in fields 1 and 2 but not as extensively as in this area of field 3. Whenever there was appreciable rainfall, the depressions in this part of field 3 (the updrain area) were quickly filled with water. These surface ponds remained for several days even though the adjacent areas (the eastern area) had regained a crust and flow through the subsurface drains had become negligible. The drying up of the pondings within 3 to 5 days was a considerable improvement to the conditions observed in 1978. No doubt this was partially due to increased evaporation caused by the cutting down of the higher sedges and grasses in the area. However, the presence of the subsurface drains may have also contributed.

The eastern half of field 3, which was closer to the outlets of the subsurface drains, did not retain ponded water as long as the area discussed above. During and after rainstorms, much water ran off the surface and into the nearby valley, via the top of the drain trenches and over the land surface. The surface pondings dried up quickly, most likely due to the combined influence of the drains, the valley, evaporation and a more permeable surface layer.

Field 2 displayed excellent surface drainage. Very little water was seen in the furrows within one hour after the heaviest rains. What water was seen was trapped by trash and fallen canes and was quickly absorbed into the soil.

In field 1 the situation was different. The two irrigation traces were laid out perpendicular to the direction of the furrows rather than parallel as in field 2. These traces created a dyke effect and caused pondings in the drain furrows upstream of the traces. These pondings did not remain for more than one day after rainfall in the subsurface drained area. In the non-subsurface drained area, however, there was considerable flooding after heavy rains. Flood conditions were more pronounced near the trace that was closer to the outlets. In some locations water stood in the furrows for as far back as 15 m from the trace. This stagnant water remained for more than two weeks even though hot and dry atmospheric conditions prevailed. Thus although water in the subsurface drained and the non-subsurface drained regions had the same restriction from the trace, the water moved off much quicker in the subsurface drained region. Furrows that were not in the vicinity of the traces also tended to accumulate more surface water in the non-subsurface drained regions and retained it for a longer period of time than those in the subsurface drained regions. A combination of trash from the canes and silt, which was eroded from the cane ridges into the furrows, may have been partially responsible for these additional pondings in both the subsurface drained and non-subsurface drained areas.

Surface pondings were also evident on the compacted traces of field 1. Most of the pondings on the traces were caused by depressions left by the tractors which had worked in the field under wet conditions. The fewer occurrences of these depressions in the subsurface drained section suggested that trafficability was much better in this region. However, even in the subsurface drained areas, the soil was too soft and muddy to support traffic of tractors and trailers for periods up to about 3 days after the drainable water had been removed. Soil traffic capacity is normally partly due to the removal of excess water by subsurface drainage and to the particular soil texture and structure available. Thus although the excess water was removed relatively quickly in the subsurface drained area, the fine soil texture was responsible for the very low bearing strength and the relatively soft muddy consistency that were in existence when the soil was at a moisture content of about field capacity. The bearing strength increased rapidly as the soil dried to water contents less than field capacity. Other soils in Trinidad and Tobago, which have better surface bearing strength than the soils at the SFC, normally have higher drainable porosities or a stonier texture.

Drain Conditions

During the initial stage of the field observations, access to most of the drain outlets in fields 1 and 2 was very difficult. There was a luxuriant growth of weeds which were tall enough to hide the 1.5 m high identification poles that were placed beside the outlets. Clearing of the weeds revealed that some of the drains were partially blocked by silt and moss. This blockage was more evident in field 1 where the outlets were at about the same level as the bed of the ravine. Poor maintenance of these drain outlets is certain to reduce the life of the subsurface drainage system. The system used in Canada of collecting the flow from several laterals into one mainline with a single outlet, would be more beneficial in commercial farm drainage systems in Trinidad and Tobago since it reduces the number of outlets needing maintenance. In this part of the SFC farm, collector drain lines were not used because it was desired to observe the flow from individual laterals.

None of the drains flowed at their full capacity. Smaller diameter pipes could convey the flows, but smaller pipes would have had less entry area, and this would have caused a lower drainage rate. Pipes of 80 mm I.D. such as those used at the SFC, would obviously be satisfactory for longer laterals in this soil.

The water flowing from the drains in fields 1 and 2 was normally colourless and odourless. In field 3, however, the outflow was light reddish-brown in colour, particularly at heavy flows. This was probably due to the fact that the soil in the trenches above the drains had not completely settled and very fine soil particles were still being forced through the filters. During and soon after liquid manure irrigation was carried out, the outflow from fields 1 and 2 was generally dark coloured and had a pungent manure odour. This observation suggested that some water entered the drain directly through the backfill rather than being filtered through the soil profile. This reality emphasised the potential danger of people drinking the water that flowed from the drains even when it was apparently very clean. One farm worker boasted that he had drunk it more than once and it was very good. Feats like this should be discouraged by signs and other communication. One meter of compact fine sandy soil may filter out solids but it certainly will not eliminate dangerous bacteria and chemicals adequately.

Growth of moss and/or other forms of plant life was observed at the outlets in fields 1 and 2. It was much more noticeable during the days following the application of manure when the flow rate was reduced to a trickle. More growth was observed in field 1, probably due to better oxygen contact with the water since field 1 outlets faced the prevailing wind and there was little air current in the vicinity of the field 2 outlets. Very little growth of moss was observed in field 3 which was even more exposed to wind currents than field 1. This suggested that the application of the liquid manure and other fertilization played a key role in the growth of the aquatic plant life.

Significant deposits of iron ochre were noticed at the outlets of the drains in field 3. Concentration of the gelatinous mass was greatest in the periods when there was only a trickle of outflow. Drain H4 (Chapter VI) had considerably higher deposits than the surrounding drains. Suspicion that a higher proportion of iron was being discharged from this drain was later confirmed by chemical analysis of drain water samples. The deposits did not remain in their original forms for a long time. They were either washed out by drain water if there was a rainstorm or alternatively they shrank into a fine coating of a reddish brown material soon after the flow of water from the drains stopped completely. This was consistent with documented observations of Ford (1979b) and Irwin (1979a) No such deposits were observed in field 2. Trace deposits were seen in field 1 although bigger deposits were observed during the rainy season of 1978. This suggested that there was either a decrease in the iron content of the soil or of the bacteria and growth conditions which are responsible for ochre formation.

Crop Conditions

In general the sugarcane in the subsurface drained areas of fields 1 and 2 appeared to be thriving better than in the non-subsurface drained areas. There were better stands and the plants appeared to be taller and healthier looking.

Lodging was more evident in the subsurface drained area of field 1 than in the non-subsurface drained area. This may have been due to the presence of heavier canes. Heavier canes could have resulted from better soil conditions for root growth and nutrient uptake.

A much higher incidence of weeds was observed in the non-subsurface drained areas. This is an often documented benefit of subsurface drainage. Better ability of the weeds to compete with the main crop under poor draining conditions is generally accepted as the reason for this situation. The weeds have become adapted over the years to the natural poor drainage conditions of the fields. Most economic crops perform better when the subsurface drainage is improved.

CHAPTER V

WATER TABLE OBSERVATIONS

Methods and Equipment

The depth of the water table below the surface was monitored using water table pipes. The pipes were generally placed at the mid-points between drains in fields 1, 2 and 3. Pipes were also placed in the undrained section of field 1 at the same distance apart as in the drained section. In fields 1 and 2 which were producing sugarcane, the pipes were located in the middle of the sugarcane ridges. This minimized direct contact with surface water which may have been present in the furrows during and immediately following rainstorms. At randomly selected locations in all three fields, the phreatic surface between drains was observed using water table pipes placed at each 1/6 spacing. The exact position of all the pipes used in the study is shown in figure A1. The water table pipes used were made from 20 mm I.D. (25 mm O.D.) Polyvinylchloride (PVC) pipes into which 5 mm diameter holes had been drilled at approximately 25 mm intervals in the lower 100 mm. The area containing the holes was wrapped with spun bonded polyester filter material to prevent soil entry. The tops of the pipes were fitted with rubber stoppers.

The water table pipes were installed by augering a hole of about 150 cm depth and 50 mm diameter and inserting the tubes. About 10 cm of pipe was left exposed at the surface. The cavity below and around the pipes was filled with fine gravel which was available at the building site. A mould of local clay soil was made around the top of the pipes to prevent water from flowing directly down the pipes from the surface. An engineer's level was then used to determine the lengths of the pipes above ground in field 3. In fields 1 and 2 a hand rule was used to obtain this distance because of the presence of the sugarcane plants. The depths of the furrows, in the vicinity of the ridges on which the pipes were placed, were also noted. A graduated blow tube was used to measure the depths of the water in the pipes.

The rainy season of 1979 was very erratic as far as suitability for water table data collecting was concerned. There were intensive rainstorms during the month of June and early in the month of July. This study was started early in July when the soil profile was approaching saturation. Observations started on 4th July had to be discontinued after three days because of repeated vandalism on the pipes in fields 2 and 3. After early July there were only two series of rainfall events that caused appreciable rise in the water tables. The first of these occurred during the month of September and the other in the month of December. Data from these two events were recorded. These two events will subsequently be referred to as event 1 and event 2 respectively.

Readings were taken as soon as practically possible after the rainfall events, and continued at convenient intervals until the water table level in the subsurface drained regions fell close to the level of the drains (about 1 m). This level was not realised during event 1 because the liquid manure irrigation system was turned on before it was attained. Observations were made in the same sequence, both within and between fields, for all data collecting sessions. Thus the time between readings for each pipe was approximately equal.

The height of the pipe above the ground was subtracted from the reading of the blow tube to obtain the depth of the water below the surface. In field 3 this represented the depth below the natural ground level while in fields 1 and 2 it represented the depth below the ridge.

Results and Discussion

Water Table Observations at Mid-Spacing and in the Non-Subsurface Drained Field

The depth of the water table below the surface was plotted against time after the first reading. The total rainfall between readings was also indicated on the graphs. The plots of the individual pipes are shown in Figures A2 through A7. Figures 4 and 5 show the plots of the mean values for fields 1, 2 and 3. Because of wide and consistent inter-row differences in field 3, the means of the rows rather than the mean of the field has been shown. From the graphs it can be seen that almost all of the pipes, in the subsurface drained regions, responded appreciably to rainfall. The mid-spacing water levels rose after rainfall events then fell rapidly in the hours following if there was no further rainfall. The exception to this was the pipes in row 3 of field 3. Because of the lack of continuous monitoring equipment, it is not known how soon after the rainfall that the water level began to fall, nor is the exact peak height known in cases where the water table did not reach the surface.

When the water level was close to the surface (40 cm or higher) the level in fields 1 and 2 fell approximately 38 and 22 cm respectively in 24 hours. In row 2 of field 3 which was taken as being representative

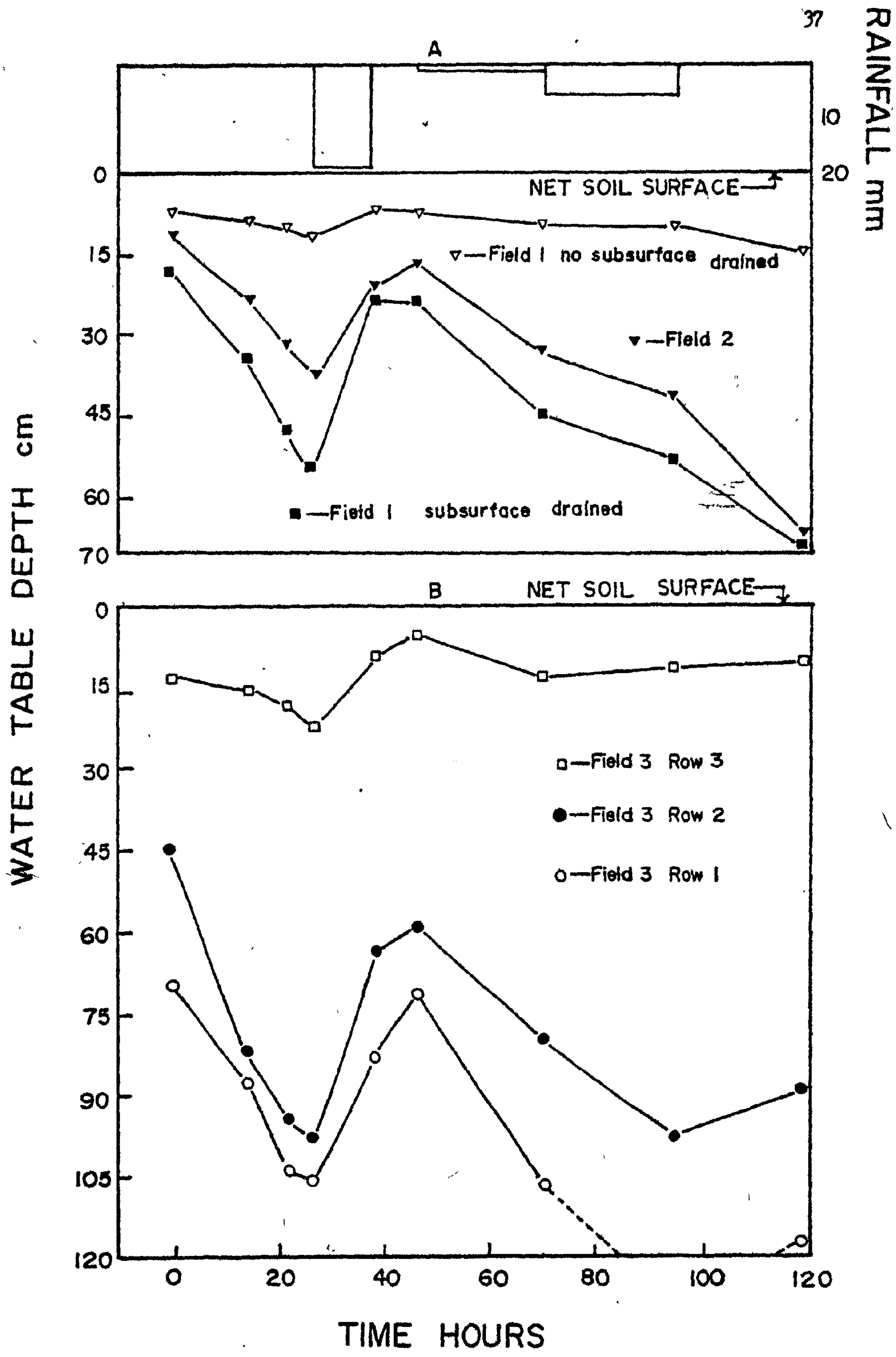

Figure 4. Mean water table depths vs time after first reading. Event No. 1, readings started at 1500 hrs on 790910.

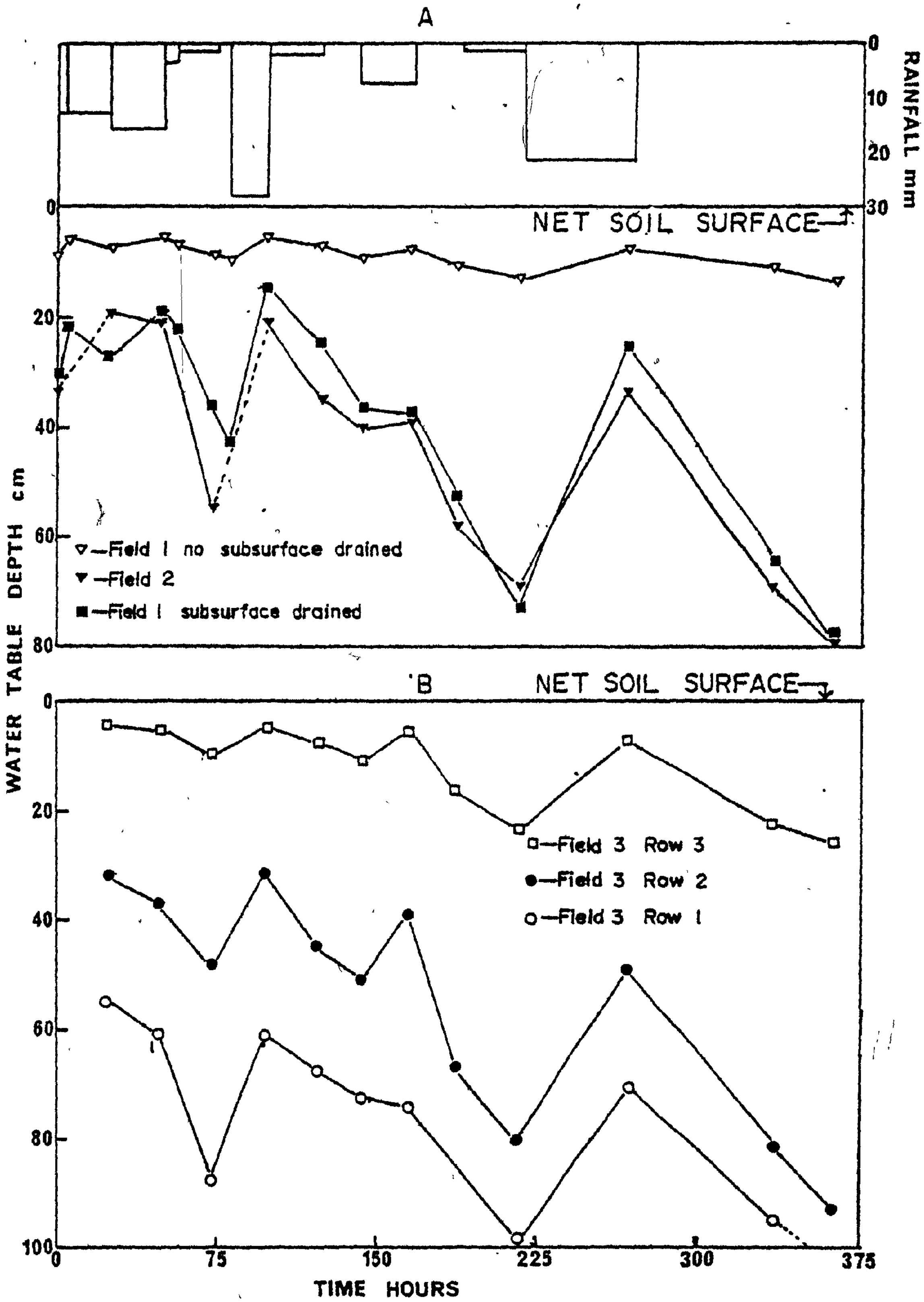

Figure 5. Mean water table depths vs time after first reading. Event No. 2, readings started at 1030 hrs on 791202.

of the field (discussed later), the drop was about 50 cm also in 24 hours. At lower levels in the profile (60 cm or lower) the fall in the same time period was reduced to 14, 12 and 10 cm in fields 1, 2 and 3, respectively. A much used criterion for adequate subsurface drainage is that the water table should drop from ground surface to at least 30 cm in 24 hours (Kidder and Lytle 1949). The subsurface drained areas of field 1 and field 3 easily met this criterion even though the water level did not reach the surface. The rate in field 2 fell short by only 8 cm. This was enough to take the water level to lower than 30 cm because the level in field 2 never came to within 8 cm of the surface. Thus it is likely that field 2 would have also met the criterion if the water level had reached the surface since the rate of fall was greatly decreased lower in the profile. The maximum fall observed in the area which was not subsurface drained was about 6 cm in 24 hours. The water level in this field did not get below 16 cm during any of the observation periods. Thus this area did not meet the general criterion of adequately drained soils.

The drop in the water level could have been due to evapotranspiration, deep percolation and lateral flow to the subsurface drains.

The areas in field 1 that were subsurface drained and not subsurface drained had similar vegetative cover. Sugarcane was planted at the same time and given the same treatments in both areas. Thus the evapotranspiration in the two areas would have been approximately equal and so should have been any water level drop due to this factor. Both areas had similar mean soil physical properties as seen in Table 1 below.

TABLE 1. MEAN SOIL PHYSICAL PROPERTIES FOR AREAS IN THE STUDY.

Soil Physical Property	Non Subsurface Drained-Field 1	Subsurface drained		
		Field 1	Field 2	Field 3
Hydraulic Conductivity -				
(0 to 1 m depth) m/day	0.144	0.154	0.571	0.060
(1 to 1.5 m) m/day		0.066	0.263	0.058
Bulk density -				
30 cm below surface gm/cm^3	1.67	1.67	1.58	1.64
60 cm below surface	1.62	1.60	1.61	1.60
Drainable Porosity -				
30 cm below surface	0.023	0.026	0.034	0.029
60 cm below surface	0.024	0.021	0.032	0.029

Therefore the great difference in water table depths could not have been due to differences in soil physical properties. This eliminated the percolation and lateral flow suppositions. Thus one could safely conclude that the greater rate of fall of the water table levels in the region that was subsurface drained was due to the presence of the subsurface drains.

The inter-field mid-spacing differences in the water table fall rates could have been due to a combination of factors. It is generally accepted that, under similar conditions, the rate of water table drawdown is inversely proportional to the square of the spacing between drains. The subsurface drains in field 3 which had the closest spacing (11.43 m) showed the fastest drawdown rate while those in field 2 with the farthest spacing (22.86 m) showed the slowest rate. One cannot automatically conclude, however, that this descending order of drawdown rates was due solely to the spacing between the drains. There were other factors which may also have contributed. Principal of these were deep percolation and lateral movement. Field 3 was situated adjacent to a valley with a fairly steep drop of about 6.1 m in depth (see plan). It is very likely that this valley also influenced the water table drawdown in this field. The valley would have created a greater hydraulic gradient thus inducing lateral and deep seepage to it.

Field 3 was sparsely covered with grass and weeds thus allowing more opportunity for direct action on the surface by the wind and the sun to increase evaporation from the soil. The expected higher transpiration rates by the sugarcane in fields 1 and 2 may have equalised this difference however.

The difference in drain spacings seemed to be the factor most responsible for the faster drawdown rates in field 1 compared to those in field 2. Soil properties particularly drainable porosity and hydraulic conductivity indicated that movement should have been faster in field 2. The reverse was observed.

The variation of the levels in the three rows of field 3 is worthy of special comment. In both events the pipes of row 3 showed very slow drawdown and the water level remained very high for the duration of the observations. This contrasted with the pipes in rows 1 and 2 whose levels did not rise very high and fell very quickly. Part of this difference may have been due to the closer proximity of rows 1 and 2 to the valley which would have induced greater drawdown due to deep percolation and lateral flow. This variation between the rows may also have been due to differences in the soil structures. However, although the area in which row 3 was located had a very hard and almost impermeable surface layer (see qualitative observations), measured soil properties did not justify such a large difference in drawdown rates. The surface ponding that was evident in the region of row 3 does suggest that there was some physical impediment that was preventing the flow of water to the drains. One such impediment could have been the clogging of the filter materials around the drain tubes by the silt in the region.

Phreatic Surface Drawdown

The depth of the water below the surface at the times after the first reading was plotted against the distance from the drains to produce the graphs shown in Figures A8 through A12. There is no graph for field 3 from event 1 because there was no measurable water level in the majority of the water table pipes. Generally these graphs show that there was a gradient from the mid-spacings of the adjacent drains to the two drains. This indicated that there was a seepage of water through the profile to the drains. In field 1 the levels at the mid-spacings were consistently slightly lower than that of the adjacent inner pipe. This suggested that the influence of drains A5 and A3 was greater than the drain considered (A4) thus influencing the drawdown for more than one half of the drain distance. It is also possible that errors, induced by placing the water table pipes exactly at the center of the cane ridges, caused the pipes to be located at a position that was further away from the drain than the mid-spacing location. Figure A10 indicates that one pipe (second from right) apparently had response problems in event 1 probably due to smearing of the soil when the pipe was being installed.

