PERFORMANCE ANALYSIS OF DIFFERENT SUBSURFACE DRAINAGE MATERIALS INSTALLED IN THE LOWLANDS OF MUMIAS SUGAR COMPANY ESTATE

BY

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DECLARATION

I declare that this thesis is my work and has not been submitted for a degree in any other university.

Kabeu 23/4/96

M.W. Kabeu Date

This thesis has been submitted for examination with my approval as a university supervisor.

23/4/96

Eng. R.K. Muni Date

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LIST OF ABBREVIATIONS

ASAE - American Society of Agricultural Engineers.
ASCE - American Society of Civil Engineers.
B - C - Benefit - Cost (analysis).
BFD - Bagasse Filled Drains.
COEX - Control Experiment.
df - Degrees of freedom.
ICID - International Commission on Irrigation and Drainage.
ICNR - India Committee on National Resources.
ILRI - International Institute for Land Reclamation and Improvement.
ISSCT - International Society of Sugar Cane Technologists.
KSSCT - Kenya Society of Sugar Cane Technologists.
MS - Mean Squares.
MSC - Mumias Sugar Company.
PCD - Porous Concrete Drains.
PDI - Per Day Index.
PO - Percentage of Occurrence.
PPVC - Perforated P.V.C.
QLDSSCT - Queensland Society of Sugar Cane Technologists.
RFFD - Rock Filled French Drains.
SASTA - South African Sugar Technologist's Association.
SEW - Summation of Excess Water.
SS - Sum of Squares.
SSTT - Total Sum of Squares.
TCH - Tonnage of Cane per Hectare.
TESH - Tonnes of Extractable Sugar per Hectare.
TEST - Tonnes of Extractable Sugar per Tonne of cane.

TERSH - Tonnes of Extractable and Recoverable Sugar per Hectare.

TVD - Top Visible Dewlap.

USDA-SCS - United States Department of Agriculture - Soil Conservation Services.

DEDICATION

This manuscript is dedicated to The Work, and to the members who have played and continue to play an important role in my life.

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PERFORMANCE ANALYSIS OF DIFFERENT SUBSURFACE DRAINAGE SYSTEMS IN THE LOWLANDS OF MUMIAS SUGAR COMPANY ESTATE

By:

Margaret W. Kabeu

ABSTRACT

The Mumias Sugar Company (MSC), which is the study area, has a nucleus estate measuring over 3,000 ha. These comprise 2,527 ha of well drained uplands and 870 ha of poorly drained lowlands. The poorly drained lowlands were of interest to this study.

An experimental subsurface drainage system was designed and installed in these lowlands. The experimental set up consisted of different drainage materials applied as five treatments in three replicates. The experimental design used was a randomised complete block design. The treatments applied were perforated PVC pipes, porous concrete drains, loose rock filled French drains, bagasse filled drains and a control, without any drains. The first three drains had been wrapped in polyfelt as a filter material.

This study was carried out with the aim of establishing the overall effectiveness of the drainage materials as far as commercial sugarcane growing is concerned, and thus making recommendations on the material to be adopted for the lowland sugarcane fields. Performance analysis was carried out through the analysis of data collected on water table depths, drain discharge, and crop response data (yields and other crop parameters).

Perforated PVC and porous concrete drains functioned efficiently lowering the water table fast and to relatively low depths (up to 150 cm +). Bagasse filled drains did not perform as well as the PVC or concrete drains, while the performance of the rock filled French drains was relatively poor. Cane yields obtained were good for all treatments, being in most cases higher than the expected yield for the variety (95 - 115 t/ha). Other crop response parameters also had relatively high values. Differences observed in the various cane response data were however not statistically significant. This could be explained by the fact that the experiment

went through a dry spell that occurred in the region shortly after planting. The cane in all treatments thus experienced approximately similar drainage conditions in the initial stages of the crop's establishment. This is also the critical period for sugarcane as far as drainage is concerned.

From the cane and sugar yield stand point, therefore, there appears to be no advantage among the various treatments. This meant that no materials could be justifiably recommended for adoption at this stage. Further monitoring of the experiment was found necessary in order to sample an adequate range of crop / seasonal weather variation interaction.

1 INTRODUCTION

Due to the country's increasing sugar requirements, commercial production of sugarcane has had to extend into the poorly drained areas. Many of these soils, however, can (if they are well drained) be rated among the most productive soils in the world. Maximizing production in these areas would thus require the introduction of drainage works.

The installation of a drainage system aims at lowering the water table and thereby improving rooting conditions for the crop, particularly during the wet season. A much desirable end result is increased sugarcane and sugar production. To achieve these goals, an adequate and properly designed drainage system is required. There is, thus, a need for work aimed at establishing the adequacy of drainage systems for a particular soil and crop, especially where drainage materials are concerned. This can be done through monitoring the performance of installed drainage systems. Little work has been done in this area in developing countries. In Kenya, such work has not been carried out previously.

At the Mumias Sugar Company (MSC), in particular, an experimental subsurface drainage system has been installed in the lowland cane fields of the nucleus estate. The system, which consists of different types of drainage materials, was installed in 1993 with the aim of establishing the most effective drainage materials for the area. The experimental system was of a randomised complete block design with five treatments i.e. perforated P.V.C. pipes, bagasse filled drains, porous concrete drains, loose rock filled french drains and a control - without any drains, these being in three replicates. This study was a follow up of the work started in 1993 and was thus based on the same system. Interest here was in establishing the performance of the different subsurface drainage materials in order to determine their adequacy for the soils found in the Mumias lowland sugarcane fields.

1.1 Background

The Mumias Sugar Company (MSC), is situated in Mumias division, Kakamega district of the Western province of Kenya at Latitude 0° 21'N and Longitude 34° 30'E (Fig. 1.1). It is at an altitude of 1314 m above sea level.

The region is characterised by bimodal rainfall, with peaks in March - May and September - November. The mean annual rainfall (26 years Average) is 1998.8 mm (MSC., 1994).

The company was incorporated in 1971 following a feasibility study by Booker Agriculture and Technical services (now Booker Tate) and was commissioned in 1973, with the Government of Kenya holding 71% of the shares. The original factory sugar production capacity was at 45,000 t/yr but steady expansion and growth over the last 19 years have seen the capacity to a current level of 200,000 - 213,000 t/yr, (Makatiani and Toywa, 1994).

Currently, the company commands 33,000 ha of sugarcane growing area, the greater part of which is under the sugarcane outgrowers. The company itself has a nucleus estate covering 4,400 ha, of which 3,397 ha are planted with cane (Makatiani and Toywa, 1994). These have been divided into well drained uplands (2527 ha) and poorly drained lowlands (870 ha). Such a division is based both on general topography as well as soil types (Owende, 1990).

The lowlands, which are the areas of interest to this study, are flat areas that position on the banks of river Nzoia and the smaller streams that flow through the MSC nucleus estate (see fig. 1.1). The soils in the lowlands are mainly silt loams. These have an impermeable 2 m thick clay layer (gley), underlying the 0 - 50 cm top soil horizon (Home, 1991). This is the cause of poor subsurface drainage in the area. The soil in the lowlands are, however, suitable for sugarcane production if they are adequately drained (Home, 1991 quoting Bookers, 1970). It is in view of this that the poorly drained lowlands have become an area of focus in recent studies.

Initially, cutoff drains had been dug to catch up slope seepage. Parallel field drains and quarter drains (perpendicular to the field drains) had been installed. According to Home (1991), these failed to perform well. Home (1991) proposed a subsurface drainage system to be installed without disturbing the existing field layout. An experimental subsurface drainage system, consisting of various types of drainage materials, was designed and installed in 1993. However, before any of the materials can be termed effective, there is a need to evaluate their performance in terms of water table control, crop response to drainage as well as cost effectiveness.

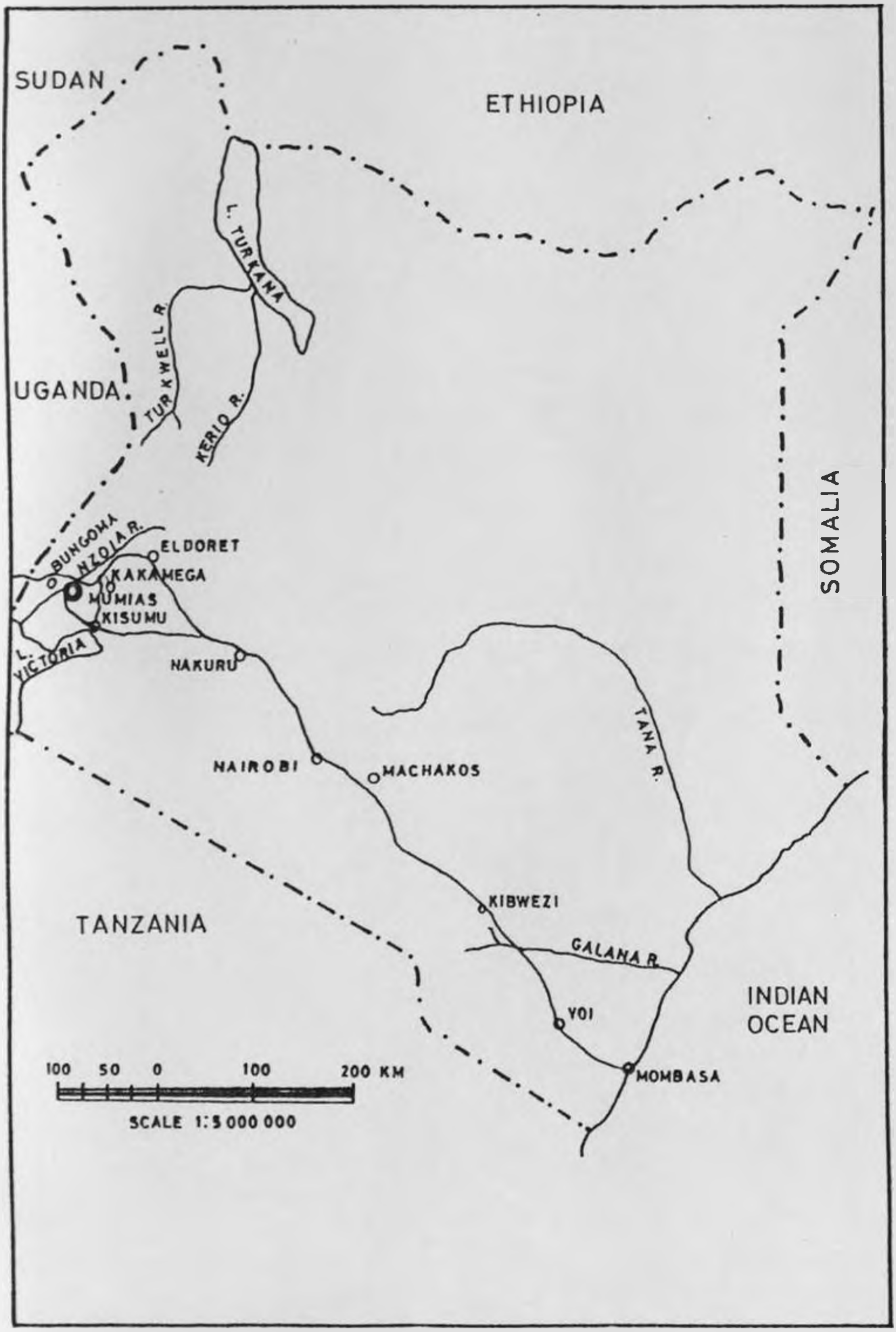


Fig. 1.1 Mumias - Geographical location in Kenya

Fig. 1.2 Layout of Mumias Sugar Company estate showing experimental plot

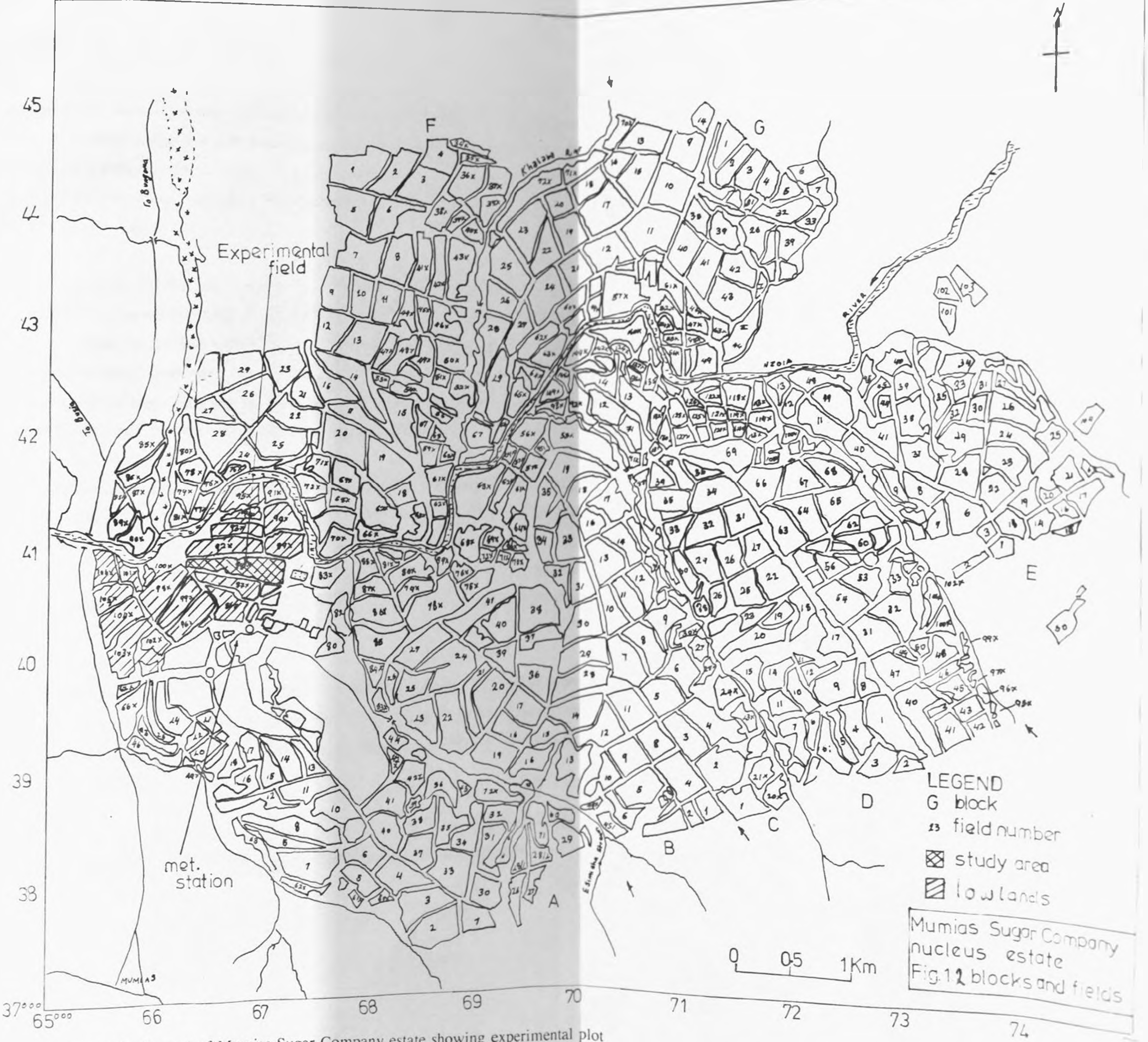


Fig. 1.2 Layout of Mumias Sugar Company estate showing experimental plot

1.2 Justification

Despite its growth, the performance of the sugar industry in Kenya has not been at its best. However, the country's sugar requirements have continued to increase, to an extent that the current demand greatly exceeds the supply. In a bid to increase the sugar supply, production has been forced to extend to areas which would originally have been termed less suitable - in this case, poorly drained areas.