The series of phreatic surface curves from individual drains were of similar shape for the both events. The classical elliptical shape that is predicted by Hooghoudt's equation (Chapter VI) was not observed between any of the drains examined. The curves generally became flatter as the height above the water table became smaller. There was, however, some variation in phreatic surface shape between different drains. This variation may have been due to spacing or to variations of soil properties or a combination of both factors. The mid-spacing Hydraulic Conductivities (auger hole method) at the specific locations were 0.086, 0.418 and 0.041 metres per day for fields 1, 2 and 3, respectively. In an anisotropic soil (assumed in this case) the angle which the flow path makes with the horizontal is inversely proportional to the horizontal hydraulic conductivity. The relation being

$$a = \tan^{-1} \frac{K_v}{K_h \tan b}$$ (U.S. Soil Conservation Service 1973)

where, a = the angle between the path of flow and the horizontal

b = the angle between the vertical axis and the line of force

K_v, K_h = Vertical and horizontal hydraulic conductivities.

Thus the field with the highest horizontal hydraulic conductivity was expected to have the flattest gradient.

Figure A12 shows the influence that surface ponding can have on the water table reading. Surface ponding developed in the vicinity of the pipe to the left of the graph and so influenced a disproportionally high reading. However, as soon as the ponding disappeared the water level in the pipe quickly dropped to equilibrium with the water table in the rest of the field. Thus indicating that surface ponding may induce readings that do not accurately reflect the situation in the surrounding field.

CHAPTER VI

DRAIN FLOW RATES

Materials and Methods

Flow rates were measured at the outlets of drains located in fields 1, 2 and 3. Observations were made on Drains A2 to A5 in field 1, A9 to A11 in field 2 and H2 to H4 in field 3. These drains were used because there was a constant spacing between them and adjacent drains. The exception to this was A11 which was located 19.8 m away from line B (see plan), it was used in order to maintain a minimum of 3 sampling units in each field.

A graduated 10 litre bucket and the second hand of a watch were used to take the readings. The measurements were taken during the same time period as the water table observations. The same sequence of obtaining readings, both within and between fields, was maintained at all times. The mean of two readings per drain was recorded in units of litres per minute.

The outflow rates were converted from litres per minute to drainage rates of volume per day per unit of area drained, i.e. mm/day using the following steps:

1. $AD = EL \times \frac{S1 + S2}{2}$

where, AD = Area drained

S1, S2 = distance from adjacent drains

EL = Effective length = $L - (\frac{S1 + S2}{6})$

L = Actual length of subsurface drain pipe

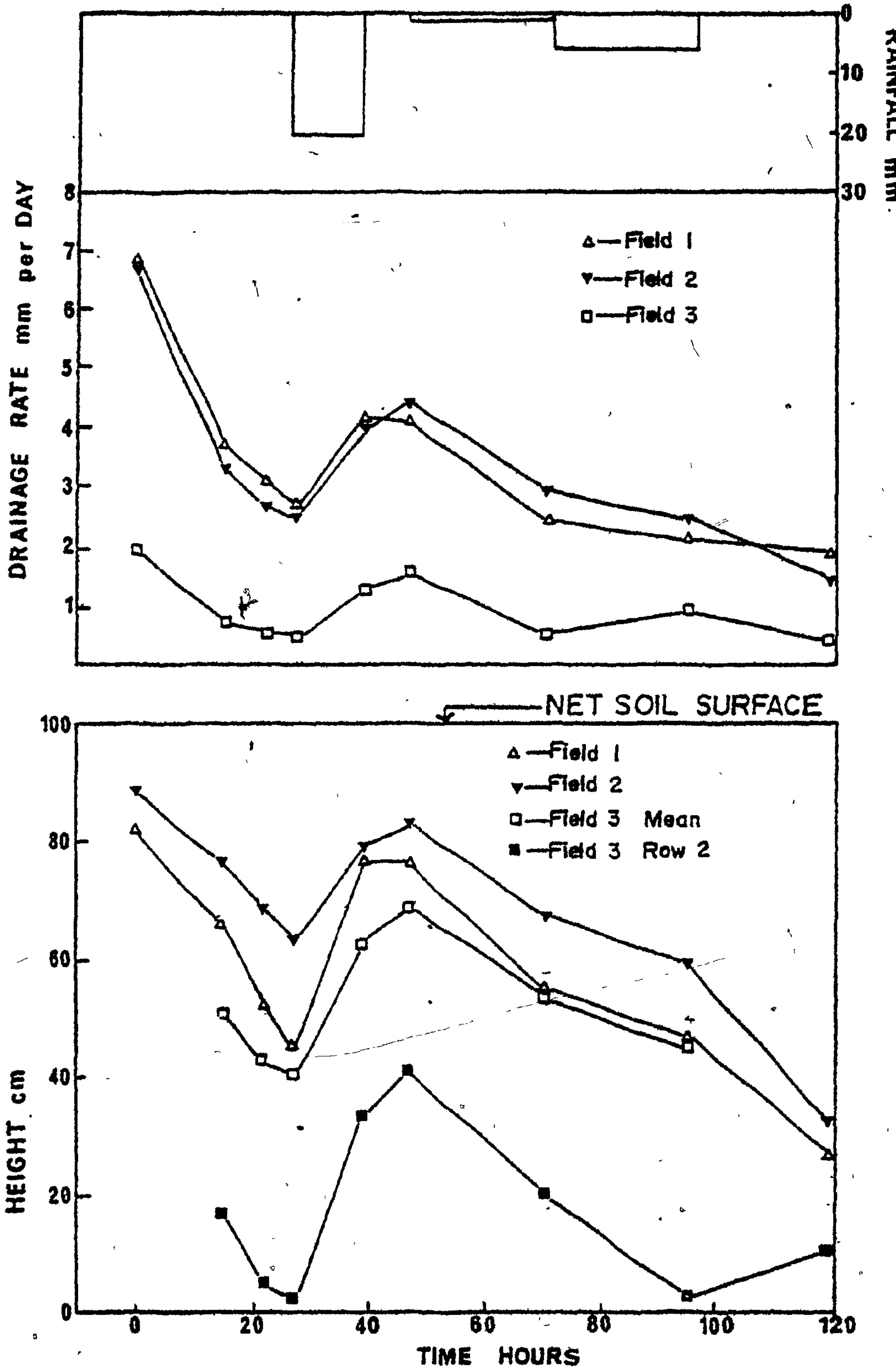

Figure 6. Mean drain outflow rates and corresponding water table heights vs time after first reading. Event No. 1 readings started at 1500 hrs on 790910.

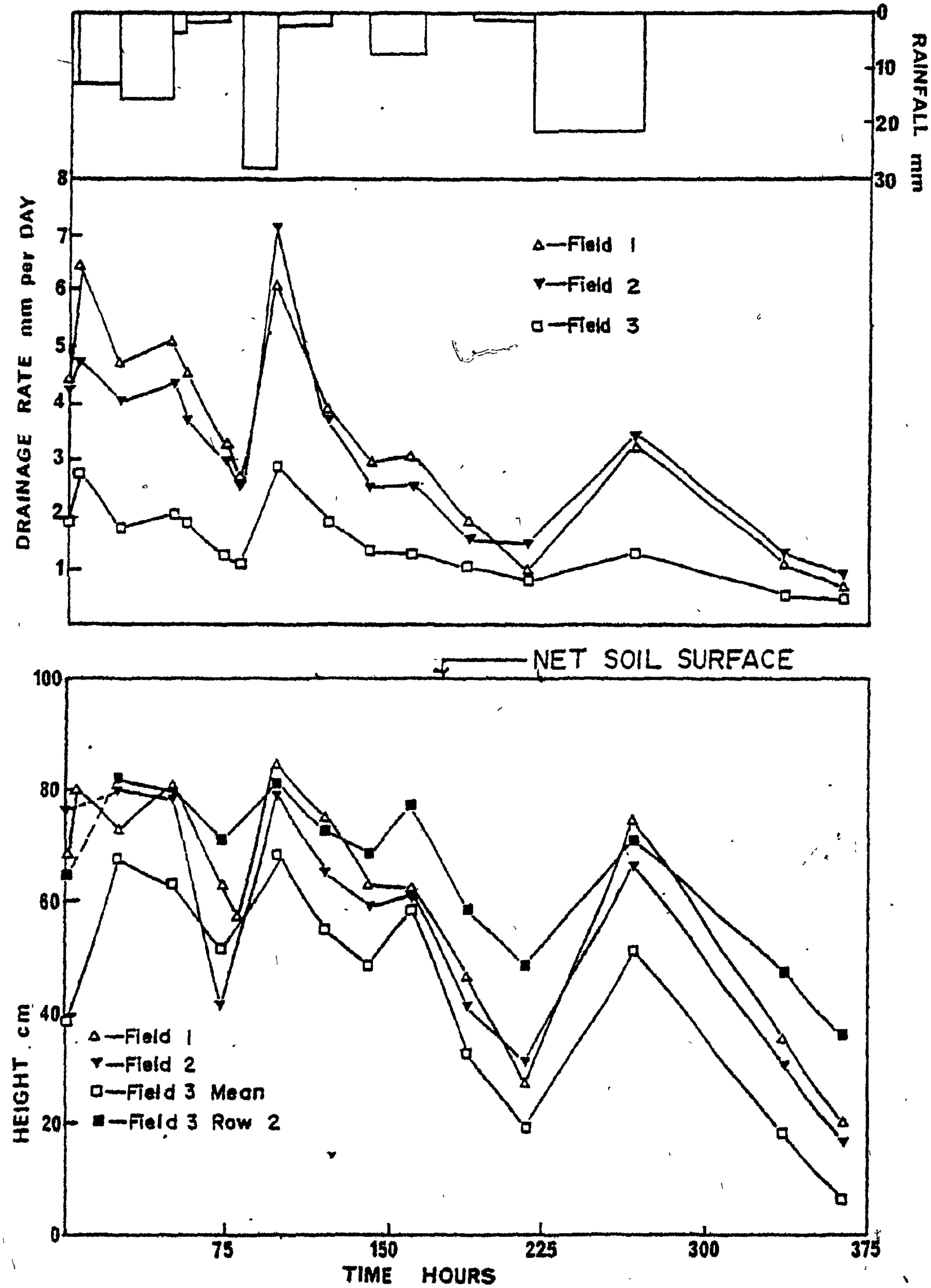

Figure 7. Mean drain outflow rates and corresponding water table heights vs time after first reading. Event No. 2 readings started at 1030 hrs on 791202.

2. Litres/minute to give 1 mm/day runoff

$$= AD(m^2) \times \frac{1\ \text{mm}}{\text{day}} \times \frac{.001\ \text{m}}{1\ \text{mm}} \times \frac{1\ \text{lit}}{.001\ \text{m}^3} \times \frac{1\ \text{day}}{1440\ \text{min}} = C$$

C is a constant for a given drain.

3. $$\text{mm/day} = \frac{\text{lit}}{\text{min}} \times \frac{1}{C}$$

Results And Discussion

Figures A13 through A16 show the rates obtained from individual drains plotted against time after the first reading. Figures 6 and 7 show the average drainage rates and the mean heights of the water table above the drains, for each field, both plotted against time. The rainfall bar graph at the top of Figures 6 and 7 represents the total precipitation from rainfall events between outflow observations.

Figures A13 through A16 reveal that the drains within each field showed similar fluctuations with time and that there was not a large intra-field variation between drains. Also there was a rapid response to rainfall and a gradually decreasing outflow after rainstorm events. From these observations one can infer that the drains were functioning in that they were removing water from the root zone. The quick response to rainfall, and the rapid decrease in the rates during the early hours following rainfall indicates that there was appreciable flow through the trench backfill and into the drains. The water could have entered the trench either from the furrows that were directly over the trench or from other furrows via the more permeable ridges and plough zone in a manner similar to that described by Taylor et al (1980). The best illustration of the phenomenon was seen in Drain A5 which always showed highest response to rainfall but subsequently its rates always fell to below that of the other drains.

The height of the water table above the drains showed similar response to the drainage rates in the three fields. The ratio of the change in drainage rates to the change in water table elevation was higher in the initial hours after rainfall than in the days following. This was apparent in fields 1 and 2. This pattern was consistent with the suggestion that some water was seeping directly into the drains from the trench soil rather than through the field profile during and immediately after rainfall. The leveling off of the ratios at later periods suggested that the lowering of the water table at this stage was the main source of water for drain flow. In field 3 there were relatively low drainage rates compared to water table drop. This indicates that the drains alone were not responsible for water removal from the profile. This observation supports the suggestion that there was some deep seepage to the adjacent valley.

The drainage rates recorded from fields 1 and 2 in 1979 were generally higher than those recorded from the same drains during the rainy season of 1978. The fields were not cultivated at the time of the observations in 1978. Mean recorded peaks for 1978 (mean of 2 events) were 3.03 and 5.29 mm per day for fields 1 and 2, respectively, for the 1979 season peak values (also mean of 2 events) were 4.25 and 5.77 mm per day. The rainfalls and soil and crop conditions for 1978 were not identical with those of 1979. Thus comparisons between years may not be valid. However, the increases in drainage rates during the second season of drain life are normally expected. Probable reasons for these increases were better hydraulic conductivity in the top layers because of land preparation for cultivation and better conductivity in the lower layers due to the wetting and drying process in the year after drain installation.

The drainage rates as measured in the field were compared with rates theoretically predicted by Hooghoudt's equation. Hooghoudt's equation can be written as:

$$R = \frac{4}{L^2} \left(2\ de\ K_b h + K_a h^2\right)$$

where, R = drainage rate, m/day

L = Spacing between drains, m

de = Equivalent depth to impermeable layer, m

K_b = Hydraulic Conductivity below drain level, m/day

K_a = Hydraulic Conductivity above drain level, m/day

h = Height of water table above drains, m

Hooghoudt's equation was used because it was the only one of the established drain spacing equations for which enough field data were available. The equivalent depth was assumed to be 1 m.

Graphs of height of water table above drains against both the recorded and theoretically predicted drainage rates were plotted and are presented as Figures 8 and 9. The outflow data are the results of observations following two rainfall events. Two graphs for field 3 have been presented based on the mean water table heights for row 2 and row 3 and on the heights for row 2 only. The graph based on data from row 2 gave a more realistic curve and was used in inter-field comparisons. The lack of change of water table height with time in the pipes on row 3 has been described in Chapter V.

A commonly used criterion for the subsurface drainage of arable

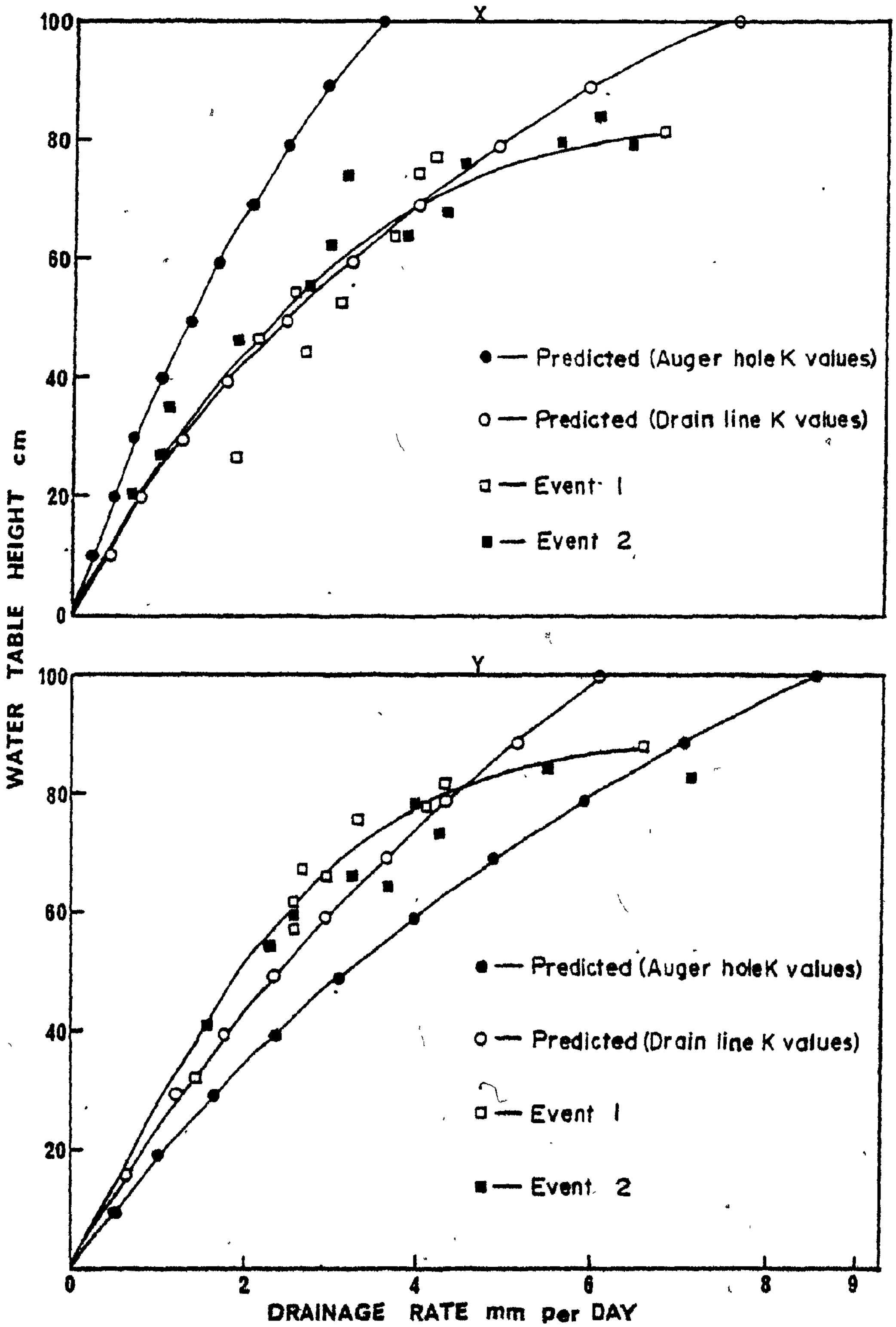

Figure 8. Mean drain outflow rates vs corresponding water table heights for events Nos. 1 and 2 in field 1 (X) and field 2 (Y).

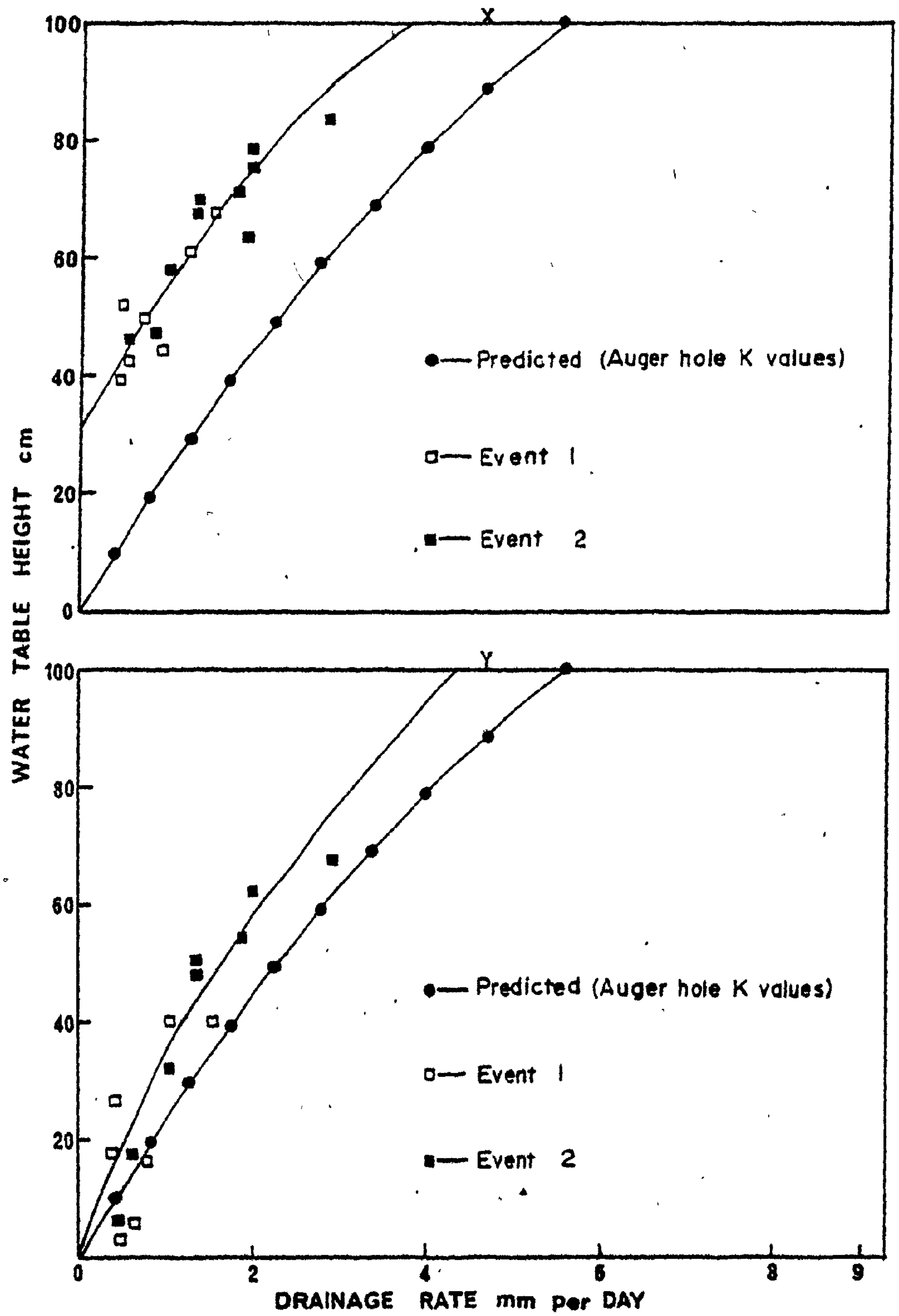

Figure 9. Mean drain outflow rates vs corresponding water table heights for events Nos. 1 and 2 using mean h values for field 3 (X) and h values for field 3 row 2 (Y).

lands in the Netherlands is that there should be a discharge rate of 7 mm per day in combination with a water table of 50 to 60 cm above drains, the drains being at 1 m depth (Kessler 1973). When the water table height was 60 cm above the drains, observed outflow rates were 3.20, 2.80 and 2.65 mm per day (mean of 2 events) for fields 1, 2 and 3, respectively. Predicted rates (based on auger hole hydraulic conductivity values) at the same elevation were 1.61, 3.99 and 2.79 mm per day. Thus the Netherlands drainage criterion was not achieved in any of the fields. This was expected because of the relatively high bulk densities, low hydraulic conductivities and low drainable porosities of the soils in the area. Thus in order to obtain similar rates to the afore-mentioned criterion narrower spacings between drain laterals will have to be used. For example, drains placed at half of the existing spacing would have had predicted rates of 6.44, 15.95 and 11 mm per day at water table heights of 60 cm above the drains. Experiences with the subsurface drained areas during the 1978 and 1979 rainy seasons have revealed that there were not many days during which the water table remained consistently closer than 40 cm to the surface. Thus the increased cost of closer spacing would probably not be justified for sugarcane. It appears that the drainage criterion for the Netherlands is impractical for sugarcane production for the soil and climatic conditions at the SFC. Actually, rates of over 7 mm per day and on one occasion over 8 mm per day were measured from individual drains. However, these rates were recorded when the water table was about 80 cm above drain level, (less than 20 cm from the soil surface).