Looking specifically at the MSC nucleus estate, one can say that its full potential, in terms of sugar production, has not been realised - for various reasons; one of the reasons being that a substantial portion of the land (about 30%) is poorly drained. To meet the desired requirements, however, production must not only extend to these lands but yields thus obtained must also be high. This calls for improvement of drainage in these areas. If these were drained, MSC nucleus estate could possibly increase its production.

Implementing a drainage project is, however, an expensive affair. Also, subsurface drainage is a measure of land improvement that is expected to function over a long period of time. The implementation of drainage works thus requires careful consideration beforehand. One of the aspects deserving attention is the adequacy of the drainage system - in this case - in terms of the drainage materials to be installed. Subsurface drainage requires appropriate materials to ensure a proper functioning of the system.

At the MSC nucleus estate and even in other sugarcane growing areas in the country, there is potentially a large area to be drained. It is therefore important that an effective subsurface drainage material be established, at an experimental level, for the sake of ensuring the success of any forthcoming installations.

Generally speaking, if the drainage design factors and concepts are to be improved further, the systematic monitoring of the performance of drainage systems is indispensable.

1.3 Objectives

The overall objective was to establish the adequacy of different subsurface drainage materials installed and thus make recommendations on the one to be adopted for the lowlands of the MSC nucleus estate.

In order to achieve the above objective, the specific objectives that had to be realised were as follows:

i, To monitor the performance of different subsurface drainage materials currently installed at the MSC nucleus estate, in terms of water table control and crop response to subsurface drainage.

ii, To establish the cost effectiveness of installing the subsurface drainage works.

1.4 Scope

For this study, subsurface drainage performance was assessed with the drains being considered as a package of drain lines and envelope material. Crop response to drainage was judged by assessing cane and sugar yields and some features reflecting the extent of stress on sugar cane where drainage is concerned, viz plant population and plant height. The cost effectiveness of the drainage works was to be established through the evaluation of costs and benefits directly related to the improved drainage. This was thought to be important and relevant as the reason for improving land drainage was to ensure increased production.

2 LITERATURE REVIEW

Drainage is considered important for commercial sugarcane production especially in the low lying areas of the humid tropics. In some sugarcane growing areas, subsurface drainage systems have been used. These are systems consisting of a network of deeply installed field drains establishing a base in the soil, well below the main root zone (Smedema and Rycroft, 1983). Their main purpose is the removal of ground water though they may also handle surface runoff.

The primary objective of drainage a drainage system is to control and manage ground water table within specified limits. This goes to making agricultural land more productive by increasing crop yields, permitting switches to more valuable crops and reducing the cost or effort of production (Schwab *et al.*, 1981; Amer and Lesaffre, 1990). Most crops will respond favourably to drainage if the system so installed is adequate. However, a substantial number of drainage works have been less successful than hoped for, others have been out right failures (Dieleman, 1979). Such failures are very expensive both in terms of investment costs and failure to achieve the desired goals of increased production.

Subsurface drainage systems have been used in many sugarcane growing areas. Enough is known about the performance of subsurface drainage materials under ideal conditions. Precisely what will happen under particular soil conditions cannot be predicted, in which case, field investigation on the performance of subsurface drainage material should be a prerequisite to the implementation of a drainage project.

2.1 Drainage materials

Regarding drainage materials, the specific aspect of each of two groups, viz drain pipes and envelopes, will be discussed in the ensuing subsection. Discussion will however be restricted to those materials that have been used in this project.

2.1.1 Materials for pipe drainage

i, Concrete Pipes

Concrete pipes are normally used as alternatives where clay tiles are not readily available or where large diameter pipes are required. Their production is also much simpler than that of clay pipes. Experience from India has shown concrete to be an efficient drainage material for the reclamation of waterlogged areas (ICNR, 1963). Elsewhere in the world, concrete drains have also been found to function quite effectively.

Concrete is, however, affected adversely if exposed to the action of acids or sulphates in the soil (Cavelaars, 1974; Dierickx, 1983; Smedema and Rycroft, 1983; Summers *et al.*, 1990; USDA - SCS, 1971)

ii, Plastic Drains

These are flexible conduits that will develop good bearing strengths if they are suitably installed (USDA - SCS, 1971). They are made of either polythene (PE) or polyvinyl chloride (PVC). PVC pipes are more common. Perforated PVC pipes have been used in this particular project. Plastic drains have been used successfully in many problem areas for the improvement of subsurface drainage and other soil conservation services applications (Wesselling, 1972; Perez, 1984). PVC, though, is not very impact resistant at low temperatures (Cavelaars, 1974; Smedema and Rycroft, 1983) and is likely to undergo creep deformation over time (Perez, 1984).

iii, French Drains

These are also known as blind inlet. Here, entry of water to the drains is facilitated by a backfill (e.g. gravel, loose rock, organic material, etc). In this particular case loose rock has been used as backfill material for the French drains. French drains mainly serve to remove excess water in localised areas of poor drainage.

2.1.2 Drain envelope materials

Drain envelopes are materials other than earth placed on or around drain pipes. According to Cavelaars (1974), Humbert (1968) and Wesseling (1972), drain envelope materials serve the purpose of :

i, Facilitating water flow into the drain (Water conducting function), and
ii, Preventing entry of soil particles into the drain (Filtering function).

The effectiveness of an envelope material depends on its ability to provide a voluminous permeable surrounding to the drain, which keeps the soil from the vicinity of the drain openings but remains porous enough and is not sealed on contact with the surroundings. Envelope materials in common use include:

a, Granular material e.g loose rock and gravel.
b, Synthetic material e.g polyfelt and polystyrene.
c, Organic material e.g peat and coconut fibre.

Granular envelope materials are usually used in fine and silty dispersive soils, and unstable soils. Granular materials, especially graded gravel and sand have historically been used as "ideal" envelope materials around subsurface drains, especially in arid and semiarid areas. Graded gravel meets the requirements of good envelope material in that it provides structural support for the pipe and has a higher permeability than the surrounding soil.

Organic materials are not commonly used in humid regions, probably due to their unknown life expectancy (as a result of fast decomposition) and difficulty in handling.

According to Dierickx (1993), gravel envelopes have shown serious short comings and organic materials are prone to deterioration. Also in most areas, granular and organic materials are either in short supply and very costly, or absolutely non - existent (Knops and Dierickx, 1979). Synthetic envelope materials are widely used in various parts of the world (Knops and Dierickx, 1979).

Because of the rapidly increasing demand for drain envelope materials, there is an immediate need to learn about the most efficient use of drain envelopes. Their clogging and blocking characteristics may also require thorough investigation.

According to FAO (1980), drains installed in hydraulically unstable soils or in fine textured soils with low permeability may require envelope materials. Knops *et al.* (1979) suggested that envelopes were required in those soils where soil particles tended to migrate towards and into the drain pipes. According to Dewey and George (1988), soils with a high fine sand fraction appeared to be the most likely to require a filter. Other soils likely to respond (to a sand envelope) were swelling black clays with vertic or melanic A horizons and gleyed subsoils.

Drain envelope performance strongly depends on soil conditions, especially the initial moisture content of the particular soil. Also an envelope material which acts well in a given situation can be poor in another one (Dierickx and Yüncüoglu, 1982). The systematic assessment of the performance of drain envelope materials for particular soils is therefore of great importance. For the development of better envelope materials, research must be focused on quantifying parameters which are decisive for the envelopes' performance (Stuyt, 1982).

In this project, envelope materials that have been used are polyfelt (synthetic) and bagasse (organic). Bagasse is the fibrous residue from crushed cane, which is similar in composition to wood, except that it has a much higher moisture content (Blackburn, 1984). The use of bagasse as a filter material is a new idea and as such (bagasse filled drains) has not been tried elsewhere.

2.2 Subsurface drainage performance - Theoretical considerations

In assessing the performance of pipe drainage systems, it is worth understanding the flow path that the water has to follow on its way from the land surface, through the entire drainage system to the outlet. The flow can essentially be divided into four stages (See fig.2.1a) i.e.,

Stage 1:	Vertical flow which comprises infiltration and percolation of excess water.
Stage 2:	Horizontal flow towards the drain and partly radial flow in the vicinity of the trench.
Stage 3:	Flow from the trench boundary to the inside of the drain pipe.

Stage 4: Flow through the pipe system to the outfall.

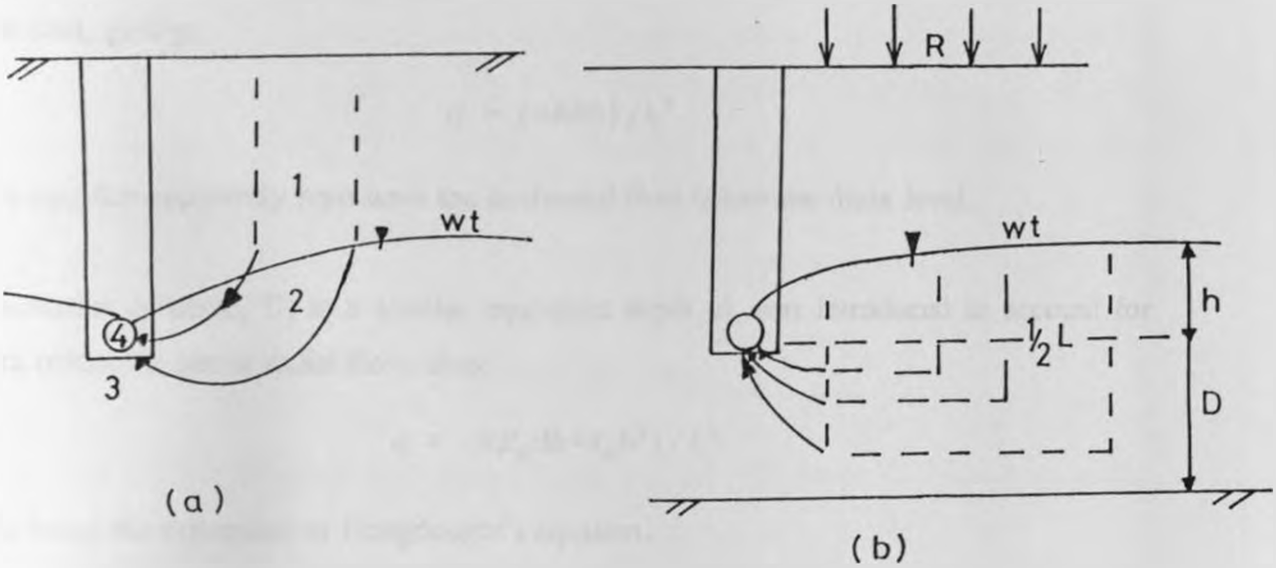


Fig. 2.1 Flow to drains for open ditches and pipe drains: a) shows the four stages of flow; b) shows the flow as described by Hoogdought.

In the figure above:

wt = Water table R = Recharge i = impervious 1...4 = flow stages

h = Water table height above drain level at mid point

D = Height above impervious layer of water level in the drains

The flow as shown in fig. 2.1b was described by Hoogdought in 1940 (Wesseling, 1979), using a formula based on equations derived for horizontal flow to ditches reaching an impervious layer. These equations had been derived assuming steady state conditions. The equations were combined and presented as:

$$q = (8K_bDh+4K_ah^2)/L^2$$

where: K_a = Hydraulic conductivity of the layer above drain level, (m/day)

K_b = Hydraulic conductivity of the layer below drain level, (m/day)

q = Drain discharge rate per unit surface area, (m/day)

D = Height above impervious layer of water level in the drains, (m)

h = Water table height above drain level at mid point, (m)

L = Drain spacing, (m)

If D is much greater than h, the second term in the numerator can be neglected against the first term, giving:

$$q = (8KDh)/L^2$$

This equation apparently represents the horizontal flow below the drain level.

A reduction of depth, D, to a smaller equivalent depth, d, was introduced to account for extra resistance due to radial flow, thus:

$$q = (8K_b dh + K_a h^2)/L^2$$

This being the expression of Hoogdought's equation.

A more realistic picture is presented in equations derived for the unsteady state conditions. For simplicity, however, the Hoogdought's equation is more commonly used to describe flow to drains.

The height, h, which is the height of the water table above the drainage base midway between two drains, constitutes the head driving the ground water towards the drains.

The placement of piezometers at the transition from one stage to another can serve to show head losses in each stage. The corresponding flow resistance can be determined from the following equation, which is an analogy to Ohm's law.

$$H_i = q' w_i$$

Where: H_i = Head loss in the ith stage, (m)
q' = Discharge per unit drain length (m^3 /m day)
w_i = Resistance in the ith stage (days /m)

Thus total flow resistance, H, is:

$$H = \sum H_i = \sum q' w_i$$

Total head losses in the system that are greater than the requirement would lead to some extra resistance normally referred to as entrance resistance, which would in turn result in the drainage system failing to control the water table adequately (Cavelaars, 1974) and consequently to drain failure. Factors that can cause that occurrence of extra resistance, and subsequently affect drain performance, are dealt with in section 2.3.

2.3 Factors affecting subsurface drain performance

Occurrence of failure of subsurface drainage works is not uncommon. A knowledge of the factors affecting drain performance is important in assessing drain performance.

According to Shafer (1940) and Schultz *et al.* (1970), drainage system performance may be affected by:

i, Improper construction.
ii, Lack of inspection and maintenance.
iii, Improper design of the system.
iv, Improper manufacturing process.
v, Physical structure of the soil.

Manufacturing processes can be assumed to have now improved to an extent that they would not be expected to greatly affect drain performance. Failures due to physical structure of the soil may be avoided by ensuring proper construction (Crecy, 1982). Thus, of the above mentioned factors, improper construction, lack of inspection and maintenance, and improper design are probably the greatest causes of drain failures (Shafer, 1940).

2.3.1 Improper construction / installation

Improper installation is a major cause of failure of subsurface drainage systems. There are a lot of problems that can be associated with poor installation.

Uneven grade, for example, may cause a reduction in the velocity of water. This would affect the cleaning process of the drains.

Failure to shape the bottom of the trench to fit the drains may cause the drain to crush due to uneven earth pressure. This would not occur if the trench was well shaped and thus pressure was well distributed over the bottom section of the drain. Poor alignment leads to lines with open joints, allowing soil entry into the drain and reducing the velocity of water in the drain as well as the drain capacity. Poor construction of the joints also allows dirt into the drains as well as formation of holes over the course of the drain (Shafer, 1940; Cavelaars, 1974; Smedema and Rycroft, 1983; Schultz *et al.*, 1990).

Careless backfilling causes the drain to move out of line and breakages may occur (Shafer, 1940); Backfilling of the trench has a direct and significant effect on the flow to the drain (Hwang *et al.*, 1974). Conditions of backfilling material around the drain are of great importance. These conditions depend on the structural stability of the soil and moisture status at the time the trench is filled (Raadsma, 1974). Careful control of backfilling procedures will therefore have a significant influence on the performance of the drainage system (Hwang *et al.*, 1974).

Ideally, installation should be carried out during the dry season when the ground is able to support heavy machinery, otherwise serious compaction would occur (Smedema and Rycroft, 1983). Soil compaction due to field traffic and wet conditions causes impedance to infiltration and percolation and ultimately lead to drain failure. Installation under wet conditions, and thus under poor soil conditions in the filled trenches, also causes high entrance resistance and consequently poor drain performance (Cavelaars, 1974; Smedema and Rycroft 1983; Schultz *et al.*, 1990). Also as the condition of backfill material around the drain greatly depends on the moisture status at that time (Raadsma, 1974), backfilling under wet conditions e.g. during a rainfall season and / or when there is a high ground water level, may prove fatal as far as the drainage system is concerned.

Improper installation, especially when applying trench backfill may lead to problems during stage 3 of the flow (see fig. 2.1a). In practice, most drain failures occur in this stage. For such a case, the potentiometric heads in an inadequately functioning drain would be as shown in fig. 2.2.