Drainage coefficients suggested by Schwab et al (1966) and

Cheing et al (1978) are more flexible than those used in the Netherlands and appear to be more applicable to conditions at the SFC. Both of these sources (Schwab) et al 1966, Cheing et al 1978 have based the establishment of drainage criterion on soil conditions (mainly their drainable porosities). For example, Schwab et al (1966) have suggested that to obtain a 30 cm water table drip per day on a soil with a 3 per cent drainable porosity, one would require a drainage coefficient of 9 mm per day. This compared favourable with the peak outflow rate of 8 mm per day which was recorded in field 2. Field 2 had a drainable porosity (laboratory determined value) of about 3 per cent and the water table drop in the first 24 hours was close to 30 cm. Cheing et al (1978) made similar recommendations.

The above discussions seem to clearly indicate that the adoption of drainage criteria, established elsewhere, to Trinidad and Tobago conditions will not necessarily produce optimum results. It will be necessary to utilize some of the above criteria in designing other pioneering subsurface drainage systems. However, reliable drainage coefficients for Trinidad and Tobago will only be established after many more field observations have been made and more local experience gained. It is likely that drainage rates should be higher for vegetable crops than for sugarcane and grass crops.

Figure 8 shows that the relation between measured rate of discharge and head above drain depth, in both fields 1 and 2, was curvilinear. The radius of curvature, however, changed drastically from about heads of 50 cm in field 1 and 60 cm in field 2. This deviation is probably due to the hydraulic conductivity in the top layer of the soil profile being greater than the hydraulic conductivity at depth. This led to shallow discharge through the top layer (the plough zone) when the precipitation rate exceeded the rate of downward flow through the underlying layer (the undisturbed subsoil). This virtually confirms the supposition that was made in earlier sections.

The above observations enable one to partially explain the reason for the difference in the observed curves and those based on Hooghoudt's equation. Hooghoudt's equation assumes a uniform hydraulic conductivity down to drain level and a layer change at drain level. It is now obvious that this condition did not exist in either field 1 or field 2. Deviations were also observed at heads lower than 50 cm in field 1 and 60 cm in field 2. This was probably due to the use of higher mean hydraulic conductivities than actually exist in field 2 and lower values in field 1. Hydraulic conductivity values based on the measured values of drainage rates and water table heights were calculated and shown in Figure 10. These calculations were based on Hooghoudt's equation and they gave K_a values of .348 and .389 m/day for fields 1 and 2, respectively and K_b values of .120 and .203 m/day. These values should be preferred over the values obtained from the auger hole tests if drain spacings are to be calculated in the future since they reflect what was taking place throughout the soil profile. Similar calculations were not made for field 3 because of the generally low water table levels that were observed in this field, and the difference between the water table depths observed from the two rows of observation pipes.

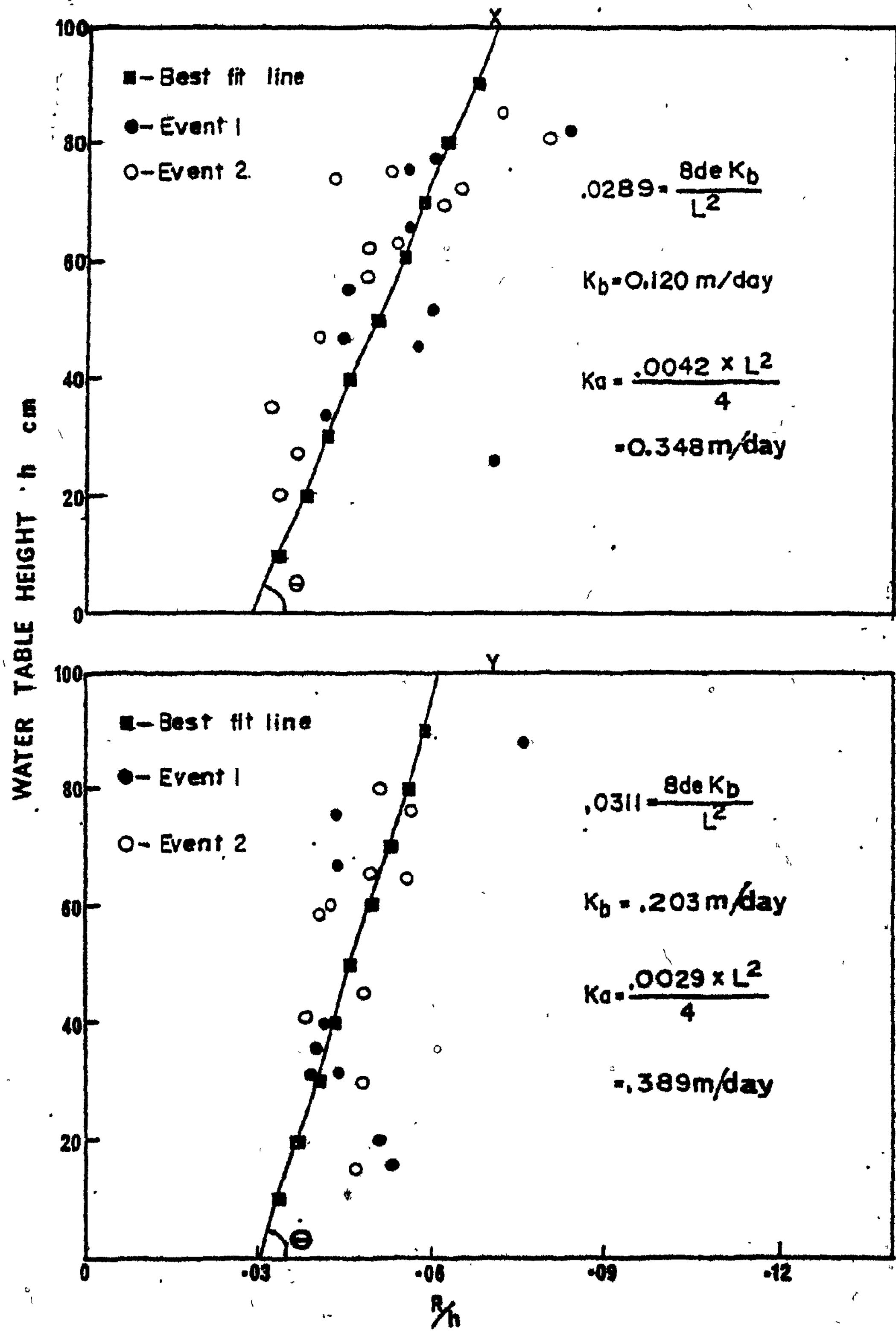

Figure 10. Ratios of drainage rate to water table height ($R/_h$) vs mean heights of water table for field 1 (X) and field 2 (Y).

CHAPTER VII

HYDRAULIC CONDUCTIVITY AND DRAINABLE POROSITY DETERMINATIONS

Measurement of Hydraulic Conductivity

Hydraulic conductivity was determined using the Auger hole method as described by Van Beers (1976). Values were determined for two layers. The value for the first layer (K_a) was obtained by augering a hole of about 1 metre. All holes were 10 cm in diameter. It was impossible to obtain measurements in some of the holes in fields 1 and 2 when the water level was close to the surface. This was due to the unstable condition of the walls of the holes which led to a soupy mixture of water and sand rather than water only flowing into the hole. A polyvinyl chloride (PVC) screen with 2 mm openings was unable to contain this failure. As a result new holes had to be augered when the water level subsided.

The same hole that was used to obtain the K_a values was used to obtain the value of the lower layer (K_b). This was done by augering a further 50-60 cm after the water level had subsided to about 90-100 cm below the surface. This was not quite the same as the method described by Van Beers. It was used because prior augering to install water table pipes did not indicate a layer change at or about drain level. Fewer K_b values than K_a values were obtained because the water table had already receded to depths greater than 1.3 m at some locations before the deep holes were augered.

Comments on Hydraulic Conductivity Measurements

Table 2 shows the measured values of Hydraulic conductivity.

TABLE 2. HYDRAULIC CONDUCTIVITY VALUES AT SFC MEASURED BY AUGER HOLE METHOD.

Field	Row	Layer	K m/day Position 1	2	3	4	5	Mean	Std. Dev.[y]	C.V.[z] %
1-DR[w]	1	a	.251	.046	.086	.098	.270	.154	.084	54
1-DR	2	a			.173	.152				
1-DR	1	b		.107	.108	.015		.066	.049	74.2
1-DR	2	b			.034					
1-UDR[x]	1	a	.240	.100	.156			.144	.072	50
1-UDR	2	a	.052	.173						
2		a	.324	.418	.665	.877		.571	.25	43.8
2		b	.277	.176	.335			.263	.080	30.4
3	2	a		.119	.013	.038	.054	.060	.040	66.7
3	3	a		.041		.114	.043			
3	2	b		.060			.114	.058	.046	79.31
3	3	b			.00		.058			

[w] DR - Subsurface Drained

[x] UDR - Non-subsurface Drained

[y] Std. Dev. - Standard Deviation

[z] C.V. - Coefficient of Variability

Wide variations in Hydraulic conductivity values were found. The coefficient of variability was below 50 per cent in field 2 only. Field 3 showed the largest variation in both the K_a and K_b layers. Similar variations have been reported in the past (Van Beers 1976, De Boer 1979). These variations were not unexpected. Field observations during the 1978 and 1979 rainy seasons indicated that there were fairly wide inter- and intra-field variations in soil conditions which would lead one to expect wide variations in hydraulic conductivities.

It is generally believed that variation, especially in poorly pervious material, is mostly due to the larger pores becoming clogged while the auger hole is being made. This may result in lower K values than actually present being measured. In spite of its limitations, however, the Auger hole method is still considered to be one of the best methods of estimating Hydraulic Conductivity for practical purposes of drainage design. That is the reason why it was used in the study.

Drainable Porosity

The drainable porosities of the soils in the three fields were estimated by a laboratory method and a field method based on the drain outflow rates and water table changes with time.

Materials and Methods

Laboratory Method. Duplicate soil samples were taken at depths of approximately 10, 30 and 60 cm from pits located at the positions shown in Figure A1. They were collected in thin wall aluminium cores. Average dimensions of these cores were 7.36 cm (I.D.) and 3.92 cm (length). The samples were collected with minimal disturbance by first

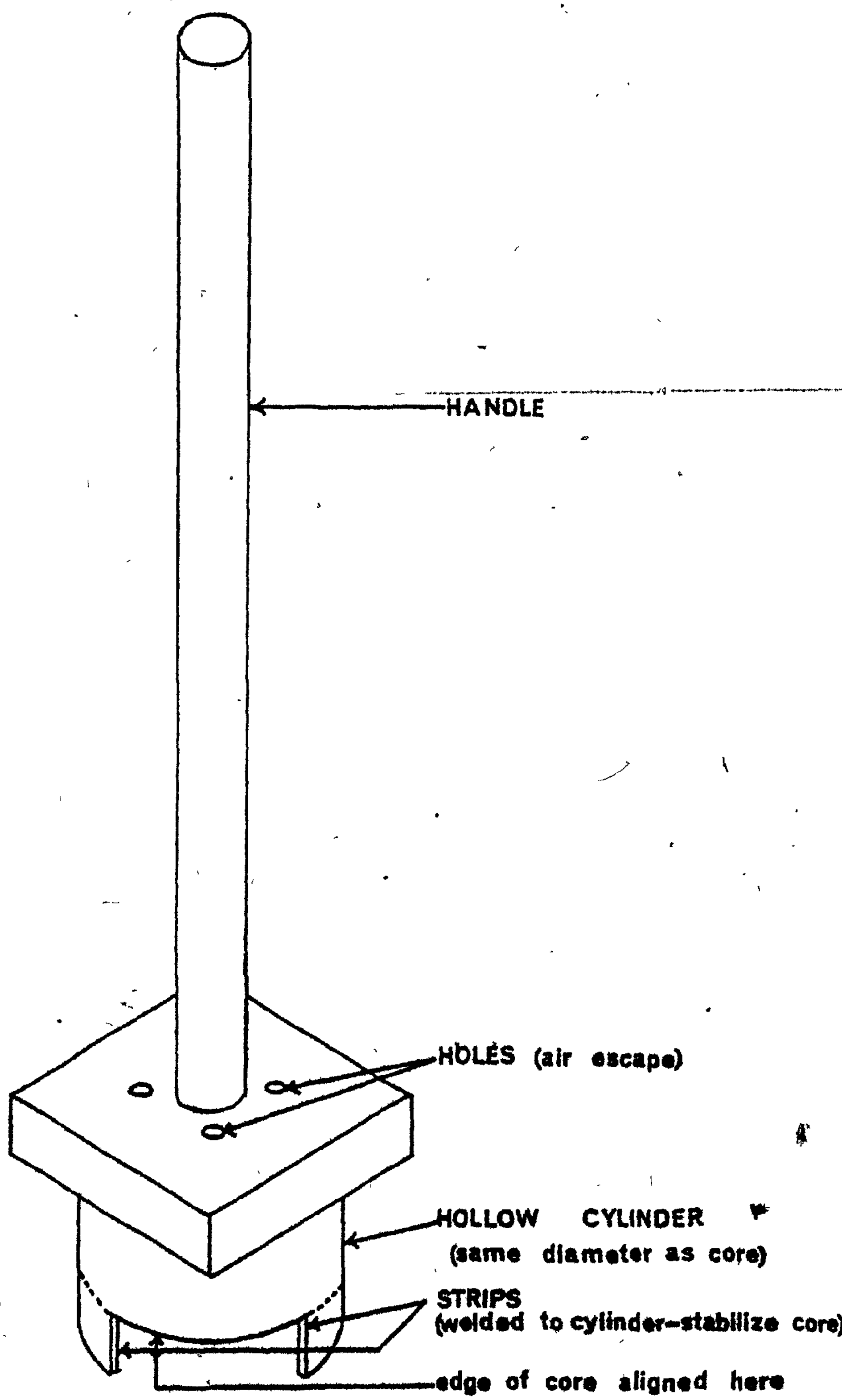

Figure 11. Tool used in extracting soil core samples.

carefully removing the soil above the sampling position. The core was then attached to the sample removal apparatus shown in Figure 11 and placed on the soil surface. The handle of the apparatus was gently tapped with a hammer until the entire core was below the surface. The cores were carefully dug out and trimmed. Those samples that did not occupy the whole core volume because of holes, flaking, etc. were rejected and new samples collected at the locations. Suitable samples were placed in plastic bags to retain moisture. Samples within fields were taken under similar moisture conditions (on the same day). The same conditions did not exist in all fields at the time of collection. Samples from fields 2 and 3 were collected under relatively dry conditions. Those from field 1 were collected under wet conditions.

After careful packing and transportation to the laboratory at the University of the West Indies, the samples were saturated and successively subjected to suctions of 20, 40 and 60 cm on a tension table apparatus. They were weighed at saturation and after each suction. The procedure was similar to that described by Vomocil (1965). Suctions of 80 and 100 cm were also desired. These were not achieved on the tension table apparatus in spite of repeated efforts. The samples were transferred to a pressure vessel apparatus where the 80 and 100 cm pressure were applied. They were then oven-dried at 105°C to constant weight.

Drain Outflow and Water Table Method. The drainage outflow and water table data given in Chapters V and VI were used to estimate the drainable porosity. The relation used was:

$$f = \frac{\text{depth equivalent in time t of (drainage and evapotranspiration)}}{\text{water table drop in time t.}}$$

The initial time increments after rains were not used in the calculations. There were two reasons for this:

(i) direct entry of water from the trenches to the drains was suspected;

(ii) it was not known if the water table was rising or falling when observations were made immediately after rains. An evapotranspiration rate of 5 mm per day (12 hours) was used. This value was based on the findings of Archer (1976).

Results and Discussion

Laboratory Method. Drainable porosity values were calculated as suggested in Black (1965) using the relationship:

$$S_n = \frac{100}{V_b \rho} (W_1 - W_t)$$

where, S_n = percentage of soil volume drained under a suction of n cm of water,

V_b = bulk volume of the sample in milliliters before drying,

W_1 = Weight of sample after soaking and before drainage on the tension table,

W_t = Weight of sample in grams after drainage on the tension table, and

ρ = density of water in gm per cm^3.

This was chosen over equations using particle density (Vomocil 1965) because the particle density was not obtained. It was felt that because of the large size of the samples, blotting and weighing saturated samples would not have created larger errors than using an arbitrarily assigned particle density value.

TABLE 3. ESTIMATED DRAINABLE POROSITIES AT 60 CM SUCTION - LABORATORY METHOD.

Field	Row	Sample depth cm	Drainable Porosity Position 1	2	3	4	Mean	Std. Dev.[y]	C.V.[z] %
1-DR[w]	1	30	.023	.024			.026	.0026	10.50
1-DR	2	30	.028	.028					
1-DR	1	60	.020	.018			.021	.0060	28.50
1-DR	2	60	.030	.017					
1-UDR[x]	1	30	.020	.019			.023	.0045	19.56
1-UDR	2	30	.029	.023					
1-UDR	1	60	.017	.020			.024	.0079	32.92
1-UDR	2	60	.035	.025					
2		30	.032	.035	.033	.037	.034	.0022	6.47
2		60	.029	.025	.038	.037	.032	.0063	19.69
3	2	30	.025	.036			.029	.012	40.34
3	3	30	.014	.040					
3	2	60	.037	.030			.029	.0074	25.52
3	3	60	.019	.029					

[w] DR - Subsurface Drained

[x] UDR - Non-subsurface Drained

[y] Std. Dev. - Standard Deviation

[z] C.V. - Coefficient of Variability

Graphs of mean field Drainable Porosity against suction were plotted and are presented as Figures A17 and A18. The mean estimated drainable porosities at 60 cm suction for all the sample locations are presented in Table 3. The value of 60 cm was used as the reference suction since it was felt that the drains were unlikely to induce greater average suctions. For a drain depth of 120 cm the average depth of soil above the drains is 60 cm. Thus, when the water table has receded to drain depth, the average suction in the pore water above the drains would be 60 cm, if the effects of drainage only (and not the effects of evapotranspiration) are taken into account.

The relations in Figures A17 and A18 show a slow and regular increase in drainable porosity with increasing suction. This pattern is typical of soils with relatively high bulk densities since there is normally a higher proportion of fine pores in these soils. Finer pores are emptied at much higher suctions than 100 cm. Hence the relatively low changes in suction applied did not remove much more water than was lost by the larger pores at 20 cm suction. The calculated bulk densities at 30 and 60 cm depth (Table B1) were generally greater than 1.60 gm per cm^3. These are considered to be relatively high values. Bulk densities range from 0.5 gm per cm^3 in organic soils to 1.8 gm per cm^3 in very dense mineral subsoils. Loam soils considered excellent for root vitality have bulk densities from 1.0 to 1.2. Thus the observed relations were consistent with the measured bulk densities.

The highest drainable porosities were measured in field 2 which also had the highest hydraulic conductivities and lowest mean bulk densities. Again this was consistent with what would have been expected from theoretical considerations. A higher hydraulic conductivity usually implies a higher proportion of large pores and hence a higher drainable porosity.

A similar ascending order of variability to that observed with the hydraulic conductivity measurements, was observed with the drainable porosity measurements. The smallest variability was seen in field 2 and the greatest variability in field 3. This consistency, for two proportional parameters that were evaluated in the field and the laboratory respectively, suggests that the variations were due to differences within and between the fields and not to variations in experimental technique.

The mean drainable porosities in cores taken at the 30 cm depth were greater than that for cores from the 60 cm depth in the subsurface drained areas of fields 1 and 2. This was typical since the volume of macro-pores normally decreases markedly with depth. Exceptions to this occurred in the non-subsurface drained areas of field 1 and in field 3. The values were just about equal in these two areas. The significance of this observation was somewhat negated by the large variation in values obtained at the 60 cm level at these two locations. Intuitively, one would have expected less variation with depth from the non-subsurface drained areas. This effect could be due to the existence of pondings of free water for long times in the poorly drained areas. This would cause slaking and breakdown of structure which would reduce the number of large pores.

The range of drainable porosity values determined was identical to that obtained by Ahmad and Gumbs (1978) before the subsurface drains were installed. This further indicated that the subsurface drains had no appreciable effect on the drainable porosity values.

TABLE 4. DRAINABLE POROSITIES (f) ESTIMATED BY FIELD METHOD (1979 MEASUREMENTS).

Estimate	Field	Position[w]	Water table depth mm			Drainage rate (q) mm/day			Δq x m[y] mm	$f = \frac{\Delta q \times m}{(\Delta \check{s} - ET)}$	Mean (2 estimates)
			at a hrs	at b hrs	Δš	at a hrs	at b hrs	Δq			
1	1	1	230	502	272	7.35	2.64	4.71	4.71	0.018	0.016
2	1	1	270	715	445	3.23	1.08	2.15	6.20	0.014	
1	1	2	190	400	210	6.29	3.08	3.21	3.21	0.016	0.029
2	1	2	170	305	135	3.20	1.20	2.00	5.75	0.042	
1	1	Mean[x]	190	499	309	6.91	3.00	3.91	3.91	0.013	0.014
2	1	Mean	252	642	390	3.22	1.14	2.08	5.98	0.016	
1	2	1	150	438	288	6.41	2.49	3.93	3.93	0.014	0.016
2	2	1	445	770	325	3.08	1.18	1.90	5.48	0.018	
1	2	2	075	321	246	6.70	2.62	4.08	4.08	0.017	0.018
2	2	2	410	750	340	3.39	1.30	2.09	6.01	0.018	
1	2	3	095	240	145	7.30	2.85	4.45	4.45	0.031	0.025
2	2	3	285	660	375	3.65	1.26	2.39	6.87	0.019	
1	2	Mean	105	340	235	6.86	2.80	4.06	4.06	0.018	0.018
2	2	Mean	338	697	358	3.27	1.20	2.07	5.95	0.017	

[w] In field 1 positions 1 and 2 are the means of two rows.

[x] Mean of whole field.

[y] $m = \frac{a - b}{24}$ days

Field Method. Drainable Porosity values calculated from the drainage rate and water table data are presented in Table 4 . Mean values for fields 1 and 2 respectively were 0.014 and 0.017. A similar field method performed during the wet season of 1978 produced mean values of 0.016 and 0.036 respectively (Table B3). There appears to be no clear cut explanation for the big drop in values obtained throughout field 2. It has already been seen that the drainage rates during the 1979 season were greater than in 1978. Thus it seems likely that there was a relatively faster rate of water table drawdown in 1979. The unproportional increase could have been due to increased evapotranspiration caused by the presence of the sugarcane. In 1978 the ground was covered by sparse low grass and weeds. Increased rates of deep seepage could also have contributed to the quickening of the water table lowering rate. Similar reductions may also have occurred in field 1. These, however, appeared to have been offset by the much larger increases in drainage rates that were recorded in this field. None-the-less, the drainable porosities are relatively small for all fields when compared with good draining class 1 or class 2 soils. Some of the variation in the values of f obtained by observing water table drawdown in the field may have been due to the non-constant range of water table drop between observations; hence there could have been unequal suctions in the pore water in the drained pore space at the various water table observation locations in the fields.