Failure resulting from problems in stage 3 are very difficult to rectify and may in fact be fatal. In the Netherlands, it has been found that a complete new drainage system may have to be installed (Cavelaars, 1974).

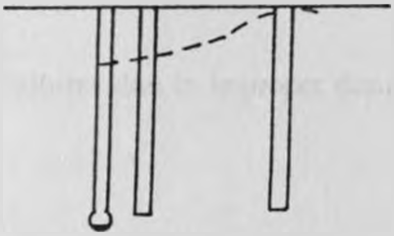


Fig. 2.2 Potentiometric heads in an inadequately functioning drainage system - stage 3.

2.3.2 Lack of inspection and maintenance

Subsurface drainage systems have been known to function well in many areas of the world. It should, however, not be expected that once drains are installed, they can continue to function indefinitely without any maintenance. Lack of inspection and maintenance would ultimately lead to poor drain performance.

Problems associated with lack of inspection and maintenance, as presented by Shafer (1940), Smedema and Rycroft (1974) and Schultz *et al.* (1990), include:

i, Filling with silt from openings over the line.
ii, Obstruction of pipe flow by high water levels in the collector ditches.
iii, Filling due to washed - out catch basins and other surface inlets.
iv, Clogging of pipes by fines, iron compounds or root growth in the pipes.

ording to Stuyt (1982), if envelope materials are used system failure is generally caused :logging of these materials.

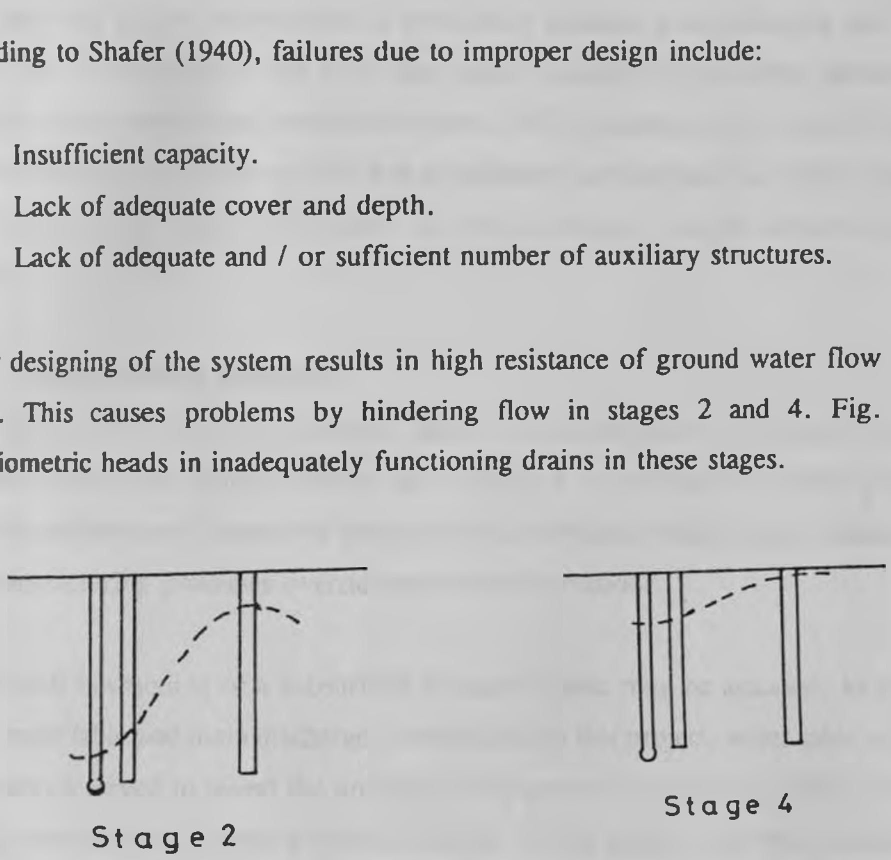
a result of lack of inspection and maintenance, the drain is likely to be put under pressure "blowholes" would occur. In this case, flow in stage 4 (fig. 2.1a) is likely to be :cted. Lack of inspection and maintenance is a major cause of failure in stage 4.

.3 Improper design

:ording to Shafer (1940), failures due to improper design include:

Insufficient capacity.
Lack of adequate cover and depth.
Lack of adequate and / or sufficient number of auxiliary structures.

der designing of the system results in high resistance of ground water flow towards the ins. This causes problems by hindering flow in stages 2 and 4. Fig. 2.3 shows entiometric heads in inadequately functioning drains in these stages.



;. 2.3 Potentiometric heads in inadequately functioning drains - stages 2 and 4.

oblems occurring here may however be remedied by the installation of more drains avelaars, 1974; Smedema and Rycroft, 1993; Schultz *et al.*, 1990).

Poorly designed and constructed head walls at the outlet may result in a collapse and thus clog the line.

2.3.4 Other causes of failure

i, Structure of the soil

Failures reported in relation to this are usually in heavy or dense clay, which prevents movement of gravitational water through it (Shafer, 1940). Crecy (1982), however, suggested that provided good construction was carried out, subsurface drainage would perform well. Problems may also be encountered in structurally unstable soils (Dierickx and Yüncüoglu, 1982). In fine sandy soils and light clay soils, drainage systems often demonstrate poor operation only shortly after installation (Stuyt, 1982). According to Anon, 1970 occasional failure occurs in non cohesive soils due to sediments moving into the drains. Depending on the structure of the soil, vertical flow i.e. flow in stage 1 may be hindered, leading to a failure.

ii, Manufacturing processes

Here failures are traceable to common factors such as improper or unclean material, poor or weak mixture and improper mixing and curing e.g. in the case of concrete pipes (Shafer, 1940). It can however be assumed that the level of efficiency that has been attained in present day manufacturing processes override previous observations.

The overall functioning of a subsurface drainage system may be assessed, to some extent, using water table and drain discharge observations. In this project, water table and discharge observations served to reveal the properly and improperly functioning drains. Drain failure mostly occurs or will become evident within the first or second year after installation. Once past this initial period, pipes can function almost permanently provided they are maintained regularly (Smedema and Rycroft, 1983).

2.4 Performance studies for subsurface drainage systems

Previous studies in drainage have tended to concentrate on the development of new or existing drainage theories. However, the need to study drainage performance in the field is something that has, of late, been receiving much attention.

Some of the work done includes studies by Fausey *et al.* (1986) on subsurface drainage in a fine textured soil with impaired permeability. Discharge measurements were carried out using V-notch weirs and water stage recorders. The system evaluated was found to be inadequate as water still remained at the bottom of the plough layer for several days following a rainfall event. Low crop yields and delays in tillage operations were also observed.

Bengston *et al.* (1983), studied the effectiveness of subsurface drainage in an alluvial soil with the aim of evaluating its effectiveness in lowering the water table, increasing crop yield and reducing surface run off and soil erosion. Findings were that tile discharge was less from crops having a long growing season as compared with those having a short growing season and that surface and tile drains complemented each other. Fausey (1983), working on shallow subsurface drainage on a Clermont soil found that the drains performed well showing minimal sediment accumulation, no structural deformation and giving very good quality outflow water.

Milburn (1987), working on drains installed in a silt loam soil at spacings of 12 and 24 m, found that subsurface drainage increased the rate of water table draw down following rainfalls, and significantly improved the agricultural capability of the soil. The average depth of drain placement was 0.85 m. The drains were installed on the impermeable layer i.e. the equivalent depth was zero. Performance of the 12 m spaced drains was however affected by iron ochre clogging.

Walker and Wells (1983), working on heavy clay soils in various locations for which subsurface drainage pipes had been installed, made recommendations on the spacing required to achieve a desirable water table draw down. Recommended spacing varied between 10.8 m and 24.2 m depending on the location. Carter and Camp (1994) found that drains installed at 14 and 28 m spacing, in a silty clay loam soil, were effective in controlling the water table. Drains placed at a 42 m spacing were not found as effective. Yang *et al.* (1977), working on a fine textured low humic gley soil in Taiwan, found that at the same spacing, drains at 1.2 m depth lowered the water table faster than those at 0.8 m depth. They also found that the narrower the spacing was, the more effective the drain would be in lowering the water table level. Smedema (1993), suggested that the performance of an installed subsurface drainage system was significantly influenced by soil management. Soil management practices referred to were those affecting soil compaction, organic matter content and plough layer formation.

Similar studies include work by Borin and Berti (1991), in which it was established that water table depth was not influenced by the year of installation of the subsurface drainage system, and that relatively few observations were statistically sufficient for reliable measurement of water table depth and discharge. Mirjat and Kanwar (1992), found that drainage performance was influenced by the method of installation in the initial stages of operation.

Quite a bit of work has been done on performance of subsurface drainage systems in developed countries. However, field drainage in developing countries is an inadequately covered subject, both in terms of attention and research devoted to the subject (Dieleman, 1979; Smedema, 1987). In Kenya, drainage performance studies have not been carried out extensively. In particular, studies to determine the adequacy of various drainage materials have not been carried out for the problem soils. This study was aimed at providing some light in this regard especially for sugarcane production with emphasis on the MSC nucleus estate.

2.5 Sugarcane - drainage requirements

Commercially viable sugarcane has been grown successfully on a wide range of land forms and soil types. According to Purseglove (1972) and Doorenbos and Kassam (1979), sugarcane does not require a special soil type. Sugarcane, though, finds its best rooting medium in well structured loam - clayey loam soils of a depth greater than 1 m (Blackburn, 1984). The soil should preferably be well aerated. A pore space of at least 50%, which at field capacity is only half filled with water, is desirable.

High water tables adversely affect sugarcane especially if it occurs when the crop has seed stalk and stubble. Sprouting of the stubble crop is considered critical for achieving a successful ratoon production. Poor sprouting of ratoons is experienced in water logged areas. Irvine *et al.* (1984), found that failure to provide adequate drainage for fields that were essentially flat, was among the factors responsible for the failure of a ratoon crop.

Sugarcane growing in poorly drained soils shows inhibited root formation, reduced transpiration and growth rates, deficiency symptoms, shorter internodes and high incidence of disease (Humbert, 1968; Purseglove, 1972). For sugarcane, stagnant soil water is fatal and land that is continuously too wet is harmful (Barnes, 1974; King *et al.*, 1965).

Water in itself does not affect plant roots, but conditions caused by water, such as reduced oxygen and a build up of carbon dioxide, can have damaging effects on the root system (Carter *et al.*, 1985; Yang *et al.*, 1977). The presence of a shallow water table may cause poor soil aeration and restrict rooting volume. As a consequence, oxygen deficiency results thus causing a reduction in water and nutrient uptake as well as causing the formation of products that are toxic to soil and plants (Wesseling, 1974; Yang and Wang, 1980 quoting Williamson and Kritz, 1970). The aim of drainage is to aerate the soil by eliminating the water accumulated above the impervious layer. Water logging in its worst form occurs when a clay subsurface layer is present.

According to Sevilla *et al.* (1980), quoting Wilkin and Ateshian (1965), water table fluctuations have a negative effect on production when the average depth of water table is below a certain optimum. Sevilla *et al.* (1980), working on the effect of water table levels of 60 cm to 160 cm on sugarcane, found a significant correlation between cane production (t/ha) and the persistence of high water levels at the depth assessed.

According to King *et al.* (1965), sugarcane can withstand free ground water for prolonged periods, even though growth be temporarily checked. It will rapidly recover and forge ahead again when excess soil water is drained. Gayle *et al.* (1987) and Gosnell (1971), found that sugarcane did not germinate in water table depth higher than 25 cm, but did at water table depths of 50 cm and below. A 25 cm depth thereafter ensured continued growth but low yields were obtained. Also reported was that high water levels caused reduction in the number of stalks as well as the growth and production of cane and sugar.

In a well drained soil with an adequate supply of moisture, sugarcane roots can penetrate to a depth of 150 - 120 cm (Goor, 1979), making sugarcane a deep rooted crop. However, for sugarcane, the roots are most active in the 0 - 60 cm depth. It is thus critical to keep the water table below the 50 - 100 cm depth. This would allow the growth of superficial roots which serve the purpose of absorbing nutrients and moisture. It is noteworthy, though, that sugarcane cannot adapt too rapidly to a falling water table (BlackBurn, 1984).

Although the effect of water table on the growth and production of several crops has been extensively studied, only a few research works have been made on the sugarcane crop (Sevilla *et al.*, 1980). In poorly drained areas, however, it is necessary to use artificial drainage in order to meet the crop drainage requirements. McIntosh (1977) highlighted the considerable waste of potential sugar production in the industry and monetary losses to individual farms, caused by even small areas of poor drainage. Worthwhile improvements in productivity and farm profits were expected to follow well planned drainage amendments. In many sugarcane growing areas, subsurface drainage is being used.

2.6 Studies on sugarcane response to subsurface drainage.

Work done in this area includes studies by Carter and Floyd (1973), working on subsurface drainage and irrigation. Findings were that cane yields and stand longevity could be increased by drainage, and that the extra production compensated for the cost of drainage system installation. Camp and Carter (1983), working on three water management systems, found that subsurface drainage systems installed at various spacings adequately controlled the water table. Sugarcane and sugar yields for the subsurface drained areas were significantly higher (6.2% and 3.1% higher respectively) than those for the undrained area.

Carter *et al.* (1988), working in the Lower Mississippi Valley, determined the response of sugarcane to water table management involving subsurface drainage and subirrigation.

Findings were that the crop responded favourably to water table management, particularly during years with above normal rainfall. Yield differences in cane and sugar obtained, were significant (on average 15% and 22% higher respectively) at the 97% and 99% levels of probability; these increases being attributed, in part, to subsurface drainage.

In both cases, (Camp and Carter, 1983 and Carter *et al.*, 1988), yield increases obtained for one year had a magnitude large enough to defray a significant portion of the system installation costs. Carter and Camp (1983) and Carter (1987) also found that with subsurface drainage, there was a potential for increasing the number of crops harvested from one planting. Yang and Wang (1980), working on fine textured low humic gley soil in Taiwan, found that the sprouting of ratoon crops was substantially higher in tile drained plots. Increases of 17%, 40% and 34% in yields of the plant crop, first ratoon and second ratoon respectively, were recorded where subsurface drainage systems had been installed. Observation on stalk elongation revealed that there were shorter lengths in surface drained plots compared to tile drained plots (up to 58 cm shorter). Also less root proliferation, mainly restricted to a depth of 60 cm, and less total dry root per unit soil volume, was observed for surface drained plots than for tile drained plots.

Studies by Irvine *et al.* (1984), showed that higher cane yields in ratoon crops were expected in fields with subsurface drainage than those without. Subsurface drained plots were found to yield 30% (19 t/ha) more cane per hectare than the undrained plots, and showed a significant difference in sugar yield per hectare in the second ratoon crop. Overall findings for the three crop cycles were that the yield of sugarcane per hectare was significantly higher in drained than in undrained plots for the 3 - year period, but yields of sugar per tonne of cane and sugar per hectare were not.

Dewey and George (1988) working on subsurface drainage within the South African sugar industry reported that yields improved considerably with an average increase of about 70% after subsurface drainage had been installed and when rainfall was either normal or well above average.

Escolar *et al.* (1971) working in Puetro Rico found that where no internal drainage was provided, the yields were significantly lower than where the drains were located at different depths irrespective of the distance between them. A rather consistent increase in cane and sugar yield was obtained with the lowering of the water table.

Carter and Camp (1994) found that sugarcane responded favourably to subsurface drainage spaced at 14, 28 and 42 m. Although sugar yields obtained among the different drained treatments were not significantly different, subsurface drainage was only found cost effective for the 28 and 42 m spaced drains.

Gumbs and Simpson (1981), found that improved root distribution and increased rooting depths could be attributed to lower water tables. Where high water tables were prevalent, adventitious roots emerged from the submerged portion of the plant in an attempt to adapt to wet conditions. Also observed was reduced tiller emergence and stalk elongation where high water tables were prevalent. In general reduction in growth observed where there were high water tables could be attributed to lack of oxygen.

Results from the above discussed studies suggest that subsurface drainage is favourable where sugarcane growing is concerned. However, it must be noted that recommendation on an effective subsurface drainage material should only be made on considering its effectiveness as far as the relevant aspects (water table control, crop response to drainage and cost effectiveness inclusive) are concerned.

2.7 The cane variety

The cane variety that had been grown in the trial fields was CB - 38 - 22 (*Saccharum officianarum*) which has its origin in Brazil. It is an early maturing variety having an optimum harvesting period of 18 - 20 months for the plant and 16 months for the ratoons. On average, it is expected to produce 66,200 millable stalks per hectare of cane. Its stalks are reasonably thick compared to those of other cane varieties. Productivity is medium (95 - 115 t/ha) even though yields from this variety are better than those obtained from several other varieties (Nyongesa, 1994; Ochieng, 1995).

CB - 38 - 22 performs well in deep upland soils and plinthitic soils in upland areas. It can however perform well in other soils provided they are well managed. Experience with the variety in SONY Sugar Company has shown that the cane performs well in both clay and loam soils, has a high tillering ability even though it is a poor germinator. It is a clean variety being resistant to diseases. It also lodges easily and lodges early under good management (Nyongesa, 1994; Ochieng, 1995).

Published literature on the performance of CB - 38 - 22 in the Kenyan sugar belts is currently not available.

2.8 Evaluating subsurface drainage performance.

Where drainage is concerned, the introduction of new techniques and materials has normally been followed by laboratory research aimed at establishing the performance of the drainage materials. This type of research, however, does not render consistent and reproducible results. This is because field conditions can hardly be simulated in a laboratory test (Stuyt, 1982). To establish the adequacy of a material for a particular field therefore, field trials on experimental plots and subsequent analysis of data obtained are necessary before the execution of large scale drainage works.

Drainage performance can be assessed in a number of ways, including:

i, Hydraulic performance i.e. Water table control and discharge.
ii, Crop response to drainage.
iii, Cost effectiveness of the drainage works.

These will be discussed in the ensuing subsections.

2.8.1 Water table control.

A drainage system is considered effective in water table control when it is able to remove excess water from the soil surface sufficiently fast especially during the wet season (Wesseling, 1972). The effectiveness of a drainage system has often been described in terms of water table heights and discharge. Although the depth of the ground water table has no direct influence on crop growth, it determines the soil moisture conditions, which in turn have an influence on crop growth. Field experiments are, nevertheless, conducted using water table depth because it is easily determined compared to other soil properties. Water table depth thus makes a suitable diagnostic characteristic for the assessment of drainage performance.

Water table depth measurements can be made using water table observation wells (open boreholes or boreholes in which perforated pipes have been placed). When the experiment serves to check the effect of different types of drainage materials, more emphasis should be laid on measurement of loss of hydraulic head in the vicinity of the drain lines, hence the use of piezometers (Dieleman, 1974).

Drain discharge may be measured using buckets of known volume and a stop watch, discharge recorders attached to drain outlets, or weirs. Buckets are disadvantageous in that using them is a laborious process. Recorders are however expensive. With weirs, there is a 20 - 30 cm head loss and also inaccuracies during low discharge. For this project, a technique similar to using the bucket, i.e. measuring cylinder and stop watch, was used. Vandalism prevalent in the region would not allow the use of other discharge measuring devices. Like water table measurements, measurement of discharge is not a complicated exercise. Analysis of the data so obtained would then serve to show the performance of the drains. Data analysis may be carried out as follows:

i, Water table and discharge hydrographs

Water table and discharge hydrographs are a useful tool in the analysis of water table and discharge data. Water table hydrographs are graphs of water table versus days. A plot of water table levels for the whole year would serve to show the water table fluctuations during the year. Rainfall hyetographs are normally drawn along with the water table graph either on a secondary Y - axis or as a separate graph. Likewise, discharge hydrographs are graphs of discharge versus time in days also serving to show the performance of the drains.

In performance studies for subsurface drainage systems, this method of analysis has been used successfully and may therefore be applied in other studies.

ii, Water table control indices

Commonly used indices, as presented by Smedema (1988), include:

a, The number of daily exceedances, W_x: this is the total number of days, in a given period of time, during which the water table depth is higher (i.e. has a lower numerical value) than a certain predetermined threshold, H_x (cm). This will be denoted by the symbol (<). Thus:

$$W_x(days) = \sum_{i=1}^{N} [(H_i<H_x) = 1; (H_i \geq H_x) = 0]$$

Large values of W_x would indicate that the water table remained above the threshold for prolonged periods and thus poor drainage. For sugarcane the crop is likely to suffer where $W_x > 14$ days.

b, The sum of depth of daily exceedances, SEW_x: this is the sum of the daily values by which water table is higher than a certain predetermined threshold, H_x (cm). Thus:

$$SEW_x \text{ (cm-days)} = \sum_{i=1}^{N} (H_x-H_i) \text{ for } H_i<H_x$$

Large SEW values would indicate the persistence of high water tables and hence poor drainage conditions.

c, Average seasonal water table depth, H (cm):

$$\overline{H}(cm) = \sum_{i=1}^{N} (H_i/N)$$

In all cases,

H_i = Water table depth on the ith day (cm).

N = Number of days per period considered.

According to Smedema (1988), the choice of the threshold, H_x, is generally not very critical as long as H_x is within the main root zone depth i.e. the upper 50 cm of the soil profile. A value of H_x = 30 cm below the surface is a commonly used threshold and hence the SEW_{30} index (Bouwer, 1974; Wesseling, 1974; Kessler, 1979). However, 30 cm is a figure which was established for cereal grains. Plant species respond differently to water table levels, making it necessary to specify the H_x for a specific crop. Carter *et al.* (1988), found 45 cm to be appropriate for sugarcane.

It would be difficult to compare the applicability of the three indices, given the complicated crop response to water logging during the growing season. According to Smedema (1988), the ideal water table control index characterizes the water table regime such that a fairly close and direct relationship exists between the index and the net - farm returns. The SEW index seems to best capture the growth reducing causal events and may show better relationships with crop yields.

Commonly used values above which yields are likely to be affected are 100 - 200 cm-days. These values were established for cereal grains in the Jsselmeerpolder soils of the Netherlands (Caverlaars, 1974; Wesseling, 1974; Carter *et al.*, 1988) but have, now and then, been adopted for other crops in various locations. It should however be noted that it is difficult to transfer results from one location to another because of the different soil types and soil conditions (Home, 1991, quoting Williamson and Kritz, 1970). The SEW value above which yields would be severely curtailed has not been established for sugarcane (Carter *et al.*, 1988; Carter and Camp, 1994).

2.8.2 Crop response to drainage.

Crops will generally show certain characteristics that reflect the effects of high water tables, and hence of drainage, on them. These characteristics can be used to assess the crop response to installed drainage works, provided the number of variables associated with the effects of drainage on crops have been reduced as much as possible when setting up the experiment.

The SEW index has been suggested as a measure of the influence of high water tables on crops, with a threshold being identified for a particular soil and crop. Plots of yields versus SEW index show the effect of water table depth, expressed in SEW values, on the crop. Values of SEW above which yields would be adversely affected can then be established.

Large SEW values generally indicate poor drainage conditions, but identical values do not necessarily imply identical conditions (Wesseling, 1974). Since these conditions are important, SEW values do not completely describe the influence of water table depth on crop growth. One can use the duration of high water table above a threshold value. The longer such a duration is, the poorer the productivity will be. This is however not enough and additional crop response parameters should also be used for evaluation.

Chieng *et al.* (1987), working on the response of four crops to various treatments, drainage at all times and drainage only during high precipitation periods inclusive, monitored yields as a measure of crop response to drainage.

Beltràn (1978), also monitored crop yields as well as studied the relation between crop yields and water table depth. Differences in drainage conditions caused by different combinations of drainage and filter materials, were useful in determining the relation between yields and water table depth; thus showing the sensitivity of the crop to high water tables.

Carter *et al.* (1988), working on sugarcane in two locations, measured cane and sugar yields and the number of plants per hectare. Excess water was correlated with average cane yield from each location to show that cane yield varied inversely with excess water. These experiments pointed out the need for drainage to help alienate the excess water problem.

Gumbs and Simpson (1981), also working on sugarcane, monitored various aspects of growth as affected by drainage (or lack of drainage). Aspects monitored were such as rooting depth, root distribution, tiller emergence and stalk elongation. In each case, conclusions on the crop response to water table depths could be made.

Yang and Wang (1980), made observations on the yields of the plant and two ratoon crops, stalk elongation, and root growth and activity for surface and tile drained plots. Root systems were examined after the cane was harvested, both by visual examination and by taking samples for laboratory analysis. Observed shorter stalk lengths and less root proliferation were attributed to oxygen deficiency which resulted from higher water tables in surface drained plots than in tile drained plots.

Others monitoring yields and plant population are such as Irvine *et al.* (1984), working in Louisiana, Camp and Carter (1983), and El-Mowelhi *et al.* (1988), working in the Nile delta of Egypt.

For this study, cane and sugar yields, plant population, internode lengths and overall stalk lengths were considered.

2.8.3 Assessing sugarcane response to subsurface drainage.

Plant species differ widely in their response to imposed conditions in their root environment. Sugarcane, in particular, will behave in a number of ways under improper drainage. In addition to the behaviour mentioned in sec. 2.5., other observations that can be used to detect the drainage situation are such as cane leaves. These assume tightly curled up positions similar to those under drought conditions.

Another aspect of interest is the yields in terms of quantity and quality (Doorenbos and Kassam, 1979; Camp and Carter, 1983). Where the crop is suffering from inadequate drainage, yields are likely to be low.

Also noteworthy is the plant population. During the sugarcane growing period, its primary shoot undergoes a process of underground branching, also known as tillering. This results in a number of sugarcane stalks forming a stool (Humbert, 1968; Barnes, 1974). However, stools surviving under conditions of inadequate drainage, and thus inadequate aeration, have only one or two weak stalks (Humbert, 1968), thus an overall lower plant population.

In assessing the crop response to drainage, a combination of the mentioned aspects may be studied.

Plant population is normally determined by counting all stalks within a certain sampling area. If experimental plots are small, counting may be done over the entire plot where feasible.

Plant height may be determined by measuring the height of a number of stalks within a sampling area and then obtaining the average, and likewise for internode length. Plant height measurements should be taken from the bottom of the stalk to the top visible dewlap (TVD); thus representing the actual millable stalk length.

The determination of cane yields can be done by weighing all the cane within an experimental area or within sampling areas where plot sizes are large and / or where no means of weighing in bulk is possible.

For sucrose analysis, small hydraulic presses have been used in many laboratories to extract juice samples from cane. For the analysis, a known mass of shredded cane is subjected to pressing in a hydraulic press. The press juice collected is then analysed for density (brix %) and absolute juice percent (pol %), (Brokensha *et al.* 1976).

Though the press method is commonly used, it has limitations in that results obtained depend on whether there is a significant level of soil present i.e. accidentally picked up with the cane samples, on varieties and also on whether the cane was trashed or burnt. Apparatus available at MSC Agronomy laboratory are for the press method. This method was used for this project.

2.8.4 Cost evaluation

Land drainage represents a capital investment intended to result in benefits such as increased productivity of cultivated land or bringing land into production. It is therefore essential that the cost effectiveness, and thus the viability of the drainage works, be established.

Cost evaluation is normally carried out on the basis of one or more of the following evaluation indices:

i, Internal Rate of Return (IRR)

This is the rate of interest earned on the unrecovered balance of an investment. The internal rate of return is a very useful measure of project worth (Gittinger, 1971). IRR is that discounting rate i such that:

$$\sum_{n=1}^{N} \frac{B_n - C_n}{(1+i)^n} = 0$$

B_n and C_n are the benefits and costs in each year over a number of years = N (Gittinger, 1971).

The formal selection criterion of the IRR measure of project worth, is to accept all projects having an internal rate of return above the opportunity cost of capital.

ii, Net Present Value (NPV)

This is the difference between the present values of benefits and costs. It is thus the most straight forward measure of project worth involving discounted cash flows. In mathematical terms, (Gittinger, 1971) defined it as follows:

$$NPV = \sum_{n=1}^{N} \frac{B_n - C_n}{(1+i)^n}$$

The notations B_n and C_n are as previously described. The selection criterion is to accept all projects where NPV is positive when discounted at the opportunity cost of capital. The disadvantage of NPV is that the selection criterion cannot be applied unless there is a relatively satisfactory estimate of the opportunity cost.

iii, Benefit - Cost ratio (B/C)

This is the ratio of the present value of benefits to the present value of costs. Thus:

$$B/C\ ratio = \frac{Present\ worth\ of\ (gross)\ benefits}{Present\ worth\ of\ (gross)\ costs}$$

With the NPV, no ranking of alternative projects is possible; a serious draw back in its use and practice. With the IRR, the major drawback is that in the case of mutually exclusive projects, direct comparison of IRR may lead to erroneous investment choice (Gittinger, 1971). Also , the difficulty in determining opportunity costs, which is also a basis for the selection criterion of IRR, can be appreciated.

For alternative projects, comparisons of costs and benefits enable the determination of the alternative that would give the greater return for the invested money. In private drainage projects, evaluation is restricted to the costs and benefits directly related to improved drainage (Jansen, 1974; Smedema and Rycroft, 1983) and hence a benefit - cost (B - C) analysis.

A Benefit - Cost analysis can be used for evaluating investments made in the past, the benefits of which have been fully recovered. In that case, all parameters for such analysis are known. Its major use, however, is as a decision making tool in deciding whether or not an investment should be made currently. Such an analysis must incorporate future prices and quantities, which are highly uncertain, and is therefore based on many assumptions (Vuuren and Jorjani, 1984).

The B - C analysis of a subsurface drainage project normally has to involve construction and maintenance costs of the drainage system, and the expected benefits due to the yield or increased yields of the agricultural products (Amer and Lesaffre, 1990). Construction costs include cost of equipment, drainage materials and transportation, and personnel costs. As presented by Amer and Lesaffre (1990):

$$C = \sum_{i=1}^{N} C_i D_i + \sum_{i=1}^{L} M_i D_i$$

Where: C = Total discounted costs.

C_i = Capital costs in year, i.

D_i = Discounting rate.

M_i = Maintenance costs in year, i.

N = Number of years the capital will be spent.

L = Project life.

The most obvious and most common kind of agricultural benefit is simply increased production. To be able to quantify the benefits in monetary terms, the market price of the product in question is normally the best price to use (Gittinger, 1971).

The benefits may be expressed as:

$$B = \sum_{i=1}^{K} B_i D_i$$

Where: B = Total discounted benefits.
B_i = Benefit in year, i.
K = Number of years for which yield values in use were obtained
D_i = Discounting rate.

Discounting enables the acquisition of one figure measuring all project benefits and likewise one figure for all project costs both being equivalent to their present values. Since the discount rate measures the marginal return to investment in the economy under study, any project showing a surplus of benefits over cost, when discounted at this rate, is desirable. Hence the decision criterion for a B - C analysis is to accept all projects with a B/C ratio greater than or equal to 1 i.e.

$$B/C \geq 1$$

According to Gittinger (1971), any discounting rate can be chosen for computing the B/C ratio provided it can be shown to be reasonable. Commonly used discounting rates are such as:

a) Opportunity cost of capital.
b) Borrowing rate for the project.
c) Social rate of return.

Gittinger (1971), suggested a discounting rate of between 8 - 14%, as per the world bank recommendation for developing countries.