The values obtained from the field data were generally smaller than those recorded in the laboratory. A direct comparison between the laboratory and the field values is not strictly valid. The field values represent a composite value for the entire saturated profile. On the other hand the laboratory values only represent the value at a particular location. Theoretically, both values should be about equal if all the water that seeped through the profile flowed out of the drains. In a densely packed subsoil as existed at the SFC, seepage towards the drains through the soil medium would have been tortuous. Thus it is not unreasonable to assume that all the water did not eventually flow out of the drains. This would have led to smaller values being obtained in the field method. This should be taken into consideration during any further design of drain depth and spacing on similar soils. Measurements made on samples in the laboratory should be applied with caution to field situations.

CHAPTER VIII

BIOLOGICAL YIELD

Both the stalk and root yields of sugarcane from the subsurface drained and non-subsurface drained areas of field 1 were compared. This comparison was carried out in order to ascertain if there was any difference in yield due to the subsurface drains.

Methods and Materials

Millable Stalks. Eight plots each from the subsurface drained region and the non-subsurface drained region were examined in the investigation of the yield of millable stalks. The size of each plot was 2 m along the ridges by two ridges across (2 m x 4.57 m). A matched pairs design was used. The experimental layout is shown in Figure A1.

The number of millable stalks in each plot was counted and recorded. Twenty tops (stalks and leaves) from each plot were randomly selected and then harvested by hand. These samples were transported to the farm centre and weighed. Following this, random representative samples of stalks and leaves from each plot were chopped into 6-10 cm pieces. Total moisture contents of these samples were determined. The chopped samples were weighed and placed in an oven at 105°C. After 24 hours they were removed from the oven, cooled and weighed. They were then returned to the oven and the procedure repeated until the difference between consecutive weighings was negligible.

The plots were all harvested on 24th November, 1979. At that time the canes were approximately 12 months old. Field conditions were wet because of overnight rain but there was no rainfall during the harvesting operations. Another harvest of the same fields was undertaken during the month of April, 1980, by the staff of the Sugarcane Feeds Centre. The same procedure was used except that twenty stalks were weighed for only four of the eight plots in both the subsurface and non-subsurface drained regions. Only the weights of three stalks from the other four plots were used.

Root Yield. Estimates of sugarcane root yield and distribution were made at four sites in both the subsurface drained and the non-subsurface drained areas of field 1. Location of these sites are shown in Figure A1 . Soil cores were used in the estimations. The cores were made in the machine shop of the SFC from standard 110 mm I.D. steel pipe. Their dimensions were approximately 115 mm (O.D.), 130 mm (length) and 5 mm (thick). One edge of the cores was tapered into a cutting edge

Samples were taken from well developed stools at distances of 1, 2 and 3 core diameters from the stools. Using the direction of drainflow as 12 O'Clock, the one-diameter samples were taken at 12 O'Clock, the two-diameter at 3 O'Clock and the three-diameter samples at 8 O'Clock. The underlying assumption was that there was equal root development all around the stool. The sample positions are shown pictorially in Figure 12. At each distance from the stool, samples were taken from four vertical positions at depths of 1, 2, 3 and 4 core lengths. Soil samples were removed by tapping the cores into the ground until they were filled. The surrounding soil was shovelled away. The core was then carefully removed, trimmed and its contents placed into labelled plastic bags which were transported to the laboratory. At the laboratory the soil was washed away after being soaked overnight in a solution of

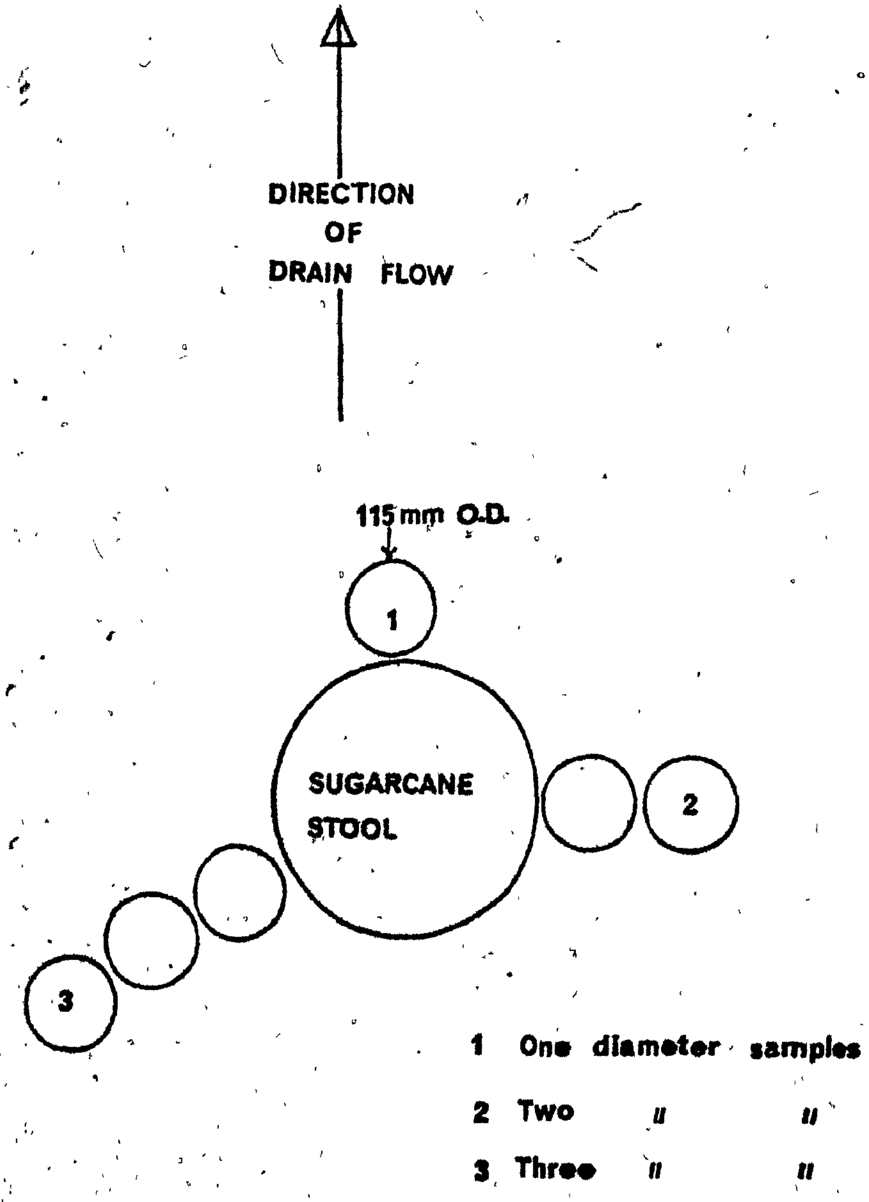

Figure 12. Diagrammatic representation of the locations of core samples, for root analysis, around a sugarcane stool.

the deflocculating agent Calgon (Sodium Hexametaphosphate). The soupy mass was washed through a 200 μm grid mesh. Roots were removed from the mesh, cleaned of any persistent soil, air dried for two weeks and finally weighed.

Results and Discussion

Millable Stalks. Wet and dry matter yields in tonnes per hectare were calculated from the data collected in the first harvest. These results are shown in Table 5. A matched pairs analysis of the dry matter yield is given in Table 6.

At the 90% level of confidence, it can be said that the difference in yield was due to subsurface drainage. However, since the 95% level of confidence is normally used as the lower limit of confidence in most scientific work, it was concluded that the 52% greater yield could be partly attributed to sampling and soil variations. However, the mean number of millable stalks, the mean percentage dry matter and the mean dry weight per cane were all greater in the subsurface drained areas. These values were 60, 24.4% and 0.38 kg respectively in the subsurface drained areas compared to 49, 22.5% and 0.31 kg in the non-subsurface drained area. These three values are very good indicators of yield since they are closely correlated to total dry matter yield.

An initial glance at the results from the second harvest (Table 7) shows that the mean total dry matter yield per hectare was 43.3 tonnes in the non-subsurface drained region compared to 40.1 tonnes in the subsurface drained area. A closer examination shows that the mean number of millable stalks was greater in the subsurface drained area

TABLE 5. SOME MEASUREMENTS OF SUGARCANE YIELDS AT THE SFC (NOVEMBER 1979 HARVEST)

Weight of sugarcane from plots on the subsurface drained and non-subsurface drained portions of field 1. Planted Nov. 1978; weeded manually early 1979; plots harvested on 791124.
Plot size 2m x 4.6m - 9.2m²

Plot No.	Millable Stalks per plot	Wet Wgt. 20 stalks kg	% Dry Matter	Dry Wgt. per stalk kg	Yield tonnes/ha	
					Wet	Dry
1	40	30.1	25.45	0.38	65.84	16.76
2	40	26.9	19.78	0.27	58.84	11.64
3	66	31.2	22.15	0.35	112.60	24.94
4	62	24.2	27.88	0.34	82.04	22.83
5	86	34.9	27.87	0.49	164.12	45.74
6	71	32.6	26.76	0.40	126.56	33.87
7	58	37.4	22.45	0.42	118.61	26.63
8	59	30.1	23.26	0.35	97.11	22.59
x̄	60		24.4	0.38	103.22	25.63
Std Dev					34.70	10.45
9	63	29.1	21.17	0.31	100.25	21.22
10	47	28.7	22.61	0.33	73.76	16.66
11	43	32.5	22.34	0.36	76.42	17.07
12	36	30.0	20.85	0.31	59.06	12.31
13	55	26.9	24.02	0.32	83.09	19.96
14	41	21.0	26.09	0.27	47.08	12.26
15	58	24.0	22.38	0.27	76.12	17.04
16	51	31.5	20.51	0.32	87.85	18.02
x̄	49		22.5	0.31	75.46	16.82
Std Dev					16.49	3.21

Note: Plots 1 to 8 are from the area with subsurface drains.
Plots 9 to 16 are from the area without subsurface drains.
Std Dev means standard deviation.

TABLE 6. MATCHED PAIRS STATISTICAL ANALYSIS OF SUGARCANE DRY MATTER YIELDS AT SFC.

Plots harvested on 791124.

Plot No.	Y Drained[w]	Y Undrained[x]	Y_D[s]	Y_D^2
1	16.76	17.04	- 0.28	0.08
2	11.64	18.02	- 6.38	40.70
3	24.94	19.96	4.98	24.80
4	22.83	12.26	10.57	111.72
5	45.74	17.07	28.67	821.97
6	33.87	12.31	21.56	464.83
7	26.63	21.22	5.41	29.27
8	22.59	16.66	5.93	35.16
			$\Sigma Y_D = 70.46$	$\Sigma Y_D^2 = 1528.54$

Sample Standard deviation $= s = \sqrt{\frac{\Sigma y_D^2}{n-1}}$

$$\Sigma y_D^2 = \Sigma Y_D^2 - \frac{(\Sigma Y_D)^2}{n} = 908.7$$

$$\therefore s = \sqrt{\frac{908.7}{7}} = 11.4$$

Sample Standard error of the mean $= s\bar{Y}_D = \frac{s}{\sqrt{n}}$

$$= \frac{11.4}{\sqrt{8}} = 4.03$$

$$t \text{ cal} = \frac{(\bar{Y}\text{ Drained} - \bar{Y}\text{ Undrained}) - 0}{s\,\bar{Y}_D}$$

$$= 2.188$$

$$\text{df} = 7; \quad 0.1 < p > 0.05$$

[w] Y Drained - Dry Matter Yield in subsurface drained plots (tonnes/ha).

[x] Y Undrained - Dry Matter Yield in non-subsurface drained plots (tonnes/ha).

[s] Y_D - Yield difference.

TABLE 7. SOME MEASUREMENTS OF SUGARCANE YIELDS AT THE SFC (APRIL 1980 HARVEST)

Weight of sugarcane from the same fields of Table 5, using the same plot sizes and crop planted at the same time as those in November harvest.

Plot No.	Millable Stalks per plot	Wet Wgt. of stalks Kg	% Dry Matter	Dry Wgt. per stalk Kg	Yield tonnes/ha	
					Wet	Dry
		(3 stalks)				
1	117	2.95	29.73	0.29	125.1	37.2
2	66	4.77	29.73	0.47	114.1	41.9
3	44	3.64	29.73	0.36	58.0	17.2
4	69	5.45	29.73	0.54	136.3	40.5
		(20 stalks)				
5	120	31.5	31.39	0.50	205.4	64.5
6	93	32.5	31.39	0.51	164.3	51.6
7	54	32.5	31.39	0.51	95.4	30.0
8	57	39.0	31.39	0.61	120.8	37.9
$\bar{x}$	78		30.56		127.4	40.1
		(3 stalks)				
9	65	5.91	31.95	0.62	139.2	44.5
10	80	5.45	31.95	0.59	158.0	50.5
11	104	6.82	31.95	0.73	257.0	82.1
12	72	5.91	31.95	0.62	154.2	49.3
		(20 stalks)				
13	30	32.95	29.61	0.49	53.7	15.9
14	70	36.36	29.61	0.53	138.3	41.0
15	56	31.82	29.61	0.47	96.8	28.7
16	63	34.09	29.61	0.50	116.7	34.6
$\bar{x}$	68		30.78		139.2	43.3

Note: Plots 1 to 8 are from the area with subsurface drains.
Plots 9 to 16 are from the area without subsurface drains.

(78 to 68). The mean percentage dry matter was about the same, 30.5% for subsurface drained to 30.78% for the non-subsurface drained. However, the big difference was seen in the dry matter weight per cane values. In the 20 stalk samples the mean dry matter weight per cane was 0.53 kg in the subsurface drained area and 0.50 kg in the non-subsurface drained. The mean weights in the 3 stalk samples were 0.64 kg in the non-subsurface drained and 0.415 kg in the subsurface drained. This difference was very much greater than was observed in any of the other determinations. Thus it was very likely that three cane stalks were too small a sample to be used in yield determinations. Thus if 20 stalk samples were used throughout, the results might have been similar to those obtained in the first harvest.

An important comparison between the two harvests was the dry matter content from the two areas. Apparently it was not too critical during the dry season (April harvest) because they were almost the same. The observed 2% difference during the rainy season could be very important to an industry like the SFC, where cane is needed all year. Two per cent more water means at least 2 per cent more energy costs for transport and processing and at least 2 per cent less feed efficiency. The sugarcane harvested in the wet season from the subsurface drained area and non-subsurface drained area respectively had 8.28 and 6.12 per cent more moisture than those harvested in the dry season. These higher moisture contents would obviously give rise to higher operating costs in the rainy season. Thus the subsurface drains would contribute towards the reduction of these costs. This cost reduction should be considered in any economic evaluation of the subsurface drainage system.

Thus although there were strong indications, there was not enough evidence to conclusively say that there was an increase in yield due to the subsurface drainage. The observed variations suggest that a more rigorous statistical design is required in any future experiments where crop yields are to be compared for different drainage treatments. This was not possible under existing field layout conditions. A more suitable design would be a completely randomised design using the present field 1 as one of at least four experimental units. This means that other experimental units would have to be sited at other locations on the farm. Ideally all experimental units should be located in the same field where variations of soil properties would be minimal. However, any inter-field variations could be handled by appropriate statistical analysis provided that the drained and undrained areas receive the same crop treatments. Large areas of similar soil are also needed because drainage effects may stretch back as much as 50 m from a drain. As a result of these requirements for large soil and crop areas, generous funding and several years duration, very few statistically rigorous crop yield vs. drainage condition experiments have been made. The observations in Tables 5 and 7 indicate that sugarcane yield measurements should contain at least 20 stalks and about 8 subplots should be sampled for any field. Annual harvestings using the same design as used in this study but at different locations in the fields should also eventually provide conclusive results. This would approximate to a randomized design with the same field being considered as a different experimental unit each year. Yearly fluctuations could then be handled similarly to the inter-field variations. The longevity of the sugarcane stands (i.e. the number of ratoons) in both the subsurface drained and non-subsurface drained regions could also be eventually used as an indicator of differences in yield.

Roots. The mean weights of roots at each position in both the subsurface and non-subsurface drained areas were calculated. These values are tabulated in Table B4. The mean total root weight in each region was determined. The mean percentages of this weight found in each position was found and shown graphically in Figure 13.

Figure 13 does not indicate any drastic difference in distribution patterns between the subsurface and non-subsurface drained regions. Intuitively one would have expected the roots from the subsurface drained areas to penetrate deeper than the non-subsurface drained areas, the drains would be expected to create more favourable soil conditions at lower levels in the profile. Figure 13 does show a higher percentage of roots at the 0 - 13 cm level for the non-subsurface drained areas (50.4% to 44.2% - mean sum of the 3 surface locations) but it is not believed to be significant at this stage.

Thus the subsurface drainage system did not seem to have markedly influenced the rooting system of the crop at the depths indicated. One season's growth under subsurface drain conditions is probably insufficient to give conclusive results of the effect of the subsurface drains on the rooting systems because marked improvements in the subsoil sometimes only occur after a few years. Also it appears that future investigations must include deeper depths since distribution seems to be almost the same at the depths investigated in this study.

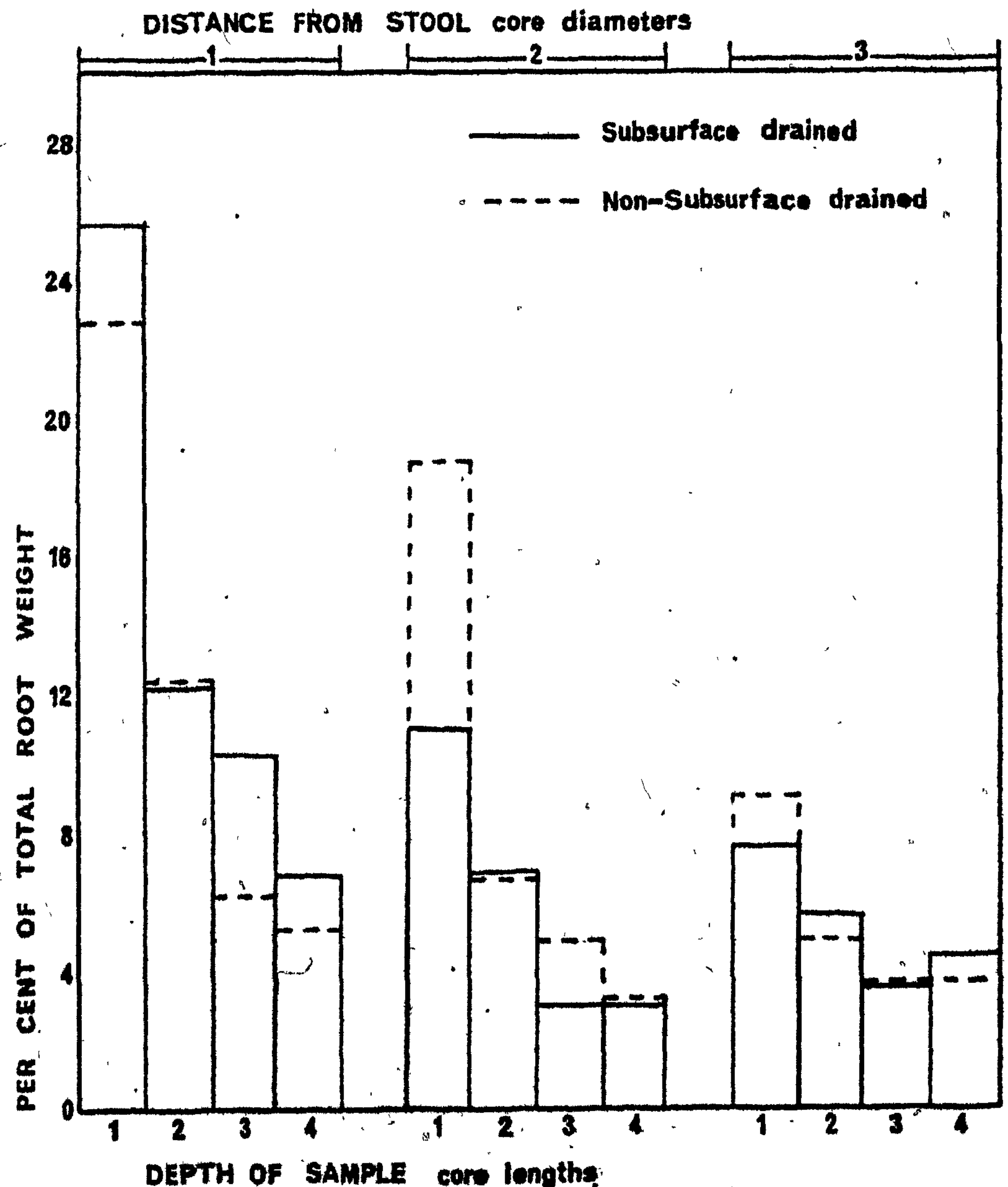

Figure 13. Mean percentage root weights vs position of samples.

CHAPTER IX

CHEMICAL ANALYSIS OF DRAINAGE WATER

The concentration of certain elements in the subsurface drainage water from the fertilized and non-fertilized areas were determined and compared.

Materials and Methods

Samples of the water that flowed from the subsurface drains were collected between the months of June and September 1979. Clean 750 ml commercial glass bottles were used as collecting vessels during the month of June. These were subsequently replaced by new 900 ml plastic bottles because it was feared that chemicals from the glass could have dissolved in the water during the inevitable long wait for analysis in the laboratory. This would have introduced errors into the analyses. Outflow from all of the drains that were used in drainage rate observations were collected. Samples were collected, at convenient intervals, after major rainfall events until flow was negligible. One set of samples was taken from field 2, during the month of August, 24 hours after the field was irrigated with liquid manure.

Immediately after collection, 10 ml of 0.1 N Hydrochloric Acid was added to each sample to reduce the rate of change of the chemicals in the samples. Preliminary tests indicated no change in concentration of the nutrients during storage.

The samples were transported to the laboratory at the University of the West Indies where they were analysed for the concentration of

Sodium, Potassium, Calcium, Magnesium, Iron, Copper, Zinc and Ammonium-Nitrogen. Atomic spectrography was the investigative tool. Concentrations were reported in units of milligrams per litre of drainage water.

Results and Discussion

The mean concentrations of chemicals for the three fields on the sampling dates mentioned are presented in Table 8. No data on the chemical composition of the soils before drain installation was available. Thus it is impossible to compare these results in terms of absolute quantities. In any case the quantities of nutrients leached out seem to have been negligible in most instances and of similar orders of magnitude to what have been reported elsewhere (Bolton et al 1970). Nutrient loss seemed to be very much influenced by the amount of water that seeped through the soil. Thus the quantities of all the nutrients decreased as the drain outflow decreased after rainfall in all instances.

Generally, there was apparently no fundamental difference in water chemistry between the cultivated fields and the uncultivated field in that the absolute quantities and the variations were similar. A notable exception to this was the total iron content. The quantities of iron in the samples that were collected from the uncultivated field 3 were substantially greater than in the other fields. This probably most accounted for the much greater deposits of iron ochre that were precipitated in the drains of field 3. The drains in fields 1 and 2 were in their second year of operation and those in field 3 in their first year. Thus it is impossible to state whether or not the difference in iron content was due to some inherent difference in the soil chemistry

TABLE 8. MEAN FIELD CONCENTRATIONS OF SOME CHEMICALS IN THE SUBSURFACE DRAINAGE WATER AT THE SFC (1979).