Since many projects have a long useful life time, projection of benefits and costs must be done over extended periods. However, since the process of discounting leads to increasing lower weights at more distant figures, projection should not be stretched beyond certain limits (Jansen, 1979). In private projects, it is desirable to use the payback period as the time span of the projections. The payback period is the length of time from the beginning of the project before the net benefits return the cost of the capital investment (Gittinger, 1971). For commercial undertakings, the payback period is normally 10 years (Kamau, 1995). This can thus be used as a time span of projections as it does cover a reasonable portion of the expected project life (20 years) while still being within the limits of discounting techniques.

According to Carter *et al.* (1992), the life of a subsurface drainage system exceeds 19 years. An amortization period of 15 to 20 years would thus appear reasonable. However if lending institutions were involved, a shorter amortization period would be required. Carter *et al.* (1992), used a payback period of 10 years for their projections.

In some cases, it is difficult to establish the actual benefits of drainage. Here, the B - C analysis is approached from the point of view of benefits required to exactly cover the costs i.e. break-even benefits (Smedema and Rycroft, 1993). Where subsurface drainage for agriculture is concerned, this means determining the crop yield increases required to justify subsurface drainage installation costs (Carter *et al.*, 1992). Thus to justify installing a subsurface drainage system the value of the average crop yield increases, attributed to subsurface drainage, must be adequate to pay for the drainage system within the payback period.

The B - C approach has a weakness in that it assumes constant benefits in each year (Smedema and Rycroft, 1983). Also errors in assigning costs and benefits can change the B/C ratio (Gittinger, 1971).

2.8.5 Statistical data analysis

Where experimentation is concerned, planning and organization involves questions on how to carry out experimental observations, frequency of observations and how to analyze the data. Depending on the type of data involved, various kinds of analysis are possible, including the statistical analysis.

When performing statistical analysis of the data, attention has to be drawn on the number of replicates and the difficulty in randomising the treatments. It is important that the correct statistical test be applied in order to draw justified conclusions, thus the need for a preliminary knowledge of the statistic of the data (Independence, distribution etc.) (Borin and Berti, 1991).

The Analysis of Variance (ANOVA), is the simplest means of comparing treatments randomly assigned to an equal number of experimental units (Little and Hills, 1978). The procedures involved in the ANOVA are:

a) Computing the total sum of squares, SSTT.

b) Computing the sum of squares and the mean squares for the sources of variation. The sources of variation are the blocks, the treatments, and the variations among experimental units within a treatment i.e. experimental error, thus SSB, SST and SSE respectively.

c) Computing the F ratio and comparing this to a tabular F value. The statistical significance of the difference between treatments can be tested by the F ratio.

A symbolic summary of the working definitions and formulas as used in the ANOVA are given in table 2.1.

In this table, Y^2_{ij} is the square of the observation from the j^{th} block on the i^{th} treatment and dot notation means that sums be obtained. C is a correction term. The respective mean squares can then be computed by dividing the sum of squares so obtained by the particular degrees of freedom. The F ratio can then be found by dividing each computed mean square value by the error mean square.

Table 2.1 Formulas for the ANOVA for t treatments arranged in a randomised complete block design of r blocks. (modified from Steel and Torrie, 1980; Ch. 9, Table 9.1).

Source of variation	df	Sum of squares
		Definition and working
Blocks	r-1	$\frac{\sum_j Y^2_{.j}}{t} - C$
Treatments	t-1	$\frac{\sum_i Y^2_{i.}}{r} - C$
Error	(r-1)(t-1)	$SSTT - SSB - SST$

The ANOVA has been used for part of the analysis in this project. Techniques for testing the effects suggested by the data are necessary especially when little is known about the nature of the treatments. These techniques are used when comparing all possible pairs of data where previous tests e.g. the ANOVA have been significant. According to Steel and Torrie (1980), various tests that can be used for further comparisons are:

i, Scheffe's test

This is a very general method in that all possible contrasts can be tested for significance or confidence intervals constructed for the corresponding linear functions of parameters. This means that infinitely many tests are permitted.

ii, Tukey's procedure

This procedure makes use of the studentised range and is applicable to pair wise comparison of values. It requires a single value for judging the significance and is thus quick and easy to use.

iii, Student - Newman - Keul's (S-N-K) test

This method is not as conservative as the Tukey's test. It uses multiple ranges for testing. This however, makes it a results - guided procedure, so that it is difficult to describe the error rate.

iv, Duncan's new multiple range test:

This test resembles the S-N-K test in that it uses multiple ranges for testing and is result - guided. It is , however, less conservative and confidence intervals are not as appropriate. Although not as powerful as earlier tests described, this test has the advantage of simplicity and is thus quite popular.

Tukey's procedure has been used where necessary in this project.

3 METHODOLOGY AND ANALYTICAL PROCEDURES

3.1 The experimental drainage system.

The experimental set up consisted of a randomised complete block design with five treatments in three replicates (See fig. 3.1). The treatments were:

i, Perforated P.V.C. pipes, (PPVC).
ii, Bagasse filled drains, (BFD).
iii, Porous concrete drains, (PCD).
iv, Loose rock filled French drains, (RFFD).
v, Control - no drains, (COEX).

Each replicate consisted of 3 drains installed at a depth of 0.9 m and spaced 12.8 m apart. The treatments were separated by polythene sheets. Influence of the adjacent field, A87 (see fig. 1.2) was prevented by means of a terrace drain separating the two fields. Among the drains installed in each replicate, the influence of the middle drain was being monitored, while the other two acted as buffer drains.

Instrumentation involved:

i, Observation wells for measuring water table fluctuations with time.
ii, Measuring cylinder and stop watch for discharge measurement.

The cane in all treatments underwent the same agronomic and cultural treatment.

3.2 Collection of water table and discharge data

The collection of water table and discharge data had been going on since the installation of the different drainage materials in 1993. This research involved a continuation of the data collection.

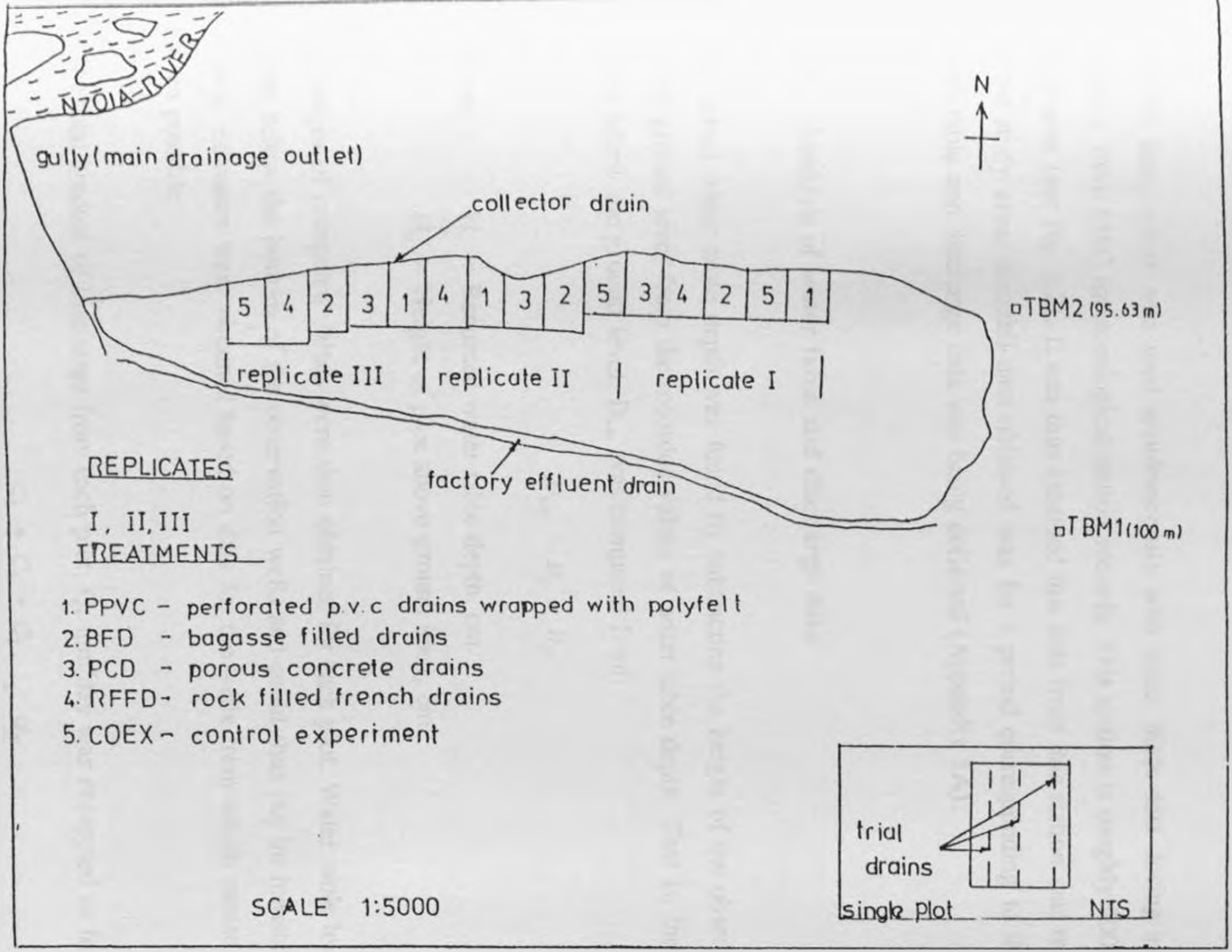


Fig. 3.1 The experimental set up.

For purposes of uniformity, instrumentation was the same as that already in use i.e., observation wells for water table measurements and measuring cylinder and stop watch for discharge measurements. Water table depth was measured using a steel tape. Measurements of water table depth and discharge (when applicable) were carried out on a daily basis.

Rainfall data, which was used simultaneously with water table data during analysis, was obtained from MSC meteorological station records. This station is roughly 500 m from the study area (see fig. 1.2). It was thus assumed that data from this station was representative of the study area. Rainfall data obtained was for a period corresponding to that in which water table and discharge data was being collected (Appendix 1A).

3.3 Analysis of water table and discharge data

The actual water table depth was found by subtracting the height of the observation pipes above ground level from the recorded values of water table depth. That is, the water table depth below the ground level, D_{wt}, was computed from:

$$D_{wt} = H_r - H_p$$

Where : H_r = Recorded water table depth, cm.
H_p = Height of pipe above ground level, cm.

Averages of computed values were then obtained for each plot. Water table levels at times went below the bottom of the observation wells and could thus not be measured. In such cases, estimates were obtained based on data for the wells from which measurements had been possible.

The total amount of discharge from each plot, Q, mm/day was computed as follows:

$$Q = \left(\frac{C_1 * C_2 * C_3}{C_4}\right) * \frac{q_T}{A_P}$$

Where: Q = Total amount of discharge from each plot, mm/day.

q_T = Total amount of discharge from each plot, ml/s.
A_P = Plot area, m^2 (=2520 m^2).
C_1 = Constant for converting ml to cm^3 = $1/10^3(l/ml)*10^3(cm^3/l) = 1$.
C_2 = Constant for converting seconds into days = 3600(s/hr)*24(hr/day) = 86400 s/day.
C_3 = Constant for converting cm to mm = 10.
C_4 = Constant for converting m^2 to cm^2 = 10^4.

Thus:

$$Q = C \sum_{i=1}^{3} q_i$$

Where : Q = Total discharge, mm/day.
q_i = Discharge from the i^{th} drain, ml/s.
C = Constant for converting ml/s to mm/day. (C = 0.0343).

The constant C was obtained from a computation involving all conversion factors involved in converting ml/s to mm/day as well as the plot area as per the equation:

$$C = \left(\frac{C_1 * C_2 * C_3}{C_4 * A_P}\right)$$

All the organised data was then keyed into the computer for analysis (Appendix 1B).

3.3.1 Hydrographs

Hydrographs were drawn based on weekly averages for a duration covering the entire data collection period. These also covered a substantial portion of the crop season. Water table data for August 1994 was however not available due to poor recording. Water table values for plot 15 (3^{rd} replicate of the control) were not available for November 1994 as the cane in this plot was heavily lodged and had covered all the observation pipes. These graphs served to show water table fluctuations and discharge patterns over the entire data collection period and thus over the crop season (Fig. 4.1 - Fig. 4.6).

3.3.2 Computation of indices.

Indices computed were TN45 and TSEW45. These are analogues to some of the indices described in section 2.8.1, i.e. W_x and SEW_x respectively. Thus:

i, TN45 was defined as the total number of days in which water table depth was higher than 45 cm below ground level (days); and,

ii, TSEW45 was defined as the total number of daily values by which ground water table exceeded a level of 45 cm below the surface (cm-days).

Computation of the TN45 and TSEW45 indices was done using a computer programme INDCOM written in Dbase IV. This is a programme that returns cumulative values of N45 i.e. days when water table level exceeded 45 cm below the ground level, and SEW45 i.e. the value in cm-days, by which water table exceeds 45 cm below the soil surface i.e.

$$SEW45 = (45-H_i)$$

Where H_i = Water table depth less than 45 cm below the surface, cm.
SEW45 is in cm-days.

The TN45 and the TSEW45 were taken as the final values of the corresponding cumulative indices. A programme listing of INDCOM and an example of the output are given in Appendix 2A and 2B respectively.

A threshold of 45 cm below the ground surface was chosen as it had been found appropriate for sugarcane (Carter *et al.*, 1988). Also, this value is less than the main root zone depth (50 cm), a requirement suggested by Smedema (1988).

Other indices computed were :

i, The percentage of occurrence, PO (%), where:

$$PO = \frac{TN45}{n} * 100$$

ii, The per day index, PDI (cm), where:

$$PDI = \frac{TSEW45}{n}$$

In both cases, n was defined as the total number of days analyzed for each month. All indices were computed on a monthly basis for all plots.

The computation of the PO and PDI was found necessary for further analysis, as a substantial portion of data was missing in at least all months and these indices were designed to bring the TN45 and the TSEW45 to a common reference point. Further analysis of PDI involved drawing graphs for the entire season. The PDIs were then subjected to statistical analysis.

3.3.3 Statistical analysis

Statistical analysis was carried out on water table and discharge data to find out if there was any significant difference within the treatments (block effects), and thus to reveal if the results obtained were solely due to treatment differences or also due to the influence of inhomogeneities of the soil within the field.

The statistical test used was the ANOVA. A means test, Honestly Significant Difference (Tukey's procedure), was used to test the effects suggested by the data. This test was used as critical values required for comparisons are smaller than those required by other tests of significance. It is also a quick and easy method to use (Steel and Torrie, 1980).

Statistical analysis was done for all discharge events and corresponding water table depths. Also analyzed were water table depths for the periods during which recessions occurred and dry spells were experienced thereafter. This was done because results suggested by the data were thought to be due to differences in soil types rather than the hydraulic performance of the drains. The soils in block 1 (see fig. 3.1) have a high clay content with the gley layer occurring at relatively shallow depths. Those in block 3 have plinthite while those in block

2 have a mixture of both.

Statistical analysis of the PDIs was carried out using STATAN a computer programme written in Dbase IV. This is a programme that performs the ANOVA procedure and returns values of the sum of squares, mean squares and the calculated F statistic. A programme listing of STATAN and an example of the output are presented in Appendix 3A and 3B respectively.

3.4 Crop response data collection

Crop response data collected was that of cane and sugar yields and other cane parameters i.e. plant population, internode lengths and overall plant height. Before commencing on data collection, some cane was cut off and discarded, from each plot, thus forming 'guard rows' (Plate 3.1). This was done in order to eliminate the influence between adjacent plots as well as the influence of the collector drain and the adjacent field A87 (see fig. 1.2). Guard rows occurring between the plot also served as fire breaks during actual harvesting.

Plate 3.1 Clearance of guard rows prior to harvesting.

3.4.1 Plant population

This was determined by counting all stalks within a sampling area. Sampling areas were taken as regions covering 3 rows of sugarcane and being 3 meters in length. Six sampling areas per plot were taken at random in accessible regions with the region between the drains being targeted. Access to the interior of the cane field was difficult as the cane was heavily lodged. Averages from these areas were considered to be able to give samples representative of the actual plant population.

3.4.2 Plant height

This was determined by measuring 10 whole stalks within each of the sampling areas described above. The stalks measured were chosen at random within the sampling areas. Measurements were taken from a reference point at the bottom of the stalk to the top visible dewlap (TVD), giving the height of the actual millable stalk.

3.4.3 Internode lengths

Average internode lengths were determined from 10 stalks within each sampling area. Stalks were selected at random. Sampling areas from which the stalks were measured were the same as those described in section 3.4.1.

3.4.4 Cane yields

Cane yields were determined by weighing all the cane within the net area for each plot. It was decided that all cane be weighed rather than taking samples so that any sections where germination may have failed to take place were not left out.

The cane was burnt before cutting to remove the leafy tops and trash. Harvesting was done on a block after block basis. This was done so as to ensure that all the cane within a block was affected by similar conditions that may have prevailed during the harvesting period. Any differences so obtained could be attributed solely to treatment differences. The guard rows here also served as fire breaks.

The cane was then cut, with care being taken to cut at the stalk bottom so as not to loose cane tonnage through high cutting as well as for the sake of subsequent ratooning which could be affected by high cutting. After cutting, the cane was loaded onto trailers using a grab loader. Weighing was done on a plot by plot basis; trailers were first assigned to a particular plot and loaded until all the cane from a plot had been collected. Once off loaded, the trailers were assigned to another plot (Plate 3.2.).

Plate 3.2 Cut cane being loaded for weighing.

All trailers from each plot were weighed at the company's weigh bridge both when loaded and after off loading. Weigh bridge tickets, from which net cane weights could be obtained (see Appendix 4), were obtained for each trailer. Total cane in tonnes from each plot was then obtained by adding figures from the tickets obtained for all trailers that served a particular plot. Thereafter, a cane loss assessment was carried out by collecting and weighing all the cane that remained on the ground after loading. Weighing was done using a mobile weighing balance.

3.4.5 Sugar yields

A sample consisting of 24 whole stalks was taken from each plot for the determination of sucrose content. Stalks were taken at random from the entire plot after the cane had been burnt. Thereafter, the sampled cane was carried to the MSC Agronomy laboratories where the cane was first chopped into pieces and then shredded. Thereafter a 500g sample was taken and put in a cylinder and then squeezed in a hydraulic press for juice extraction (Plate 3.3). The juice obtained was taken for analysis. Using a refractometer, the density (Brix) and temperature measurements were obtained, from which the corrected brix was calculated using tables. Some juice was also taken to the polarimeter from which the pol reading was obtained. Calculations that followed were that:

$$Pol\% = \frac{Pol\ reading}{Pol\ factor}$$

The Pol factor was obtained from tables (see Appendix 5A).

$$Purity\% = \frac{Pol\%}{Corrected\ Brix}$$

$$Fibre\% = \frac{Wet\ weighed\ press\ cake * dry\ fibre\%}{500}$$

500 g was the weight of bagasse subjected to pressing in the hydraulic press.

$$Available\ Pol\% = Fibre\ ratio * Pol\% * purity\ ratio$$

The ratios used were obtained from tables (Appendix 5A). Data obtained was then subjected to further analysis. These preliminary results are given in Appendix 5B.

Plate 3.3 The hydraulic press - used for juice extraction.

3.4.6 Other parameters

Other parameters measured were lodging, diseases and pests, late tillers and trash levels. This was done by visual assessment and scoring; 5 being taken as a measure of extreme cases. These parameters were measured as it was considered that such parameters would be useful during the assessment of data obtained. e.g. high incidence of diseases and pests would indicate that the crop suffered water logged conditions during the maturity stage (Barnes, 1984).

3.5 Analysis of crop response data

3.5.1 Plant population data

Plant population values obtained from the sampling areas of each plot were averaged to obtain a single value. The plant population in number of plants per hectare was then obtained by dividing the average plant population obtained by the sampling area, i.e.

$$Plant\ population = \frac{Average\ number\ of\ stalks}{Sampling\ area}$$

Plant population data obtained for each plot was then tested for significant differences using the ANOVA procedure.

3.5.2 Plant height data

Average lengths of the 10 stalks measured from each sampling area were obtained and then an average was obtained from the six sampling areas in each plot. This data was also subjected to statistical analysis using the ANOVA procedure.

3.5.3 Internode lengths

Data obtained for internode length was subjected to the same kind of analysis as the plant height data. In all cases the ANOVA procedure was executed using ANOVAS, a computer programme modified from STATAN, the programme used for analyzing the indices.

3.5.4 Cane yield data

Once harvesting had been done, a survey was carried out to establish the actual net - areas for each plot. The cane tonnage obtained was then divided by the net area to give the Tonnage of Cane per Hectare (TCH, tonnes /ha), Thus:

$$TCH_i = \frac{T_i}{A_i} \qquad \forall i = 1,2,..,15$$

Where: T_i = The total tonnage obtained in the ith plot.

A_i = Net area of the ith plot, ha.

The TCH values obtained were also subjected to statistical analysis using ANOVAS.

3.5.3 Sugar yields data

Once the available Pol% had been obtained, the Total Extractable Sugar per Hectare (TESH, tonnes/ha) was computed as follows.

$$TESH = Available\ Pol\% * TCH$$

Where TCH is as previously described.

Thereafter, the Total Extractable and Recoverable Sugar per Hectare (TERSH, tonnes/ha) was computed from:

$$TERSH = TESH * 0.1$$

Where 0.1 represents the ratio of recoverable sugar to extractable sugar. The figure was obtained from the MSC Factory Production Department.

Values obtained were also subjected to statistical analysis using ANOVAS.

4 RESULTS AND DISCUSSION

The results obtained from the analyses described in the previous chapter are presented in this chapter. The drainage materials will be referred to by their abbreviations, with the numbers 1, 2, 3, representing the various replicates where necessary; thus PPVC1, BFD1, ..., COEX3.

4.1 Results

During the organization of raw data, the following was noted :

i, It was noted that water table depths remained very deep even more than 140 cm deep in some cases and more or less constant during the particularly dry periods (mainly January / February 1994).

ii, A poor performance of BFD1, RFFD1 was also noted. The BFD1 discharged only for a short while and thereafter failed to discharge. The RFFD1 failed to discharge right from the start. For PCD1 discharge measurement was hindered as drains had been placed too low during installation i.e. there was not enough space between the drain outlet and the bottom of the collector drain to allow for discharge measurement (plate 4.1; 4,2). Where discharge was obtainable, however, it was relatively low. It was suspected that in some parts, the polyfelt got smeared with mud during installation causing the low discharge. The drain outlets also got submerged during the rainy season. Consequently outflow of water was hindered and back water effects were significant.

4.1.1 Water table hydrographs

Hydrographs were used to show water table fluctuations during the crop season. Generally, observed high water tables were attributed to occurrence of rainfall events, given that there was no irrigation. Falling water tables in periods where there was no rainfall for long periods, and therefore no discharge, were attributed solely to evapotranspiration. Detailed results are as presented in this subsection.

Plate 4.1 PCD1 - drain outlet placement hinders measurements.

Block 1

In January and February 1994, water table in all plots decreased considerably. This decrease continued until mid March 1994. However, since no discharge was observed during this

Plate 4.2 Collector drain banks at times collapsed resulting in stagnant water and hindering discharge measurements.

period, water table could be attributed solely to evapotranspiration. For those treatments in which the water table was already low as a result of previous discharge e.g. PPVC, final water table was relatively low (up to 150 cm). Later, rainfall caused the water table to rise in all the plots (fig. 4.1).

Results from the figure indicate that during rainy periods, PPVC1 was effective in maintaining the water table at more than 45 cm below the soil surface for most of the time. This was also reflected in the low PDIs and the POs computed (see fig. 4.7). In the other cases water tables remained within the main root zone during the rainy period.

Apart from PPVC1, water table in the drained treatments did not always decrease faster than in the control. During the rainy periods, the control and RFFD1 registered considerably higher water tables.

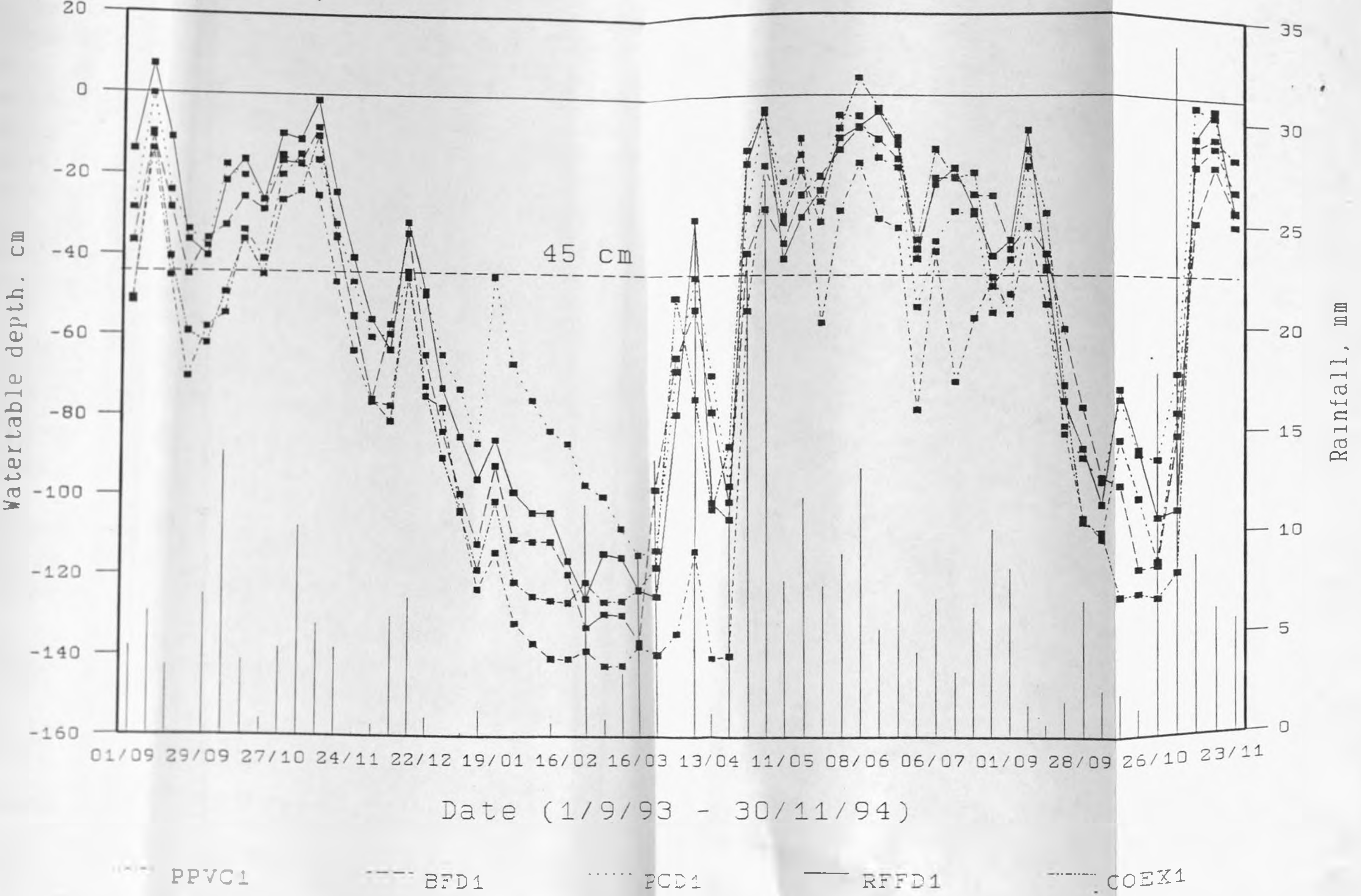


Fig. 4.1 Block 1 - Water table depths for drained and undrained plots in relation to rainfall.

Block 2

In this case it was noted that water table depth in the undrained plot COEX2 was noticeably higher than in the other plots during the wet periods. Also PPVC2 lowered water table faster and to lower depths than all the other drained treatments. PPVC2 also had correspondingly higher discharges (see fig. 4.2). PPVC2 and RFFD2 were, on average, able to maintain the water table below the 45 cm depth most of the time. For the others, water tables remained within the main root zone during the rainy periods. Throughout the rainy periods, water tables in the undrained plot fluctuated between the soil surface and the 45 cm depth, sometimes even rising above the soil surface.Water table depths dropped considerably in the period from late December 1993 to mid March 1994. During this time significant sugarcane growth had occurred and water table recessions could be attributed to evapotranspiration.

Occurrence of rainfall and reduced evapotranspiration thereafter caused water table to rise in all the treatments. Water table in COEX2 rose fastest followed by those of BFD2. Lower rates of water table rise were observed in PPVC2 probably due to the occurrence of relatively high discharges (see fig. 4.5). On average, PCD2 and RFFD2 also performed fairly well.

In October 1994, rainfall decreased and water tables dropped considerably. Water tables then rose again following heavy rains in November 1994; COEX2 and BFD2 again having relatively high water tables and PPVC2 having the lowest water table depths.

Block 3

Like for the other blocks, it was observed that water tables dropped between late December 1993 and mid March 1994, this being attributed to evapotranspiration, as previously explained.

On average, water tables fluctuated below the 45 cm depth most of the time, except for the BFD and the RFFD which at times even exhibited higher water tables than the control. Water table elevations for the various treatments are shown in fig.4.3. Water tables during the rainy periods were generally lower in this block as compared to the other blocks.

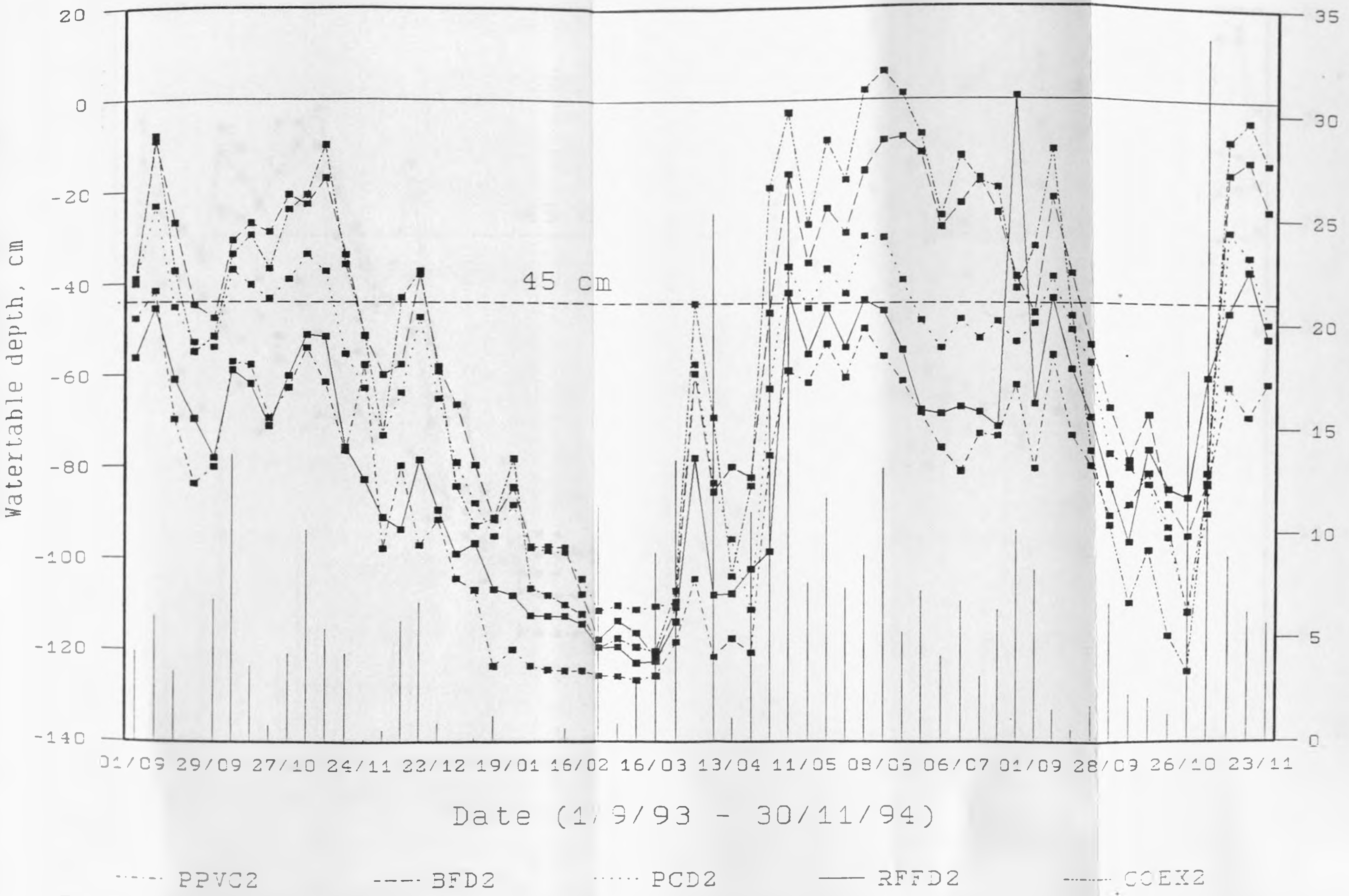


Fig. 4.2 Block 2 - Water table depths for drained and undrained plots in relation to rainfall.