	CHEMICAL CONCENTRATION mg. l^{-1}																								
	Na			K			Ca			Mg			Fe			NH_3-N			Cu			Zn			
Field	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Date																								
4/6	19.5	15.0	17.6	4.4	0.2	3.5	1.5	1.0	1.1	4.2	1.0	1.3	0.5	0.0	3.3	-	-	-	-	-	-	-	-	-
17/6	21.3	13.0	21.2	6.0	0.2	2.5	1.3	0.4	1.0	2.8	1.3	1.6	0.4	0.0	1.7	-	-	-	-	-	-	-	-	-
2/7	6.5	5.6	4.7	3.7	0.3	2.3	3.4	2.5	1.2	5.2	1.5	1.0	0.1	0.0	3.5	-	-	-	0.0	0.0	0.0	.02	.01	0.0
6/7	8.2	5.4	8.9	1.0	0.1	1.7	1.0	1.2	2.6	2.7	1.1	2.2	0.1	0.0	0.4	3.3	0.3	1.3	0.0	0.0	0.0	.02	0.0	0.1
8/7	8.2	5.5	9.8	1.2	0.1	1.7	1.4	1.2	2.5	3.8	1.0	2.0	0.1	0.0	0.3	4.3	0.0	0.3	0.0	0.0	0.0	.02	0.0	.02
15/8		14.8			2.7			-			-			-			2.8			0.0			.03	
5/9	25.2	15.0	3.3	15.5	3.7	2.6	1.5	1.4	1.3	4.2	1.4	1.0	1.2	1.9	6.9	-	-	-	0.0	0.0	0.0	-	-	-
10/9		12.5	10.0		1.3	2.5		0.6	0.4		1.1	0.9		0.9	4.5		-	-		-	-		-	-
12/9	5.9	4.9	5.4	2.7	0.4	1.5	1.2	0.5	0.8	2.4	0.8	1.1	0.9	0.3	2.9	-	-	-	-	-	-	-	-	-
14/9		5.0	7.4		0.3	1.4		0.4	1.3		0.6	1.5		1.0	4.0		-	-		-	-		-	-
18/9		5.2	8.8		0.2	1.1		0.4	1.7		0.6	1.6		1.0	3.2		-	-		-	-		-	-

of the two areas. Greater iron outflows may occur in the first year after drain installation due to loose backfill. Further analyses in subsequent wet seasons should elucidate this matter.

In spite of the liming that was carried out, the Calcium and Magnesium content from the fertilised and cultivated areas were not much greater than those from field 3 during the early part of the season. Actually the quantities of these elements were greater in field 3 during the later sampling sessions. This indicated that the majority of the applied limestone had remained in the soil.

The Ammonia-Nitrogen content in field 2 seemed to have been increased after the application of liquid manure to the field during the month of August. There was an even bigger increase in Potassium content in field 1 after manure application. The Potassium increase in field 2 was not as large as in field 1. The content of the nutrient returned to pre-irrigation levels after rains. It appears probable that the increases in Ammonia-Nitrogen and Potassium, in the drain outflows after manure irrigation, were largely due to short distance seepage of manure components through the loose backfill directly over the subsurface drains. There was not much variation in the Potassium levels in field 3.

The relative order of nutrient loss (Ca > Mg > K) that was reported by Bolton et al (1970) was not obtained consistently in the samples that were analysed. In the majority of cases the reversed order, i.e. K > Mg > Ca was measured. This was evident both in the cultivated and non-cultivated areas.

There are two main reasons why the chemical analysis of drain water is important, these are (1) the removal of nutrients that could be used by the plants could lead to deficiencies of certain nutrients in the long run, and (2) the passage of nutrients into the collecting watercourse could lead to excessive eutrophication of downstream water which could in turn lead to the prolification of algae and other plant life to undesirable proportions. The quantities measured indicates that there seems to be no imminent danger as far as either potential problem is concerned. The quantities of chemical elements in the subsurface drain outflows is much less than the quantities reaching the watercourses from overland flow.

CHAPTER X

SUMMARY AND CONCLUSIONS

Some of the major physical, chemical and biological factors associated with the subsurface drainage system were probed during the evaluation. A study of the physical aspects was important since they are needed in the establishment of drainage criteria for the SFC and other areas in Trinidad and Tobago. The biological aspects were important since yield for profitable production is the most influential statistic in the determination of the economic viability of a drainage system. The chemical aspects were important because of the need to know what elements are passing out of the soil in the subsurface drainage water into the murky watercourses.

An in-depth economic analysis was not carried out as it was considered to be outside of the scope of this work. However, because of its overriding importance in drainage design, economic factors have been considered throughout the text.

The physical investigations indicated that the drains were functioning as well as could be expected for this soil. Drainable water was being removed from the soil profile relatively quickly. Generally the water table in the subsurface drained areas was lowered much faster than that in the non-subsurface drained area. The rate of lowering of the water in the subsurface drained areas, during the first 24 hours after rainfall, compared favourably with the drainage criterion of 30 cm that was suggested by Kidder and Lytle (1949). Therefore, if saturation of the root zone is the limiting factor, it would be possible to grow a larger variety of crops in the area, during the rainy season, with little risk of crop losses due to prolonged inundation. This possibility of crop diversification during the rainy season is one of the most important advantages of the subsurface drains at the SFC.

Peak drain outflow rates were greater in the rainy season of 1979 than during the rainy season of 1978. The outflow rates during both seasons was less than the Netherlands criterion for arable land of 7 mm per day at a water table height of 60 cm above the drains. However, they compared favourably to drainage coefficients suggested independently by Schwab et al (1966) and Cheing, et al (1978). More reliable drainage criteria for Trinidad and Tobago conditions will only be established after subsurface drainage systems have been installed on several farms with different soil conditions and many more field observations have been made. The increase in the 1979 outflow rates over the 1978 rates was probably due to the "opening up" of new pathways to the drains as a result of the action of the wetting and drying process on the soil profile. Tillage prior to planting in late 1978 could have also caused some of the differences. This increasing trend should continue for at least one or two more years after which the rates should "level off" or even be reduced in magnitude. This leveling off will be due to the settling and compaction of the loose backfill over the drains. The loose backfill induced higher outflow rates by conducting some of the water directly to the drains from the high hydraulic conductivity plough zone, rather than through the undisturbed subsoil.

Both the field and laboratory measurements indicated that there was much variability in the soils of the area. Variations were not uniform but were randomly distributed throughout the fields. These soil variations in this and similar areas will pose problems for designers when making designs based on the steady state and falling water table theories since these variations will have to be accounted for. Wherever possible data obtained from field measurements rather than laboratory determinations should be used in designing subsurface drains for areas such as these.

As regards hydraulic conductivity measurements, the mean of several determinations should be used. The number of determinations that will be needed for design purposes will depend on the uniformity of the soil profile below the water table. Higher hydraulic conductivity values were obtained from field 1 by the drain line method than by the Auger hole method. In field 2 the auger hole measurements were higher. The values from drain line method should be preferred to those from the Auger hole method when designing because they represent what is taking place in the entire soil profile.

Field values of drainable porosity were typically lower than those measured in the laboratory. Thus if laboratory values of drainable porosity are to be used in design work they should be applied with caution.

It appears that the best drainage criteria for the soils at the SFC would be those based on the agronomic requirements of the major crop under cultivation. This conclusion was based on both the quantitative and qualitative observations which indicated that the surface layers of the soil dried up very quickly in those areas where subsurface drains were installed. Crops differ in their abilities to tolerate inundation. Thus in order to design for optimum water table conditions, it is at least necessary to know the requirements of the crop species, soil characteristics, watering procedure and climatic conditions. Therefore designs based on the requirements of one crop would not necessarily be applicable to other crops. Since crop diversification may be desired at the SFC and other areas, designs should not be based on crops with extreme tolerance to soil water conditions. For example, the tomato plant has very low tolerance to very wet and very dry conditions, while sugarcane has very high tolerance to both these conditions; crops like these should not be used as the basis of design.

Trafficability could also be a useful drainage criteria especially for ventures such as the SFC where harvesting is desired throughout the year. The soils at the SFC are ideal for trafficability criteria since their low drainable porosities greatly reduces the risk of overdrainage. On the other hand it was observed that even in the fields that were subsurface drained at the SFC, the soil was unable to support traffic of common tractors and trailers for periods of up to 3 days after the drainable water was removed. However, the bearing strength increased rapidly as the soil dried to water contents less than field capacity. The very low bearing strength and relatively soft consistency, at moisture contents of about field capacity, were due to the very fine texture of the soil. Designing for trafficability would therefore normally result in closer drain spacings than designing for minimum crop requirements. Closer spacing will require a higher capital outlay. This and other economic and mechanical factors should be carefully considered when deciding on drainage criteria for the SFC and other areas.

It was almost impossible to accurately separate the sources of biological response during the first season of production. This was due to the varying land use before the establishment of the SFC and the limitations of statistical designs that were possible under the conditions. Thus although the mean millable stalk yield from the subsurface drained area (November harvest) was 52 per cent more than that in the non-subsurface drained area, one could not conclusively say that these higher yields were due solely to the subsurface drains. Therefore at this stage the prospects of higher sugarcane yields due to subsurface drainage could best be described as promising. Further monitoring of the yields is imperative for additional evaluation of the subsurface drainage system. Another very important biological factor in the final evaluation would be the longevity of the stands. This will depend on the quality and quantity of subsequent ratoons. If the subsurface drains could significantly contribute to the production of an extra ratoon in commercial quantities, that would be another major benefit of the system at the SFC.

Investigations of the rooting system of the sugarcane plants revealed that there were no major differences in root penetration, at the depths and distances probed, between the subsurface drained areas and the non-subsurface drained areas. It was concluded that one season's growth under subsurface drain conditions is probably insufficient to give conclusive results of the effect of subsurface drains on sugarcane rooting systems. Studies of roots at greater depths are recommended if similar measurements are to be carried out in the future.

The quantities of the chemicals emanating from the subsurface drains were generally very small and did not pose any immediate danger to the environment. The quantities of iron, however, were large enough to encourage the deposition of substantial amounts of iron ochre at the drain outlets. Ochre accumulated when the drain outflow was reduced to a trickle. These deposits were either washed off by subsequent heavy drain outflow or they shrank into a thin skin when a prolonged dry period followed. Since very little progress has been made in the prevention or reduction of this ochre phenomenon, the hot humid conditions at the SFC may be ideal for further research providing that the ochre continues to be deposited in large quantities.

Better maintenance of the subsurface drainage system outlets is needed. In areas where the outflows from individual drains are not being studied and in subsequent commercial systems, the flow from several laterals should be collected into one main line with a single outlet. This will reduce the number of outlets needing maintenance. Better maintenance will ensure longer drain life and the continuation of investigations into the economic feasibility of subsurface drainage under Trinidad and Tobago conditions. Regardless of whether or not the subsurface drainage system at the SFC eventually proves to be economical for commercial crop production, its values as an experimental and demonstration unit are immense. Thus its implications are valuable not only for the SFC but for Trinidad and Tobago agriculture in general. Therefore it is well worth the money and the effort that was put into its installation. Its worth will be even greater if it is maintained in prime condition for a long time.

CHAPTER XI

RECOMMENDATIONS FOR FURTHER RESEARCH

Based on this study it is suggested that the following investigations into subsurface drainage in Trinidad and Tobago will be beneficial.

1. Monitoring of water table heights and drainage outflow rates using continuous recording equipment (where possible) under different crop and soil conditions. This should be undertaken in conjunction with the collection of on site meteorological data of evapotranspiration rates, temperature and rainfall. The pool of data obtained could be used to develop a water balance model. Such a model will serve as a better guide in the selection of drainage criteria, for the design of subsurface drainage systems in Trinidad and Tobago, than criteria which have been developed elsewhere.

2. Attempts should be made to more accurately relate laboratory determinations of drainable porosity with values obtained from field measurements. This will be of great value in subsequent designing of subsurface drains since in most cases only laboratory data are available at this phase. Similarly, the development of dependable relationships between Auger hole hydraulic conductivity values and drain line determinations will be beneficial.

3. Field and laboratory investigations into the nature, formation and control of iron sludges in subsurface drains will help in the reduction of clogging of drain and filter openings.

4. Experiments should be set up with adequate replication to

determine the effects of subsurface drainage on yields of vegetables, sugarcane, maize and other crops and the feasibility of subsurface drainage installations in Trinidad and Tobago.

5. The operation of farm machinery during the rainy season is presently very limited by field conditions. It is also potentially very damaging to soil structure. Studies to establish the extent of improvements (if any) of soil trafficability and the limits for machinery operation in subsurface drained fields, will provide useful information for decision makers.

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APPENDIX FIGURES

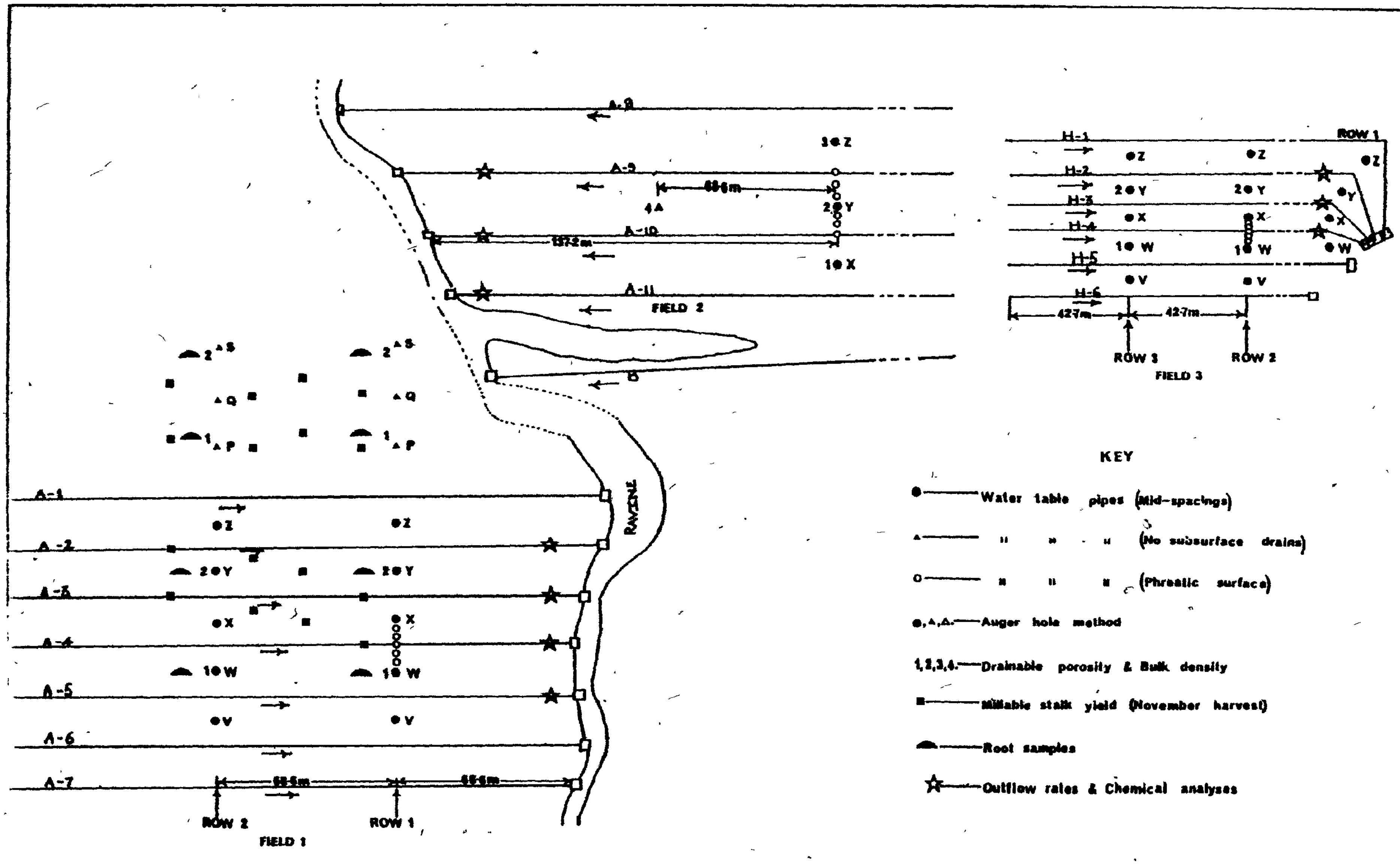

Figure A1. Location of various measurements.

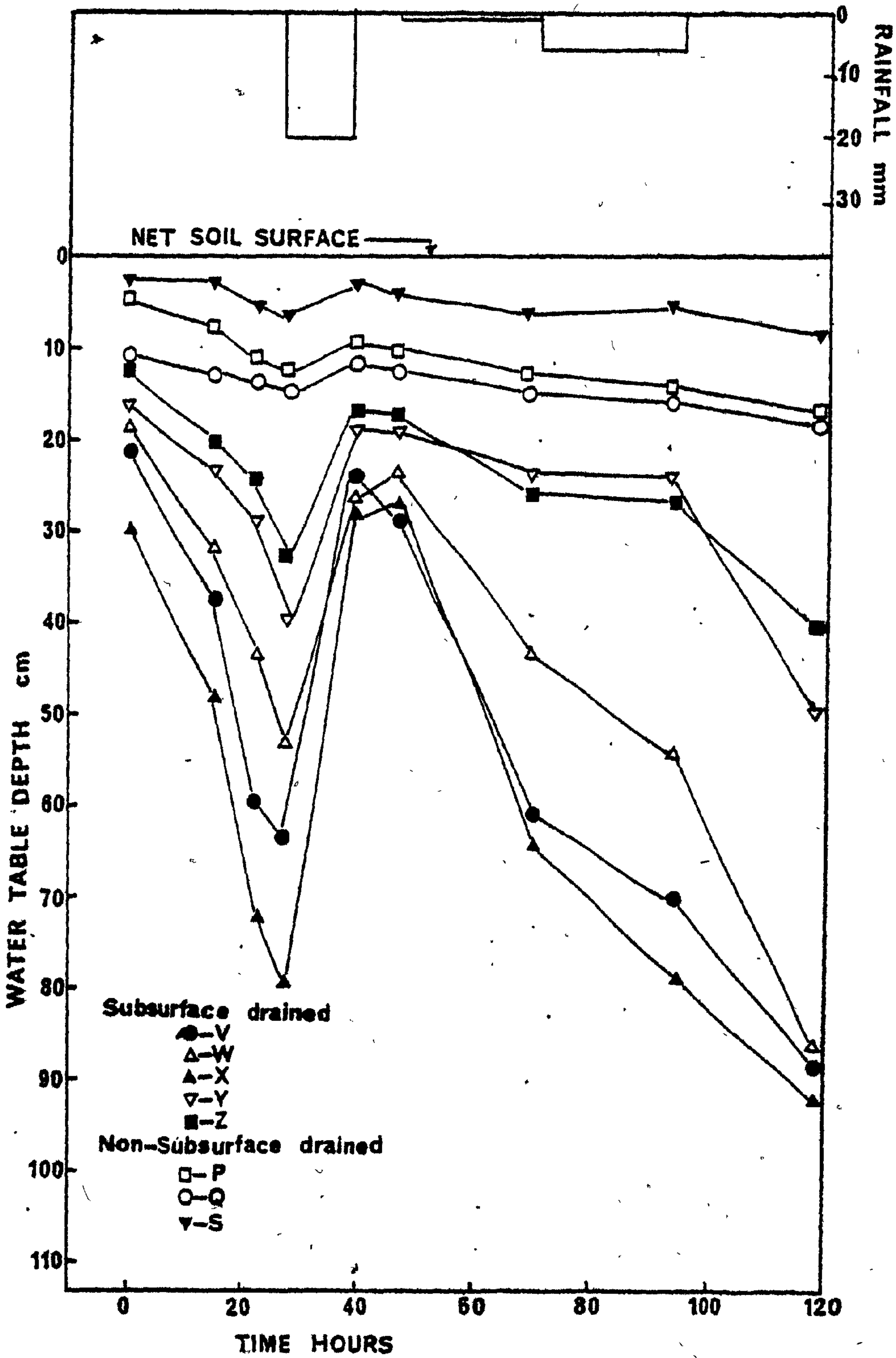

Figure A2. Water table depths at mid-spacing and in non-subsurface drained areas vs time after first reading, Field 1. Data points represent the mean of two rows. Event No. 1, readings started at 1500 hrs on 790910.

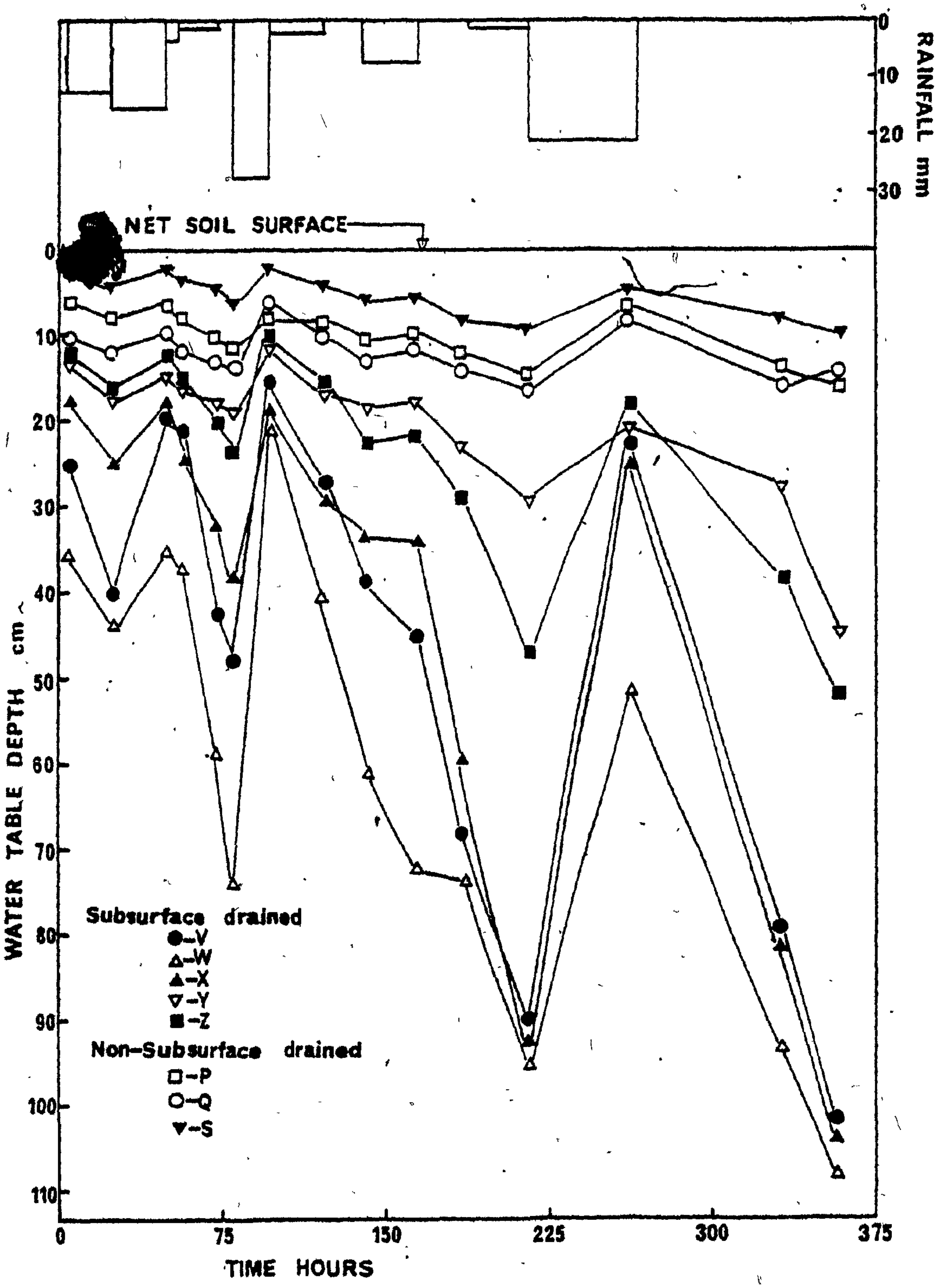

Figure A3. Water table depths at mid-spacing and in non-subsurface drained areas vs time after first reading, Field 1. Data points represent the mean of two rows. Event No. 2, readings started at 1030 hrs on 791202.