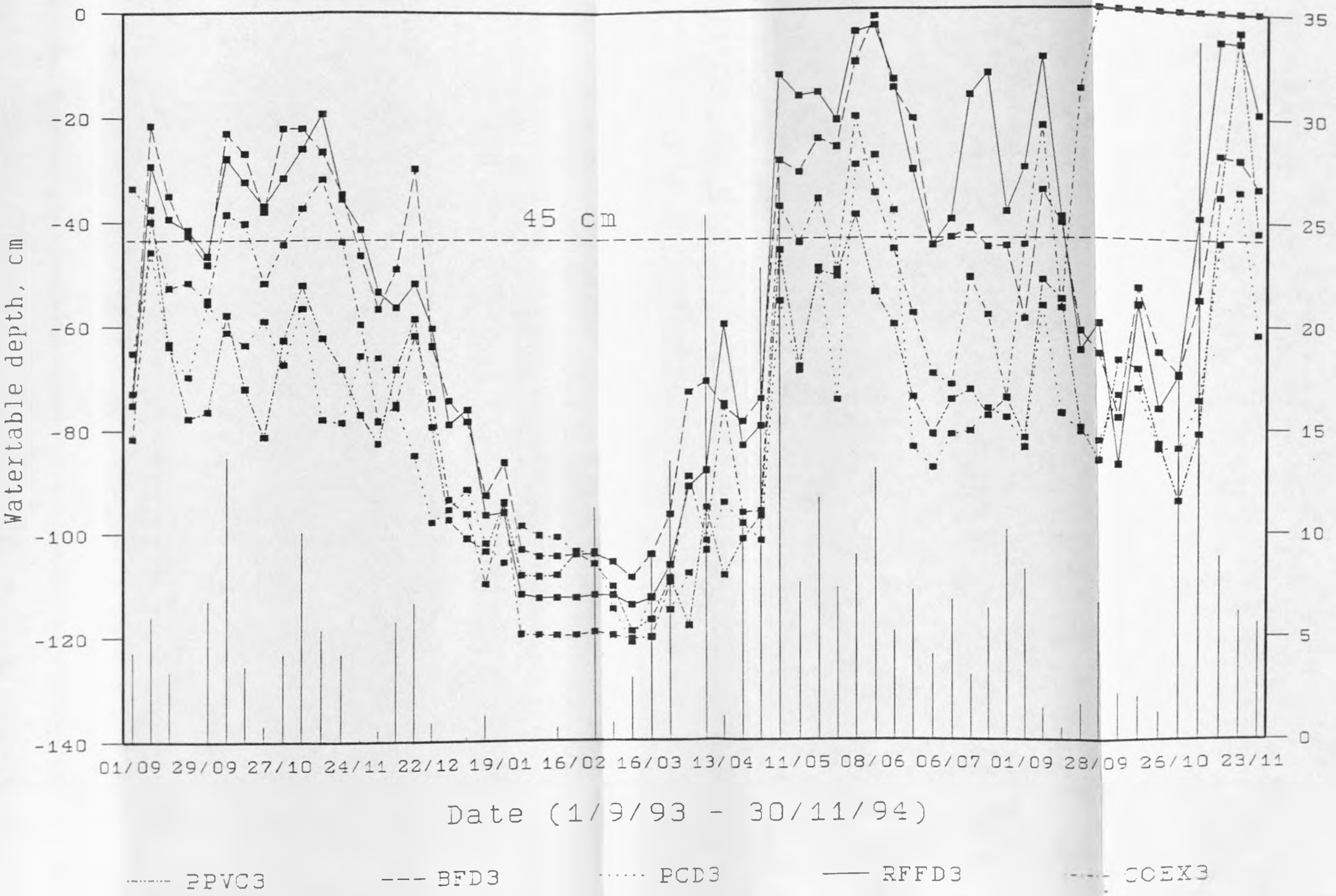


Fig. 4.3 Block 3 - Water table depths for drained and undrained plots in relation to rainfall.

This could be explained considering the differences in soil types encountered within the blocks, block 3 being in an area with a lot of plinthite and the other blocks having the gley layer occurring high in the soil profile.

Further investigations on the soil moisture characteristics of the soils in the various blocks showed that at any particular suction, soils in block 1 had a greater water content than those in block 2. Soils in block 3 had the lowest water content at the same suction (see Appendix 6).

A textural analysis showed that block 3 soils were generally coarse grained. These contained a higher sand percentage and a lower clay percentage than soils in the other two blocks (Appendix 7). These soils would naturally drain more easily, thus the lower water tables observed.

4.1.2 Discharge hydrographs

Discharge from each block for all treatments was as shown in figures presented in this sub section. Discharges were generally higher after heavy rainfall due to a larger hydraulic head. The peak rates for the drains that discharged varied widely with PPVC registering the highest average peaks for blocks 1 and 2 (15.4 mm/day and 19.9 mm/day respectively) whilst PCD3 registered the highest (16.1 mm/day) for block 3.

Specifically:

Block 1

In block 1 only PPVC showed considerable discharge (fig. 4.4). For PCD, little discharge was collected though a lot of readings were lost due to improper positioning of the drains, these having been placed too low.

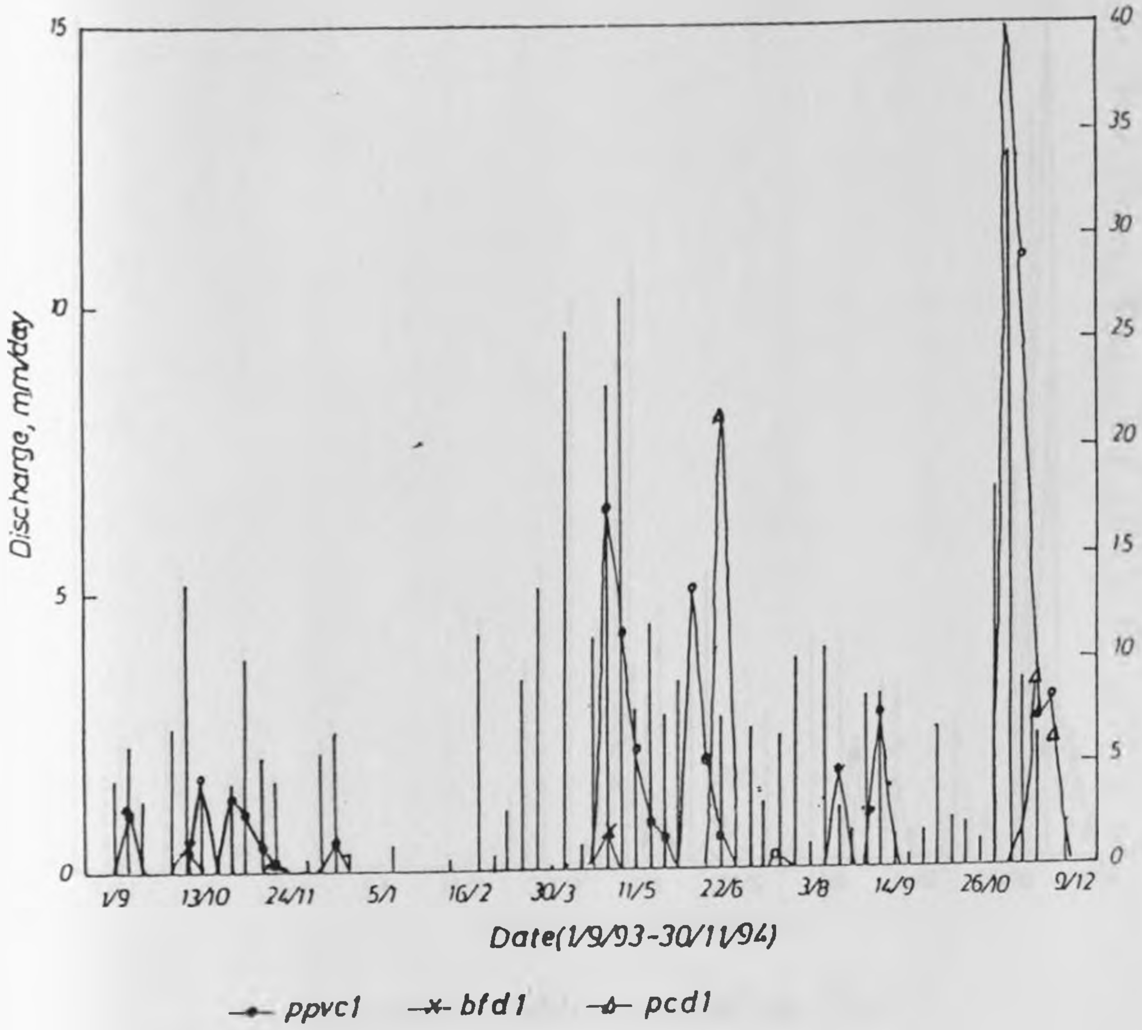


Fig. 4.4 Block 1 - Drain flows

Block 2

Here, there was at least some discharge in all the drains during the rainy periods; PPVC and PCD having the highest discharges. BFD, however, did not perform very well (fig. 4.5).

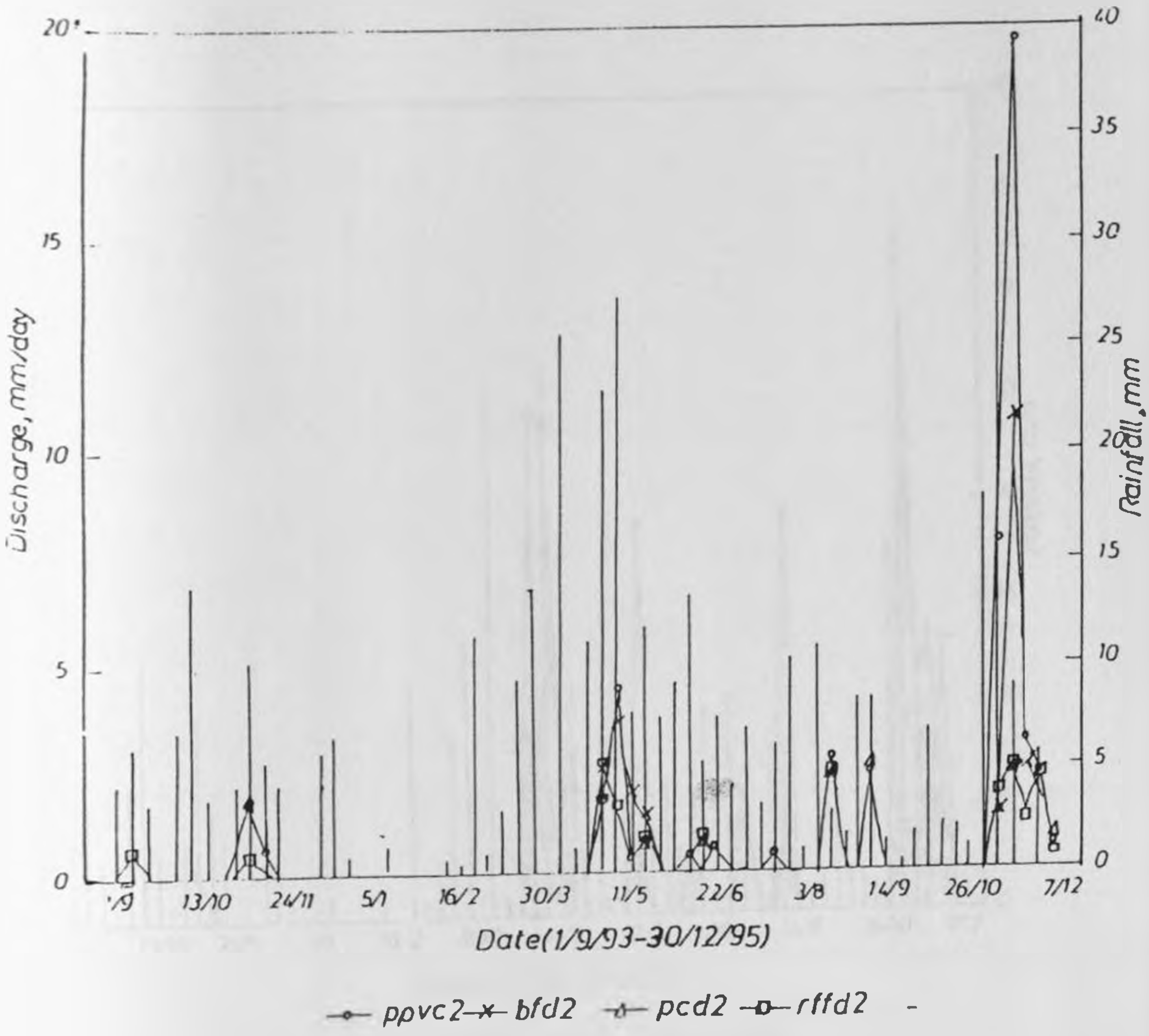


Fig. 4.5 Block 2 - Drain flows

Block 3

Discharges were higher and more frequent in these drains as compared to those in blocks 1 and 2. PCD in this case attained highest discharges for most of the time. BFD also did not perform as badly as in the other plots though its response was lagged and short lived (fig. 4.6).