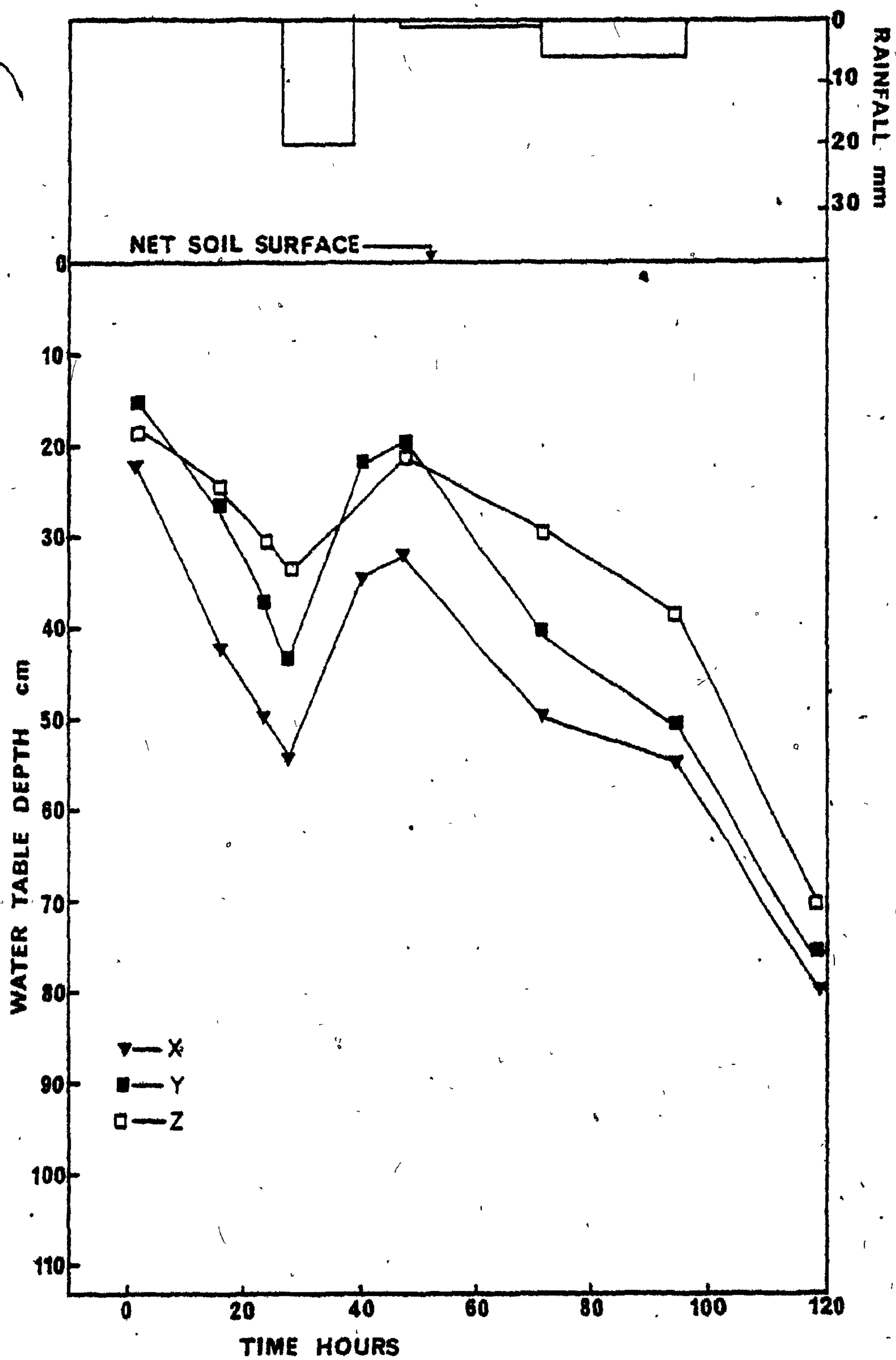

Figure A4. Water table depths at mid-spacing vs time after first reading, Field 2. Event No. 1, readings started at 1500 hrs on 790910.

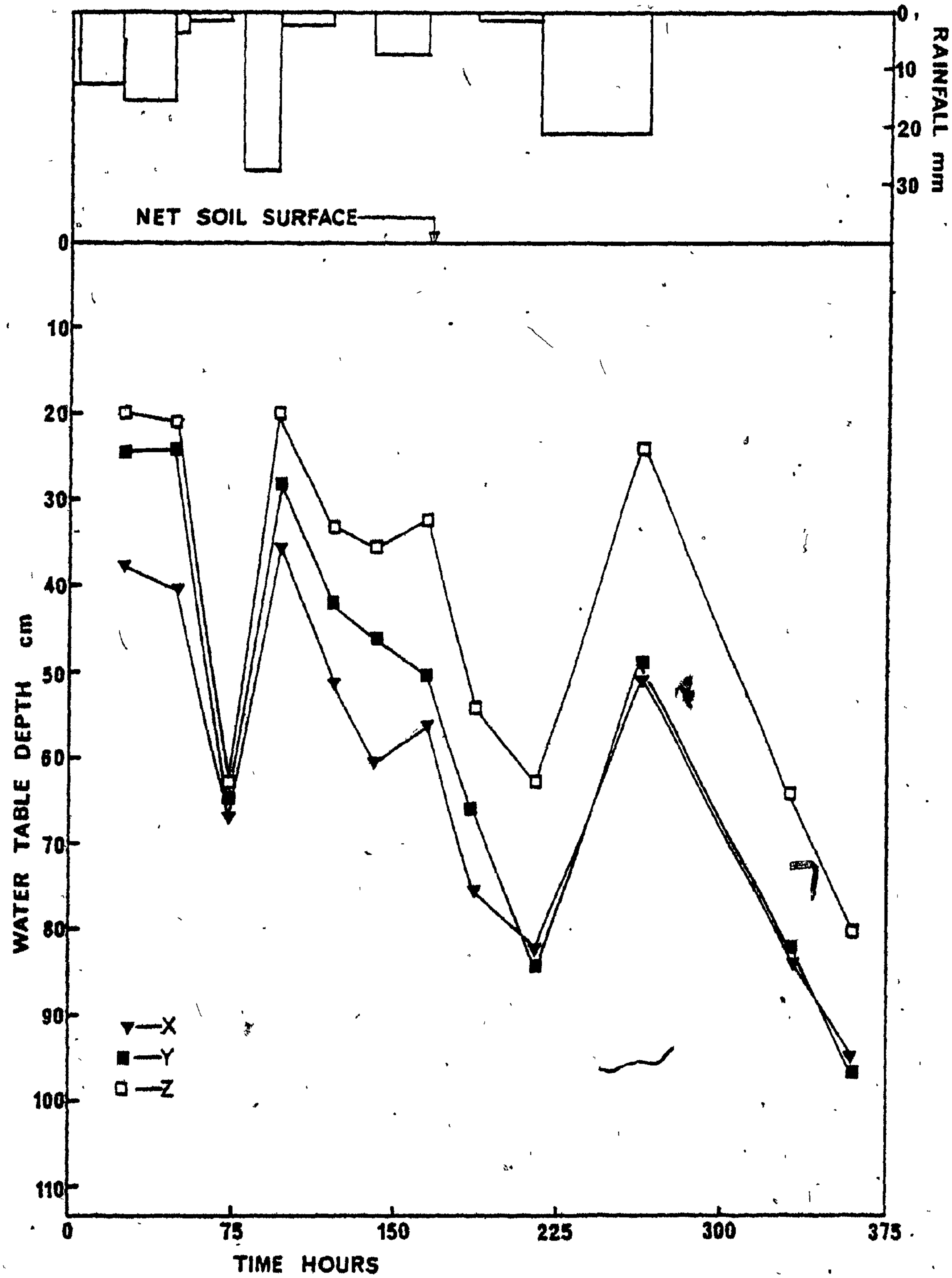

Figure A5. Water table depths at mid-spacing vs time after first reading, Field 2. Event No. 2, readings started at 1030 hrs on 791202.

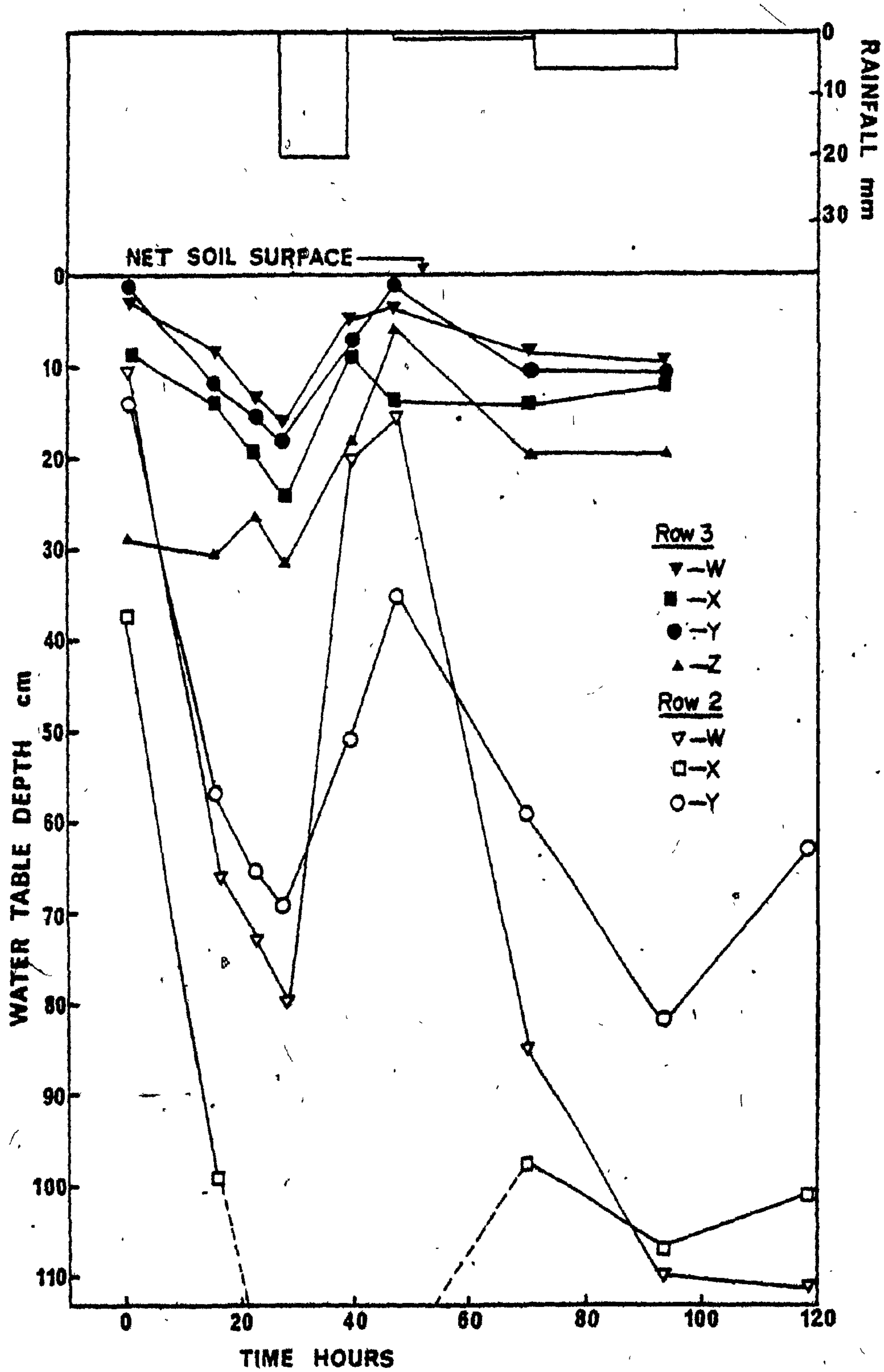

Figure A6. Water table depths at mid-spacing vs time after first reading, Field 3. Event No. 1, readings started at 1500 hrs on 790910.

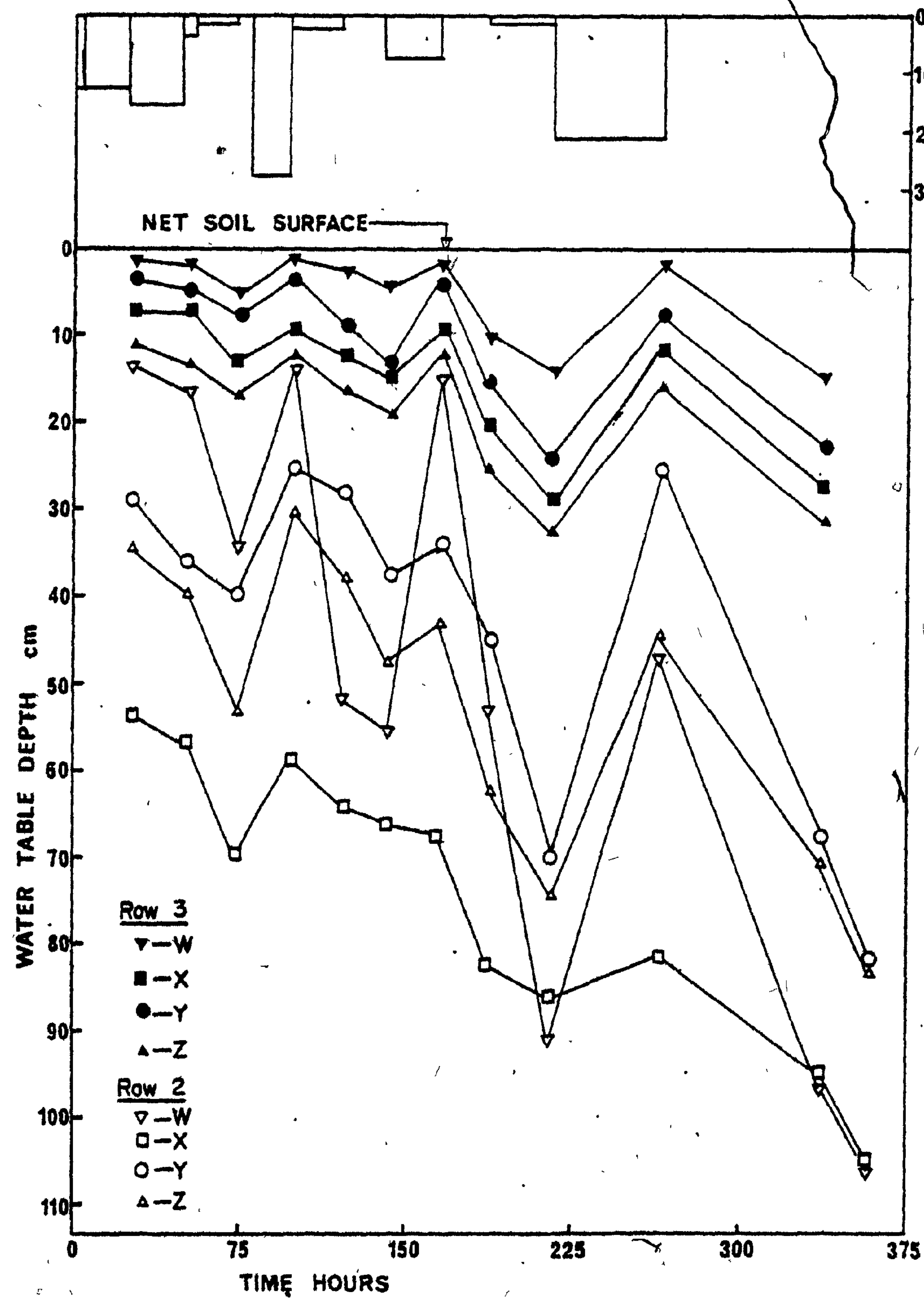

Figure A7. Water table depths at mid-spacing vs time after first reading, Field 3. Event No. 2, readings started at 1030 hrs on 791202.

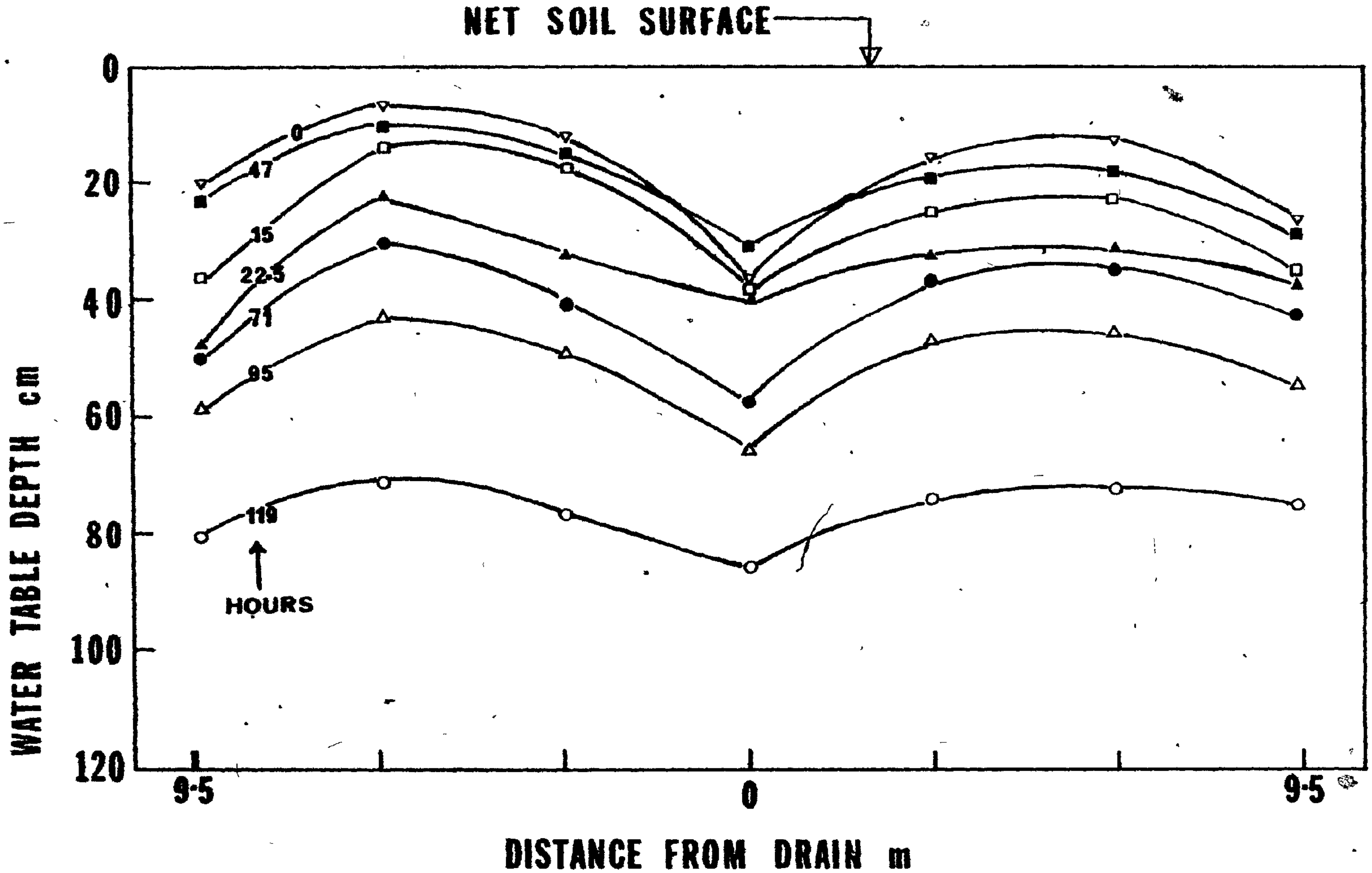

Figure A8. Depth of water table vs distance from drain A_4 at times in hours (after first reading) shown. Event 1, readings started at 1500 hrs on 790910. Water table pipes located equidistantly between the mid-spacing of drains A_5 and A_4 and the mid-spacing of drains A_4 and A_3 in Row 1, Field 1.

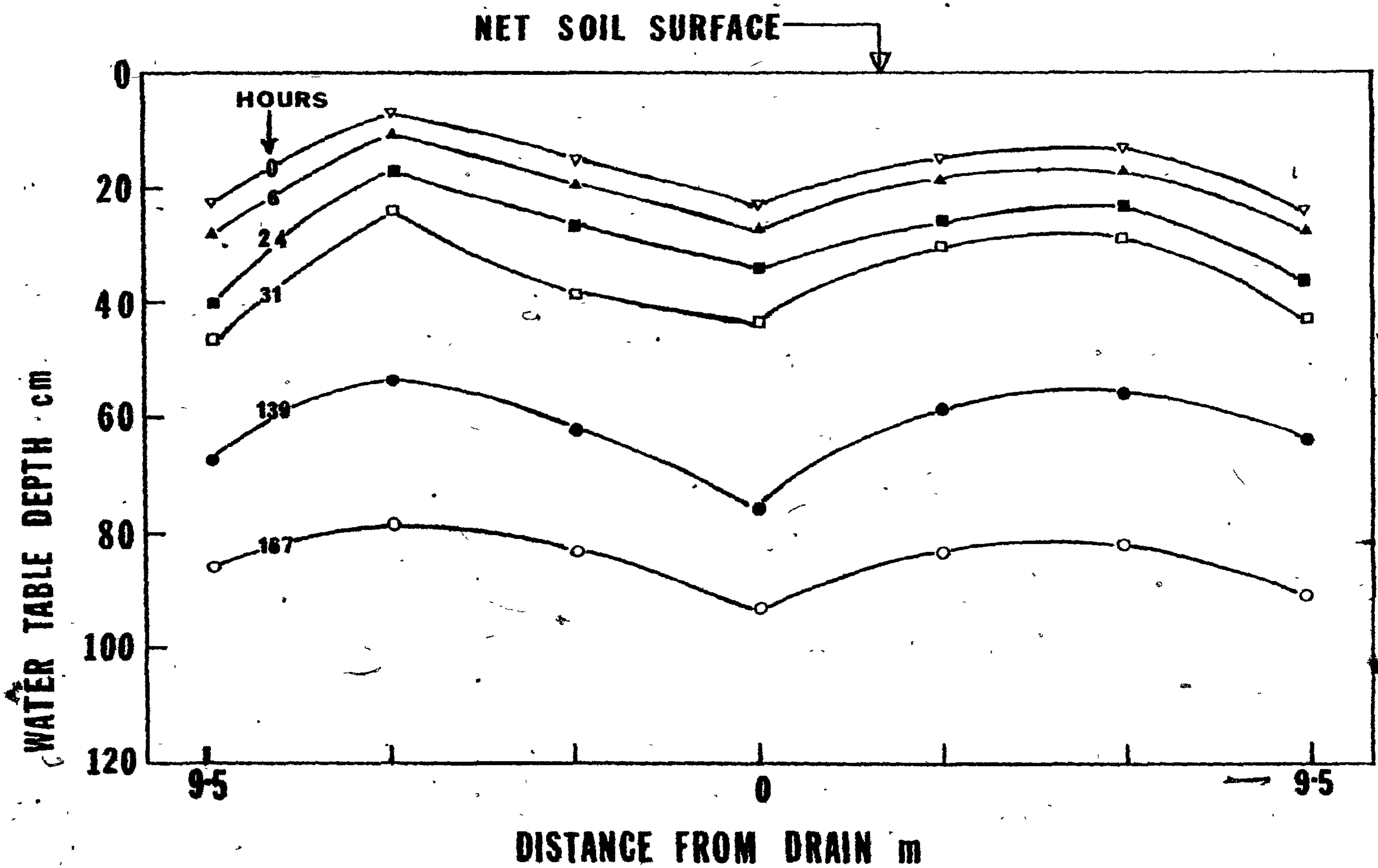

Figure A9. Depth of water table vs distance from drain A_4 at times in hours (after first reading) shown. Event 2, readings started at 1130 hrs on 791204. Water table pipes located equidistantly between the mid-spacing of drains A_5 and A_4 and the mid-spacing of drains A_4 and A_3 in Row 1, Field 1.

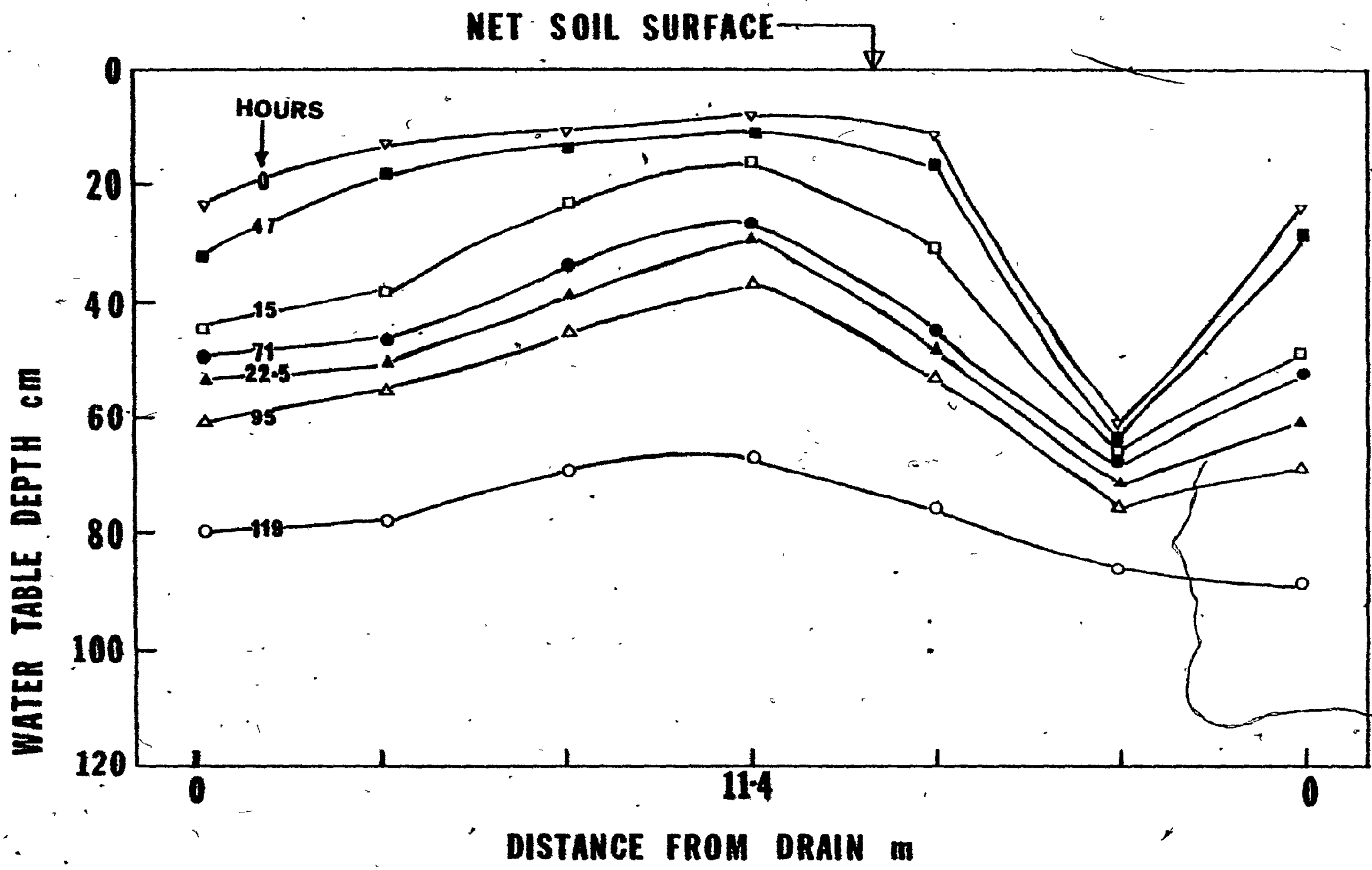

Figure A10. Depth of water table vs distance from drains A_9 (right) and A_{10} (left) at times in hours (after first reading) shown. Event 1, readings started at 1500 hrs on 790910. Water table pipes equidistantly placed between drains A_9 and A_{10} in Field 2.

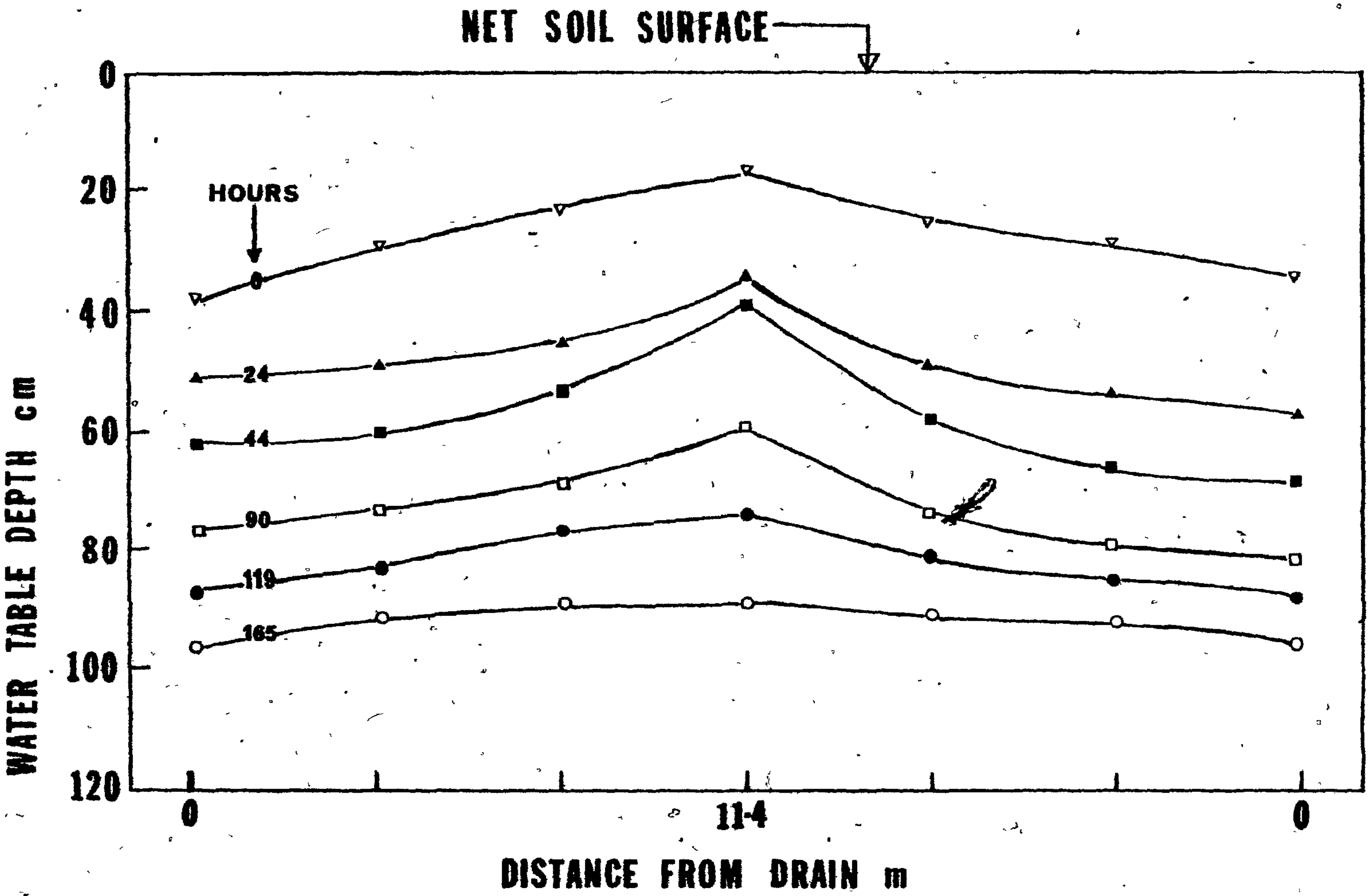

Figure A11. Depth of water table vs distance from drains A_9 (right) and A_{10} (left) at times in hours (after first reading) shown. Event 2, readings started at 1200 hrs on 791206. Water table pipes equidistantly placed between drains A_9 and A_{10} in Field 2.

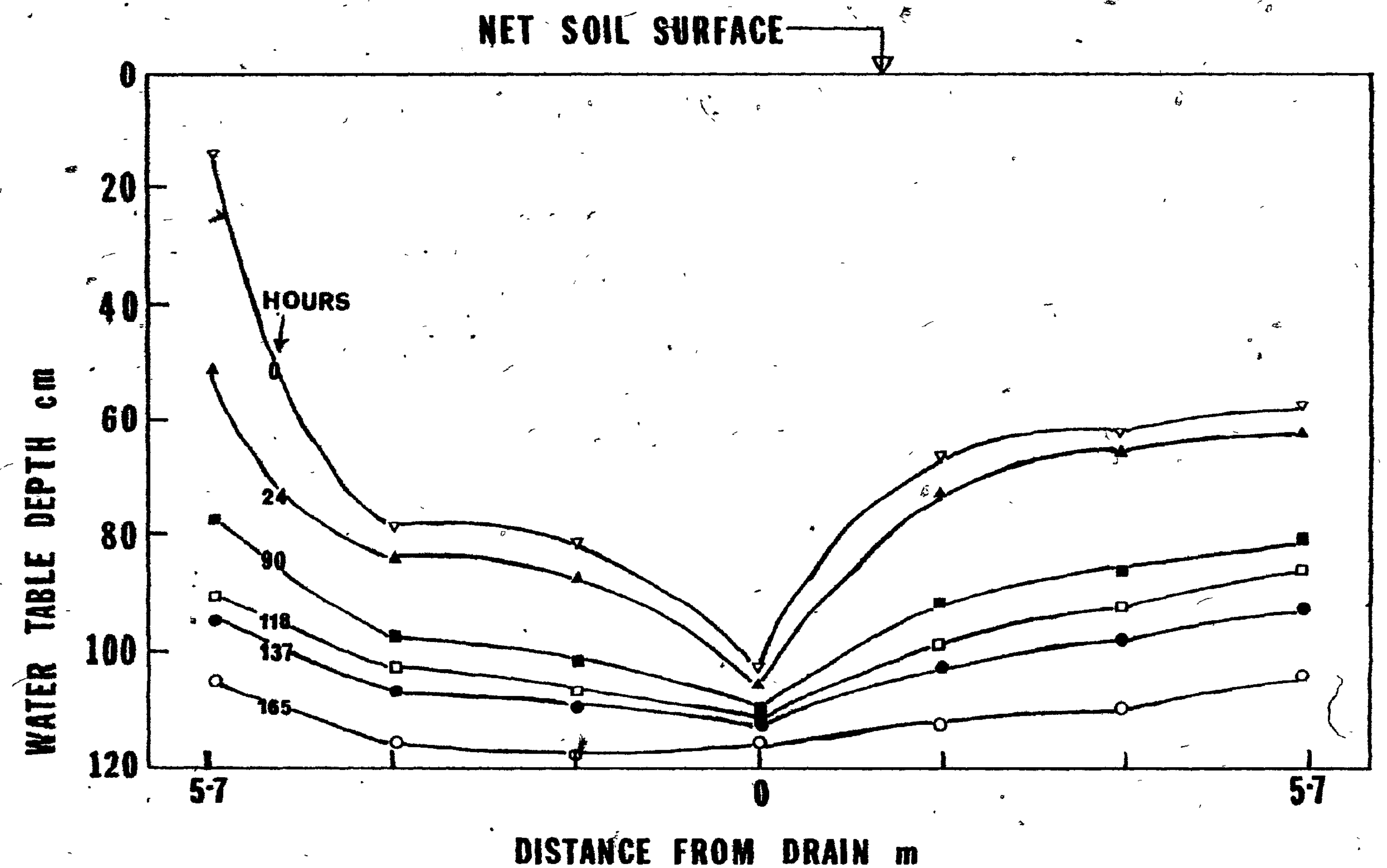

Figure A12 Depth of water table vs distance from drain H_4 at times in hours (after first reading) shown. Event 2, reading started at 1200 hrs on 791206. Water table pipes equidistantly placed between the mid-spacing of drains H_5 and H_4 and the mid-spacing of drains H_4 and H_3 in Row 2, Field 3.

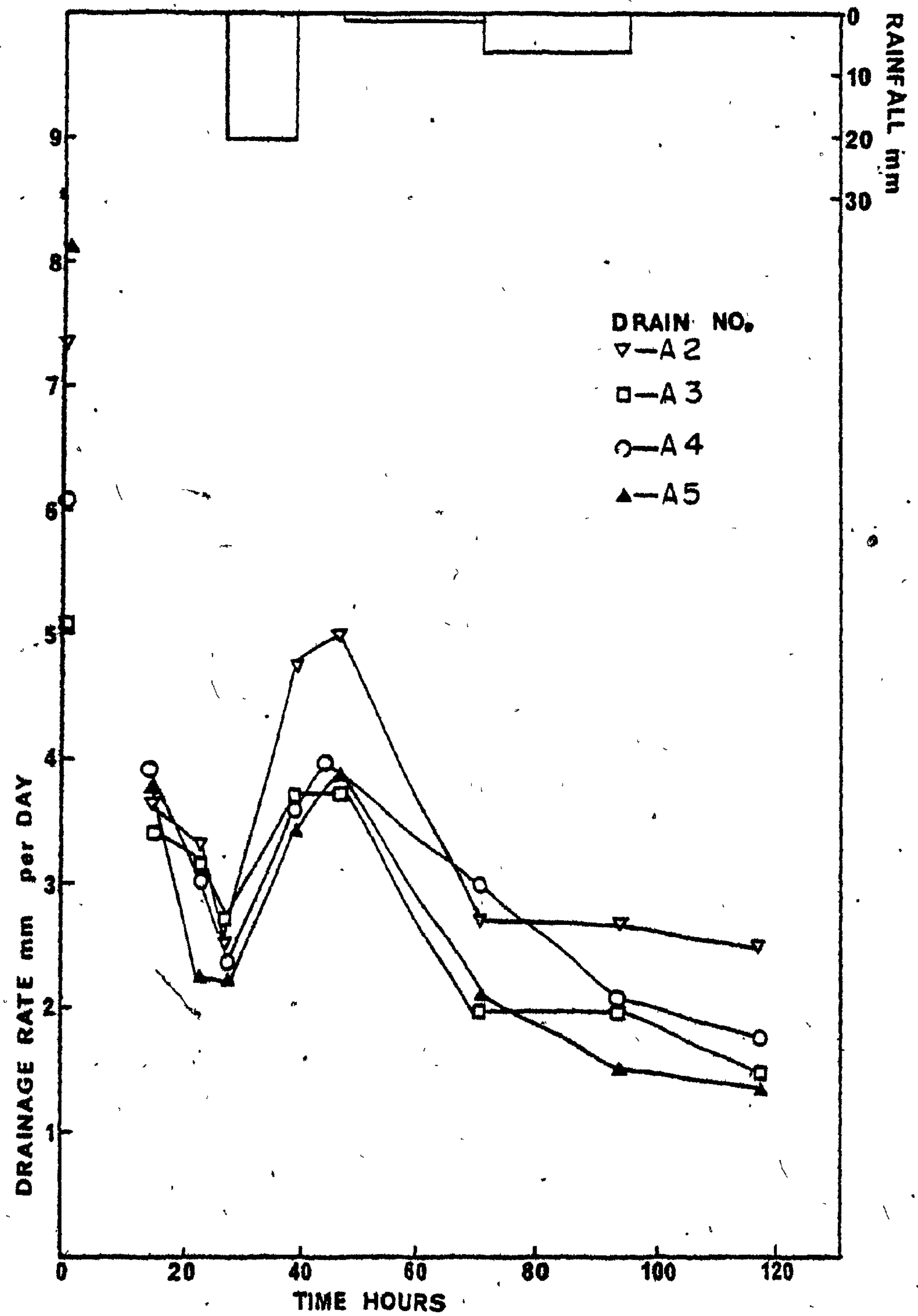

Figure A13. Drain outflow rates from field 1 vs time after first reading. Event 1, readings started at 1500 hrs on 790910.

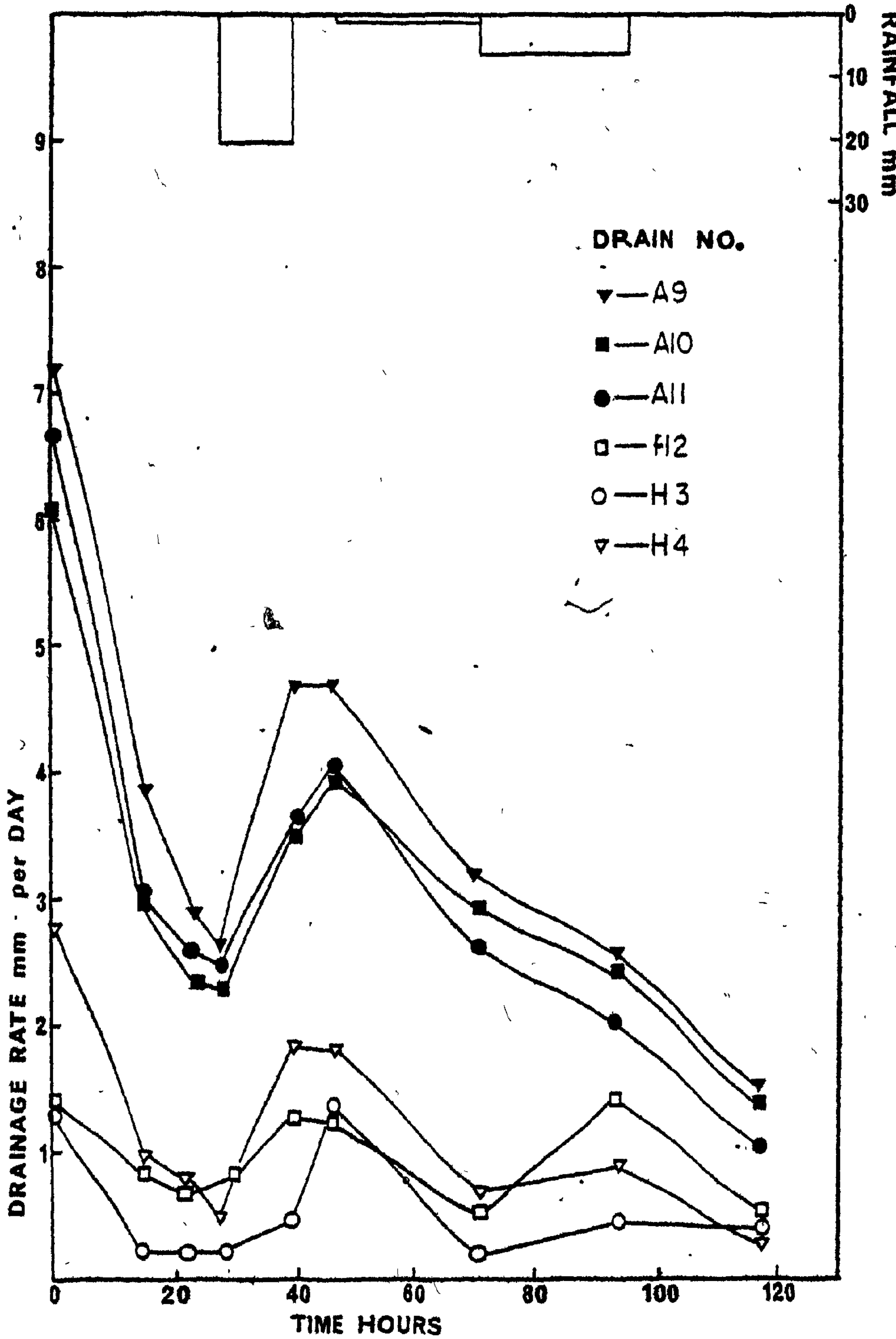

Figure A14. Drain outflow rates from fields 2 and 3 vs time after first reading. Event 1, readings started at 1500 hrs on 790910.

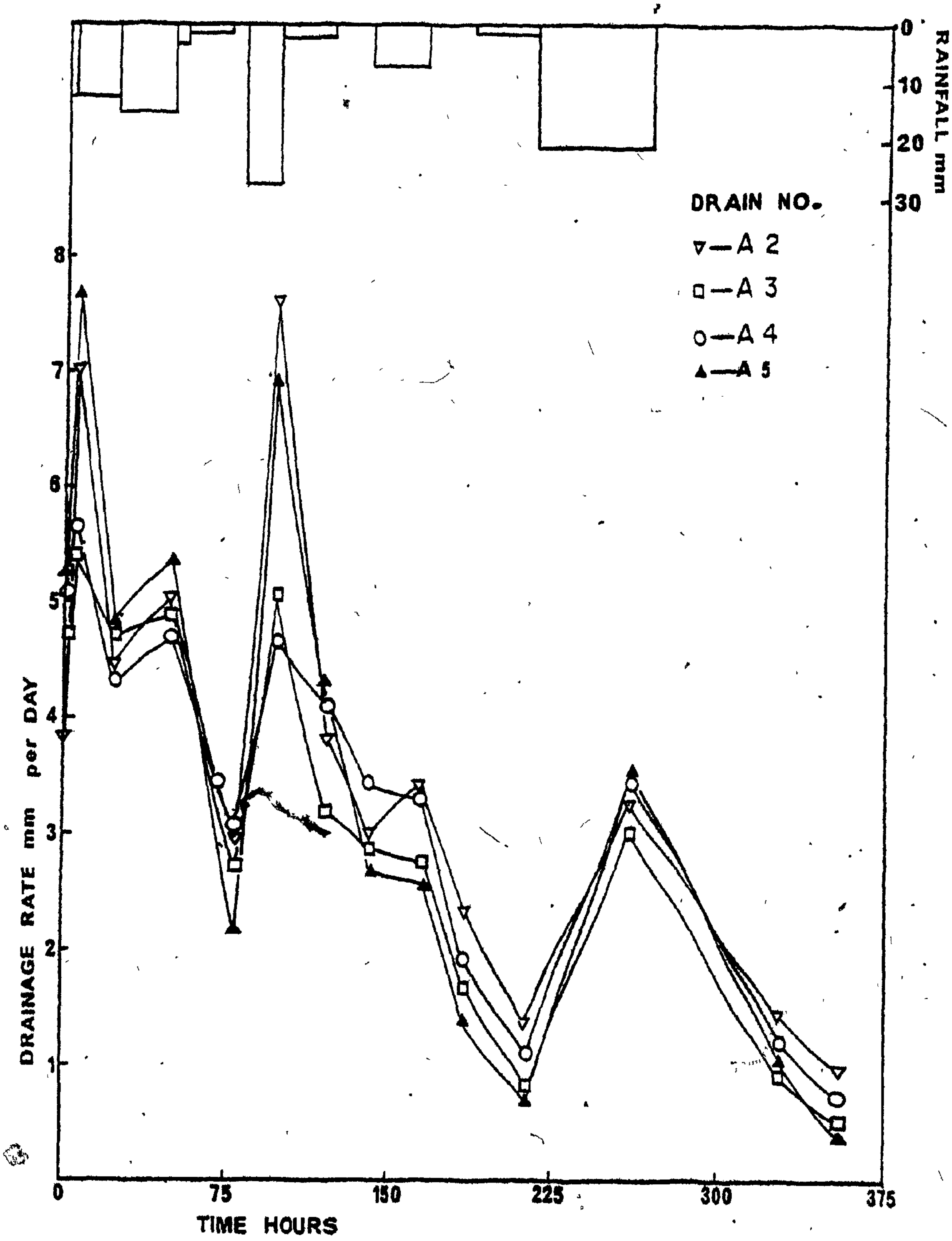

Figure A15. Drain outflow rates from field 1 vs time after first reading. Event 2, readings started at 1030 hrs on 791202.

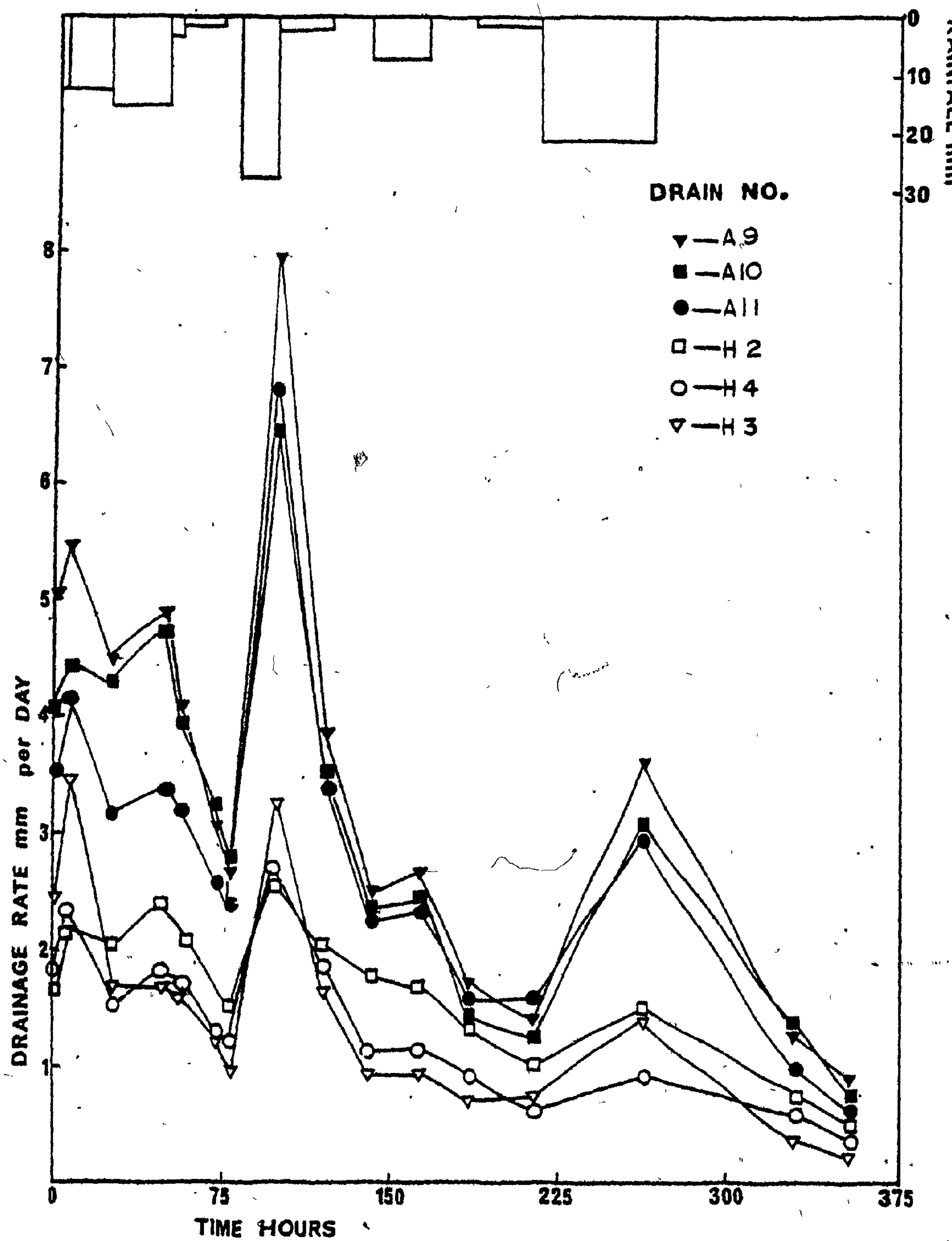

Figure A16. Drain outflow rates from fields 2 and 3 vs time after first reading. Event 2, readings started at 1030 hrs on 791202.

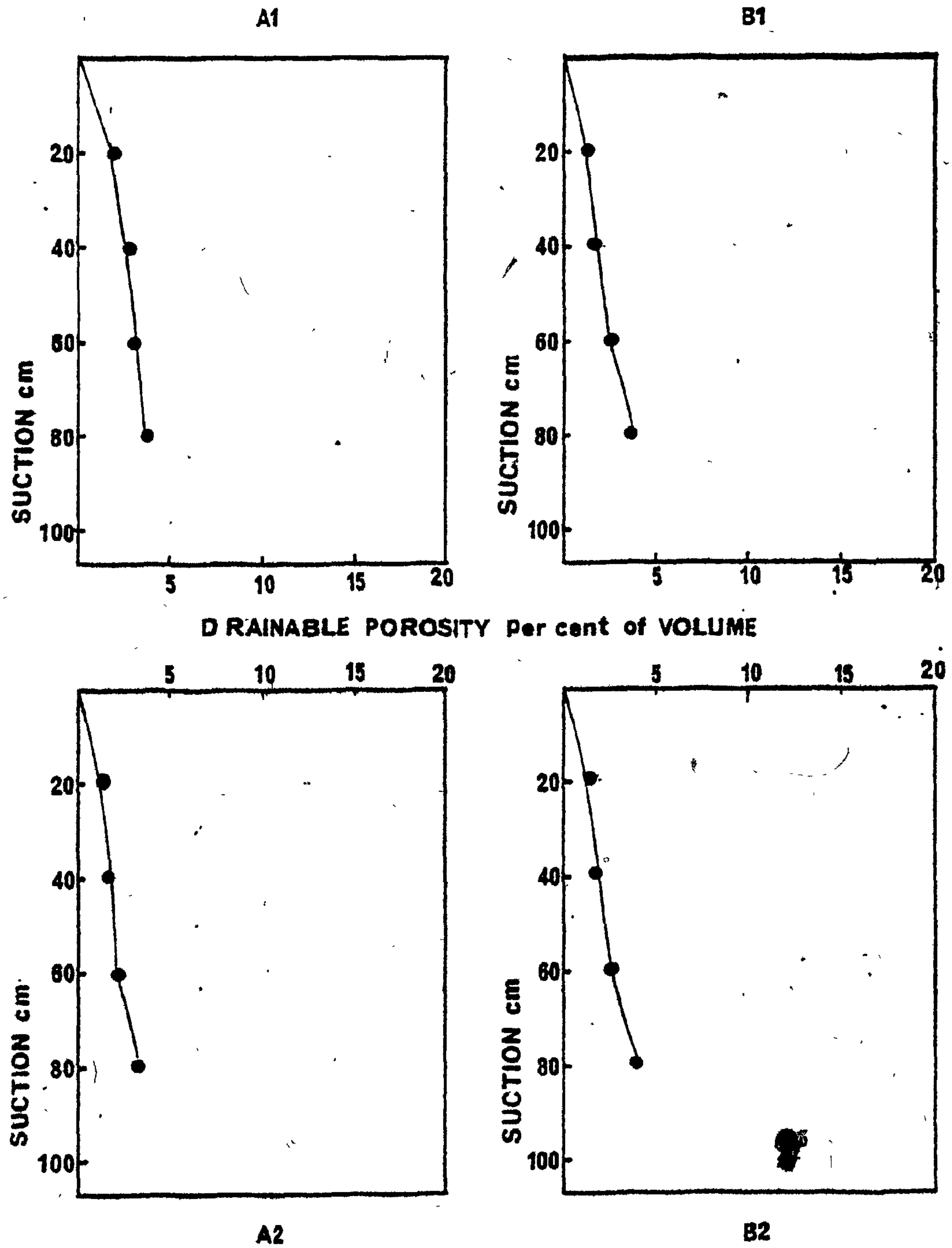

Figure A17. Mean Drainable porosity vs Suction. A_1 and B_1 represent values from field 1 subsurface drained and field 1 non-subsurface drained respectively, at sample depths of 30 cm below soil surface. A_2 and B_2 represent values from the same areas at sample depths of 60 cm below soil surface.

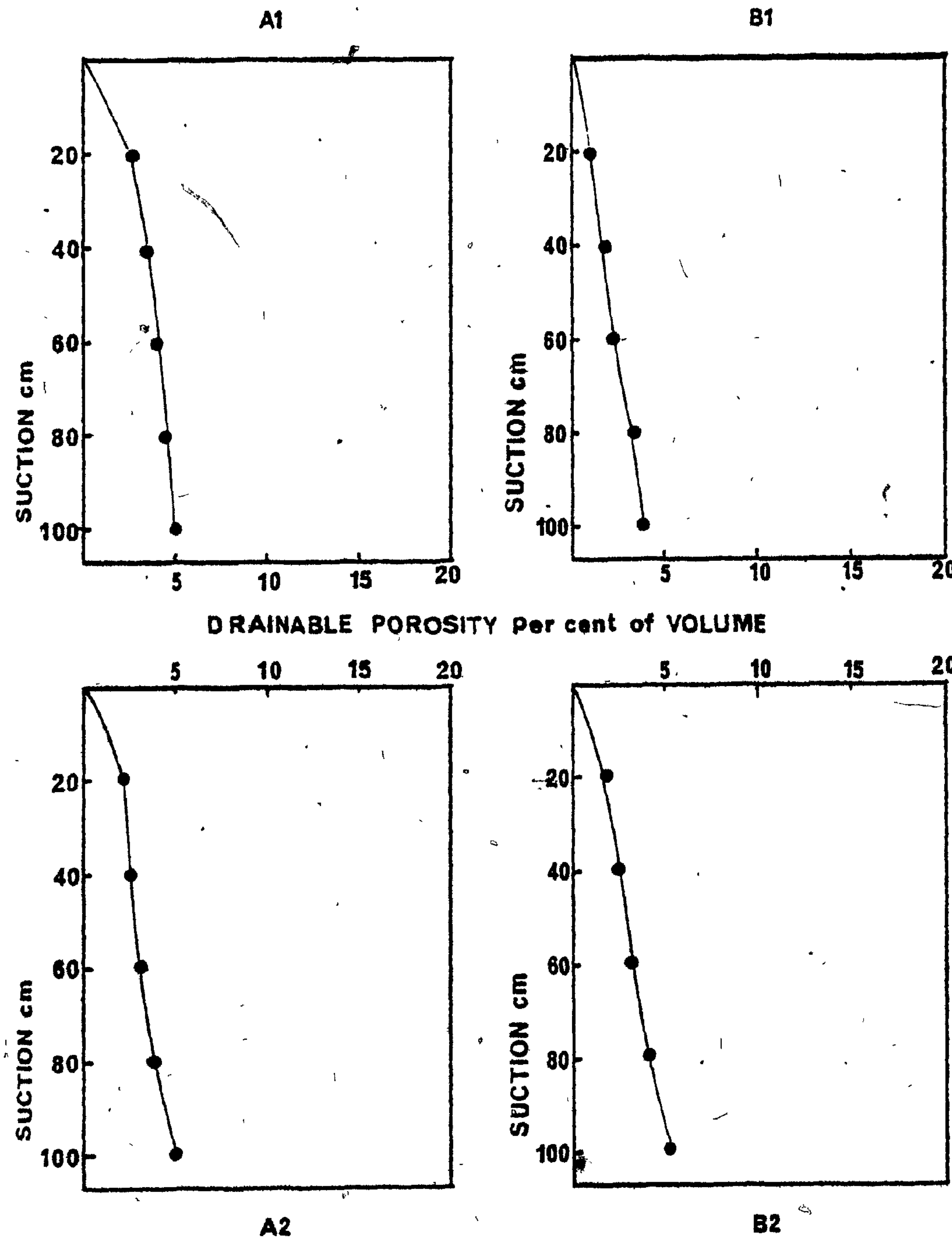

Figure A18. Mean Drainable porosity vs Suction. A_1 and B_1 represent values from fields 2 and 3 respectively, at sample depths of 30 cm below soil surface. A_2 and B_2 represent values from the same fields at sample depths of 60 cm below soil surface.

APPENDIX TABLES

TABLE B1. BULK DENSITIES AT SFC.

Field	Row	Sample depth cm	Bulk Density gm/cc Position 1	2	3	4	Mean	Std. Dev.[y]	C.V.[z] %
1-DR[w]	1	30	1.73	1.60			1.67	.054	3.23
1-DR	2	30	1.65	1.68					
1-DR[w]	1	60	1.40	1.61			1.60	.140	8.75
1-DR	2	60	1.73	1.64					
1-UDR[x]	1	30	1.73	1.65			1.67	.061	3.65
1-UDR	2	30	1.70	1.59					
1-UDR	1	60	1.68	1.64			1.62	.052	3.21
1-UDR	2	60	1.56	1.60					
2		30	1.61	1.50	1.65	1.57	1.58	.064	4.05
2		60	1.66	1.64	1.63	1.49	1.61	.078	4.84
3	2	30	1.71	1.56			1.64	.115	7.01
3	3	30	1.77	1.53					
3	2	60	1.66	1.60			1.60	.042	2.63
3	3	60	1.59	1.56					

[w] DR - Subsurface Drained

[x] UDR - Non-subsurface Drained

[y] Std. Dev. - Standard Deviation

[z] C.V. - Coefficient of Variability

TABLE B2. ESTIMATED DRAINABLE POROSITIES - LABORATORY METHOD.

	Drainable Porosity - per cent drained															
Sample depth	30-cm															
Field	1-DR[w]		1-DR		1-UDR[x]		1-UDR		2				3			
Row	1		2		1		2						2		3	
Position	1	2	1	2	1	2	1	2	1	2	3	4	1	2	1	2
Suction - cm																
20	1.14	1.80	1.98	2.16	1.44	0.96	1.86	1.80	2.10	2.16	2.52	2.46	1.32	1.62	1.14	2.16
40	1.32	2.28	2.46	2.46	1.86	1.02	2.22	2.02	2.76	3.00	3.36	3.06	1.92	3.00	1.34	3.42
60	2.30	2.34	2.80	2.88	2.00	1.90	2.94	2.30	3.18	3.54	3.66	3.30	2.46	3.60	1.38	4.02
80	3.20	3.00	3.22	3.73	2.42	3.21	4.06	3.01	3.90	4.20	4.08	3.66	3.36	5.46	1.38	4.86
100									4.38	5.16	4.62	4.20	4.26	6.30	1.39	5.46
Sample depth	60-cm															
Suction - cm																
20	1.26	0.84	1.80	1.26	1.50	1.44	1.80	1.74	1.92	1.32	2.28	2.76	1.92	1.74	1.20	1.80
40	1.32	0.96	2.16	1.50	1.62	1.56	1.92	2.16	2.46	2.10	3.12	3.36	2.76	2.40	1.62	2.34
60	2.00	2.20	3.09	1.62	1.68	2.60	3.26	2.59	2.94	2.52	3.66	3.78	3.66	3.00	1.92	2.94
80	3.55	3.34	3.51	2.46	2.01	3.50	4.10	3.43	3.48	3.42	3.90	4.68	5.58	4.62	2.40	3.36
100									3.54	3.60	4.62	8.52	6.18	5.88	2.88	4.14

[w] DR - Subsurface Drained

[x] UDR - Non-subsurface Drained

TABLE B3. DRAINABLE POROSITIES ESTIMATED BY FIELD METHOD (1978) MEASUREMENTS.

Field	Pipe	Watertable at 28 hrs mm	Watertable at 76 hrs mm	Δz mm	q at 28 hrs mm/day	q at 76 hrs mm/day	Δq mm/day	Δq x 2 days mm	f = Δq x 2 days / Δz
1	1	931	1016	85	1.865	0.360	1.505	3.01	0.035
	2	258	568	310	2.635	0.460	2.175	4.35	0.014
	3	220	492	272	3.405	0.630	2.775	5.55	0.020
	4	108	433	325	2.370	0.530	1.840	3.68	0.011
	5	99	344	245	2.320	0.700	1.620	3.24	0.013
	6	61	266	205	1.550	1.145	0.405	0.81	0.004
2	1	322	527	205	4.465	0.585	3.880	7.76	0.038
	2	591	811	220	4.265	0.470	3.795	7.59	0.0345
	3	502	802	300	5.865	0.395	5.470	10.94	0.036

Note: No correction was made for Evapotranspiration Losses in the 1978 determinations.

TABLE B4. DRY WEIGHT (GMS) OF SUGARCANE ROOTS EXTRACTED FROM SOIL CORE SAMPLES.

Distance from Stool	One core diameter				Two core diameters				Three core diameters			
Depth (core lengths)	1	2	3	4	1	2	3	4	1	2	3	4
Stool No.												
1	2.33	1.01	1.27	0.73	1.69	1.14	0.36	0.37	1.53	0.69	0.39	0.51
2												
3	4.60	2.76	1.35	0.61	1.67	0.68	0.24	0.34	0.49	0.93	0.66	0.54
4	2.50	0.66	1.17	1.09	0.69	0.65	0.54	0.42	0.73	0.48	0.22	0.72
$\bar{x}$	3.15	1.48	1.26	0.81	1.35	0.82	0.38	0.38	0.92	0.70	0.42	0.59
5	3.33	3.49	1.40	0.39	1.87	0.99	1.20	0.48	1.36	0.93	0.43	0.63
6	2.37	1.58	0.83	1.31	1.86	1.63	0.55	0.46	1.27	1.03	0.66	0.56
7	5.00	1.12	0.65	0.61	2.69	0.77	0.36	0.55	1.68	0.34	0.45	0.35
8	2.57	0.88	0.68	0.79	4.55	0.42	0.55	0.47	0.87	0.49	0.52	0.51
$\bar{x}$	3.31	1.77	0.89	0.77	2.74	0.95	0.67	0.48	1.30	0.70	0.52	0.52

Note: Length of cores 130 mm.
Diameter of cores 115 mm.
Samples from Stool No. 2 destroyed in a laboratory accident in Canada and could not be replaced.

TABLE B5. DRAINAGE COEFFICIENTS FOR TILE DRAINS IN HUMID REGIONS*.

Crops and degree of Surface drainage	Drainage Coefficient in inches per day	
	Mineral Soil+	Organic Soil
Field Crops		
Normal#	3/8 - 1/2	1/2 - 3/4
With blind inlets	3/8 - 3/4	1/2 - 1
With surface inlets	3/4 - 1	3/4 - 1 1/2
Truck Crops		
Normal#	1/2 - 3/4	3/4 - 1 1/2
With blind inlets	1/2 - 1	3/4 - 2
With surface inlets	1 - 1 1/2	2 - 4

* From Schwab et al. (1966) Pg. 449.

\+ These values may vary depending on special soil and crop conditions. Where available, local recommendations should be followed.

\# Adequate surface drainage with outlets to other drains or ditches to be provided.

1 inch per day equals 25.4 mm per day.

TABLE B6. SOME RECOMMENDED DRAINAGE CRITERIA FOR MINERAL SOILS IN CERTAIN HUMID AREAS.

Crops	Depth and Rate of Drop of the Water Table	Location	References
Field	Initial depth, 15 cm minimum; 30 cm per day through second 15 cm; 21 cm per day through third 15 cm.	Minn. USA	Neal (1934)
Field	Drop from surface to 30 cm in 24 hr and to 53 cm in 48 hr.	Ill. USA	Kidder and Lytle (1949)
Field	Drop 21 cm per day.	Va. USA	Walker (1952)
Grass	Constant depth 50 cm or less.	Netherlands	Wesseling et al (1957)
Arable	Constant depth 90 to >130 cm.	Netherlands	Wesseling et al (1957)

TABLE B7. MONTHLY RAINFALL AND POTENTIAL EVAPOTRANSPIRATION RATES IN MILLIMETRES AT TODD'S ROAD. appromimately 1-1½ miles S.E. of Longdenville, Trinidad. Source - Caroni Limited Weather Station

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total Annual
						RAINFALL							
1969	87.4	28.7	39.9	10.6	53.1	291	186	227	224	169	260	143	1720
1970	114	69.9	36.1	95.1	91.7	320	319	306	263	120	180	168	2083
1971	53.1	24.1	16.8	25.4	117	153	248	259	172	651	256	111	2086
1972	269	33.3	115	115	116	123	247	255	91.2	152	177	112	1805
1973	22.9	37.1	5.08	26.7	27.2	196	229	406	253	297	230	154	1872
1974	103	51.1	64.3	20.6	35.1	104	174	263	155	259	186	162	1577
1975	47.2	48	19.3	37.4	75.7	203	203	289	176	204	289	377	1971
1976	59.9	171	57.2	45.5	77.5	308	294	181	162	146	185	199	1886
1977	50.3	17.0	35.3	20.6	84.3	380	183	323	205	141	105	79.5	1625
1978	24.6	10.4	18.5	14.0	193	249	253	273	167	115	80.5	141	1539
1979	45.2	18.3	29.0	64.0	99.8	346	341	128	250	229	226	253	2030
11 Yr.Av.	79.8	46.2	39.6	43.2	88.1	243	243	264	192	226	198	173	1836
STD. DEV.	69.3	45.0	30.5	34.3	45.5	93.5	56.4	72.9	50.8	153	64.0	82.0	199
						MEAN MONTHLY POTENTIAL EVAPOTRANSPIRATION							
	142	145	147	150	150	127	127	130	132	130	135	137	