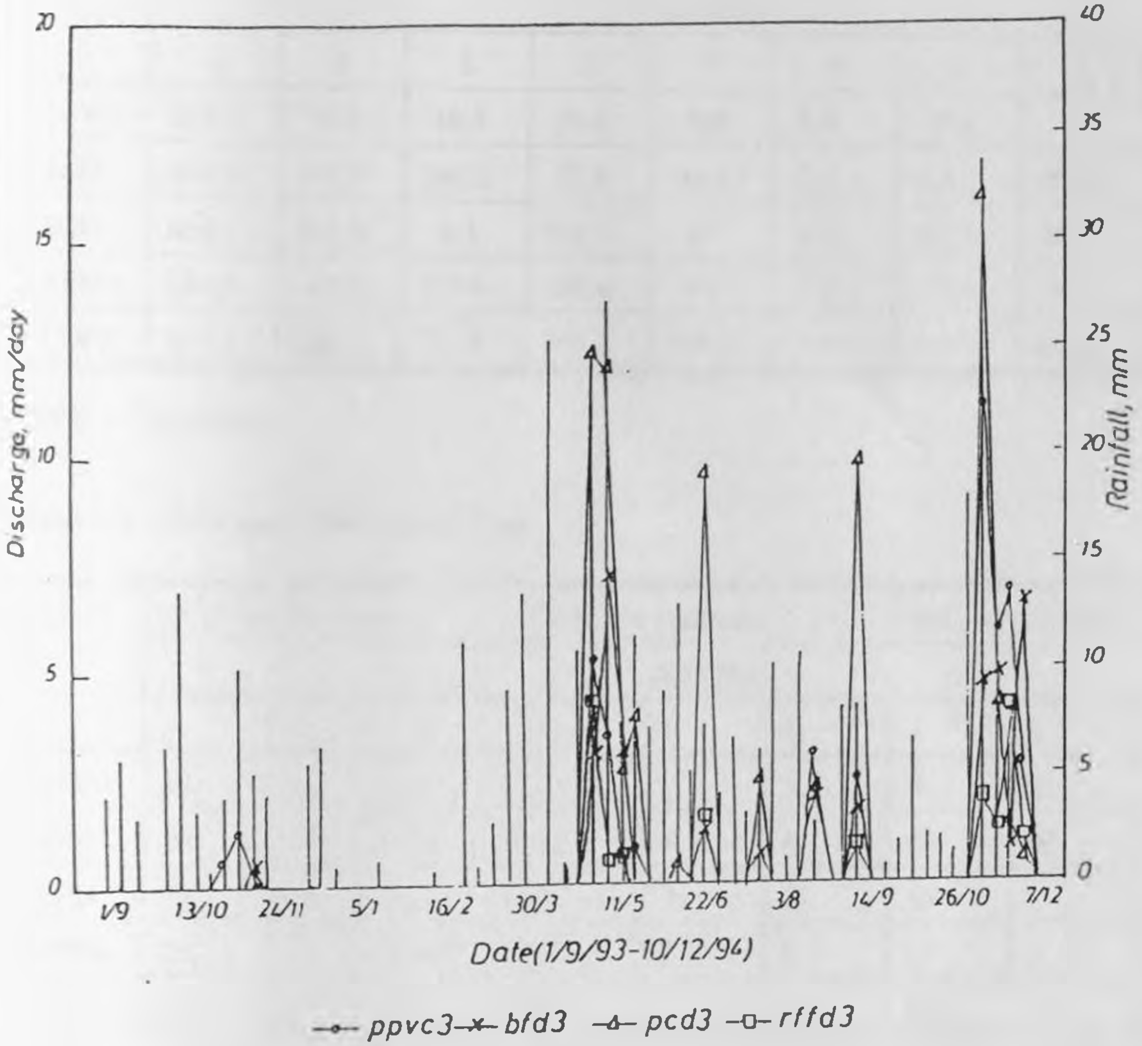


Fig. 4.6 Block 3 - Drain flows

4.1.3 Indices computation

Indices computed using INDCOM were the TSEW45 and the TN45. Some of the results are as shown in the tables 4.1 and 4.2. Figures in brackets represent the number of days for which readings were taken in the particular month.

Table 4.1 Computed TSEW45 values, cm-days.

TRT*	OCT.’93 (21 days)			APR.’94 (18 days)			SEP.’94 (23 days)		
	BLOCKS								
	1	2	3	1	2	3	1	2	3
PPVC	242.5	20.0	10.3	20.8	0.0	0.0	79.8		0.0
BFD	403.5	376.9	359.3	72.4	43.4	0.0	124.1	180.8	97.0
PCD	505.3	122.0	0.3	105.7	8.7	0.0	207.7	45.1	0.5
RFFD	541.0	10.8	254.4	185.6	0.0	0.0	257.0	14.1	281.4
COEX	215.1	296.7	73.9	195.3	118.0	0.0	279.7	266.6	560.7

*TRT = Treatment

Table 4.2 Computed TN45 values, days.

TRT*	OCT.’93 (21 days)			APR.’94 (18 days)			SEP.’94 (23 days)		
	BLOCKS								
	1	2	3	1	2	3	1	2	3
PPVC	14	1	1	2	0	0	7	0	1
BFD	19	19	19	5	3	0	12	10	9
PCD	21	13	1	5	2	0	10	7	1
RFFD	20	1	19	9	0	0	11	5	11
COEX	13	17	13	6	3	0	13	10	19

*TRT = Treatment

It can be observed that in most cases plots in block 3 had the lowest observed TSEW45 and thus water table depth here was relatively low. Also TN45 was in most cases, lower in block 3 than in the other blocks. In some cases water table was higher than 45 on all days for which data was collected. Higher values obtained for RFFD3 and COEX3 (Sep’94) could be attributed to an overflow from a blocked terrace drain, which affected these plots.

Further analysis involved the computation of POs and PDIs. Some of the values obtained are as shown in tables 4.3 and 4.4.

From the tables, it can be seen that treatments in block 1 generally had higher water tables and thus higher PDIs than the corresponding ones in the other two blocks. These were not uniformly high but varied with time. This could probably be attributed to various environmental factors e.g. differences in evapotranspiration, which also played a role in lowering the water table. High values of POs can be noticed especially in the COEXs and RFFDs. Also, that treatments in block 1 registered higher PO values than those in the other two blocks can be noticed.

Table 4.3 Computed PDI values.

TRT	SEP93	OCT93	NOV93	JUL94	SEP94
PPVC1	10.36	11.5	11.16	2.53	3.47
PPVC2	3.0	0.95	0.77	0	0
PPVC3	5.6	0.49	0.82	0	0.09
BFD1	17.99	20.15	17.55	21.15	5.39
BFD2	17.60	18.83	14.74	21.00	7.86
BFD3	10.39	17.96	10.41	3.23	4.22
PCD1	24.72	24.06	16.37	10.27	9.03
PCD2	7.81	5.81	5.02	0.17	1.96
PCD3	2.72	0.01	0.36	0	0.02
RFFD1	32.70	25.76	23.83	18.83	11.17
RFFD2	2.25	0.51	2.34	0	0.61
RFFD3	7.37	12.11	13.30	18.29	12.23
COEX1	12.01	10.24	15.31	22.34	12.16
COEX2	15.01	14.21	15.91	24.20	11.59
COEX3	2.54	3.52	6.09	0	11.12

Graphs were drawn to show the PDI and PO behaviour for the entire period. These graphs were as presented in figs. 4.7-4.9. Generally, high PDIs were associated with high rainfall and to some extent, with the number of days for which water tables were above a 45 cm depth. PDIs were highest in May - June 1994, a period in which there were heavy rains for a considerable period of time.

Table 4.4 Computed PO values.

TRT	SEP93	OCT93	NOV93	JUL94	SEP94
PPVC1	47.6	66.7	45.8	44.4	30.4
PPVC2	23.0	4.8	8.3	0	0
PPVC3	38.8	4.8	12.5	0	4.3
BFD1	85.7	95.0	75.0	100	52..5
BFD2	85.7	95.0	70.8	100	43.5
BFD3	80.9	95.0	79.2	44.4	39.1
PCD1	95.2	100.0	83.3	83.3	43.5
PCD2	57.1	61.9	33.3	5.7	30.4
PCD3	23.8	4.8	8.3	0	4.3
RFFD1	100.0	95.2	87.5	100	47.8
RFFD2	19.0	4.8	16.7	0	21.7
RFFD3	81.0	90.5	91.7	83.3	47.8
COEX1	47.6	61.9	62.5	88.9	56.0
COEX2	71.4	80.9	75.0	88.9	43.5
COEX3	38.1	4.8	41.7	0	71.4

Block 1

Here, only PPVC showed relatively low PDI values. Values obtained for the other treatments often almost equalled and at times even exceeded PDI values of the control. RFFD, in particular, showed considerably high PDIs in the early months. PCD also behaved in a similar manner except in July 1994 where the PDI value was relatively low (fig. 4.7).

Block 2

For PPVC low to nil PDI values were obtained. PDI values equal to zero meant that water table depths in the particular plot were below the 45 cm depth throughout the month. Markedly high PDI values were observed in the control and in BFD. Low PDI values obtained for the other drained plots indicated that water table depths were lowered faster by these drains as compared to the BFD (fig. 4.8).

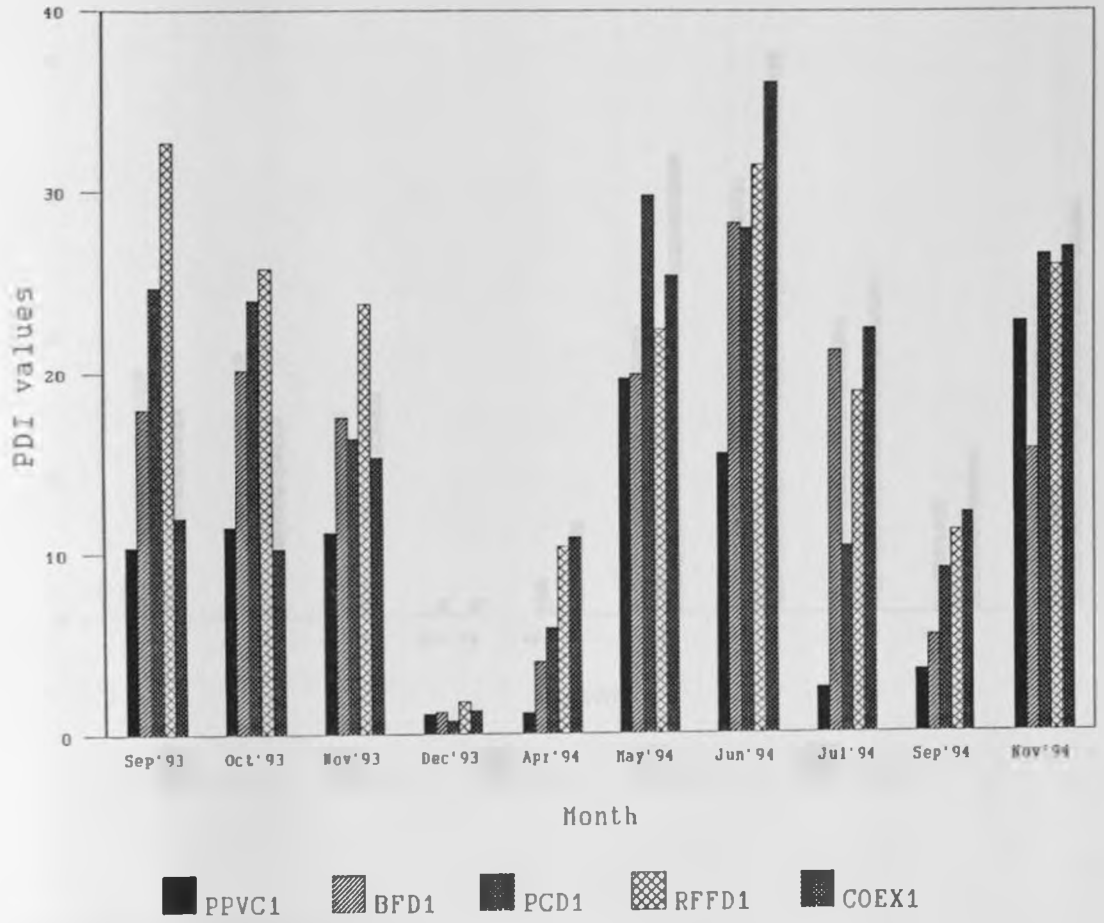


Fig. 4.7 Block 1 - PDI values

Block 3

Higher PDI values were observed in the BFD and RFFD as compared to those for the other drained plots as well as for the control. PDI values were relatively lower and at times equal to zero for PCD3 indicating that these drains lowered the water table relatively fast (fig. 4.9). It was also noted that PDI values were nil in April 1994 for all treatments, despite the fact that there was some amount of rainfall during this period. Water table rise was slower than that in the other two blocks. This could however be explained, as previously, due to variations in soil types.

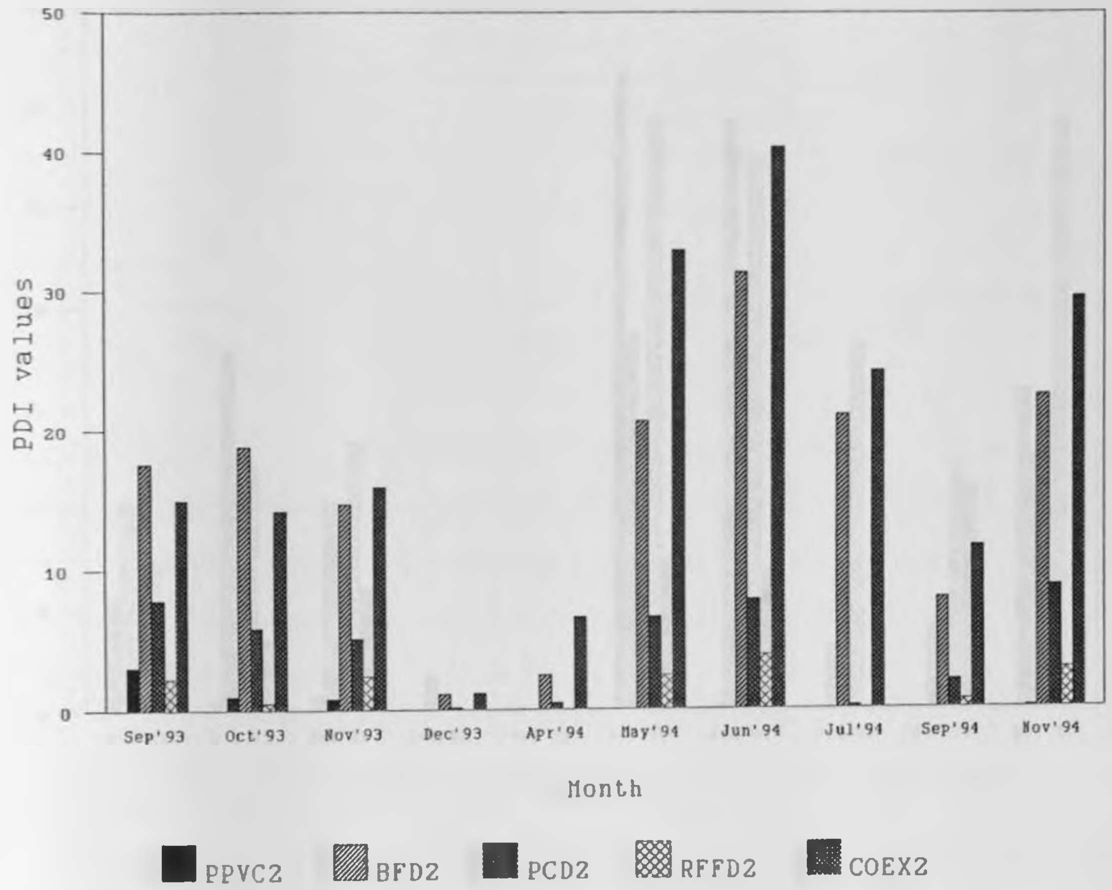


Fig. 4.8 Block 2 - PDI values

4.1.4. Statistical analysis of Water table and discharge data

Statistical analysis of water table data was first carried out for the wet periods i.e. October / November 1993, April 1994 and November 1994. Results obtained are presented as follows. In all cases df, SS and MS mean degrees of freedom, sum of squares and mean squares respectively.

Results from PCD in Oct./Nov. 1993 showed that all three replicates were different, while those of COEX showed that COEX1 and COEX2 were significantly different from COEX3, though there was no significant difference between COEX1 and COEX2. Results for PCD are shown in the tables below.

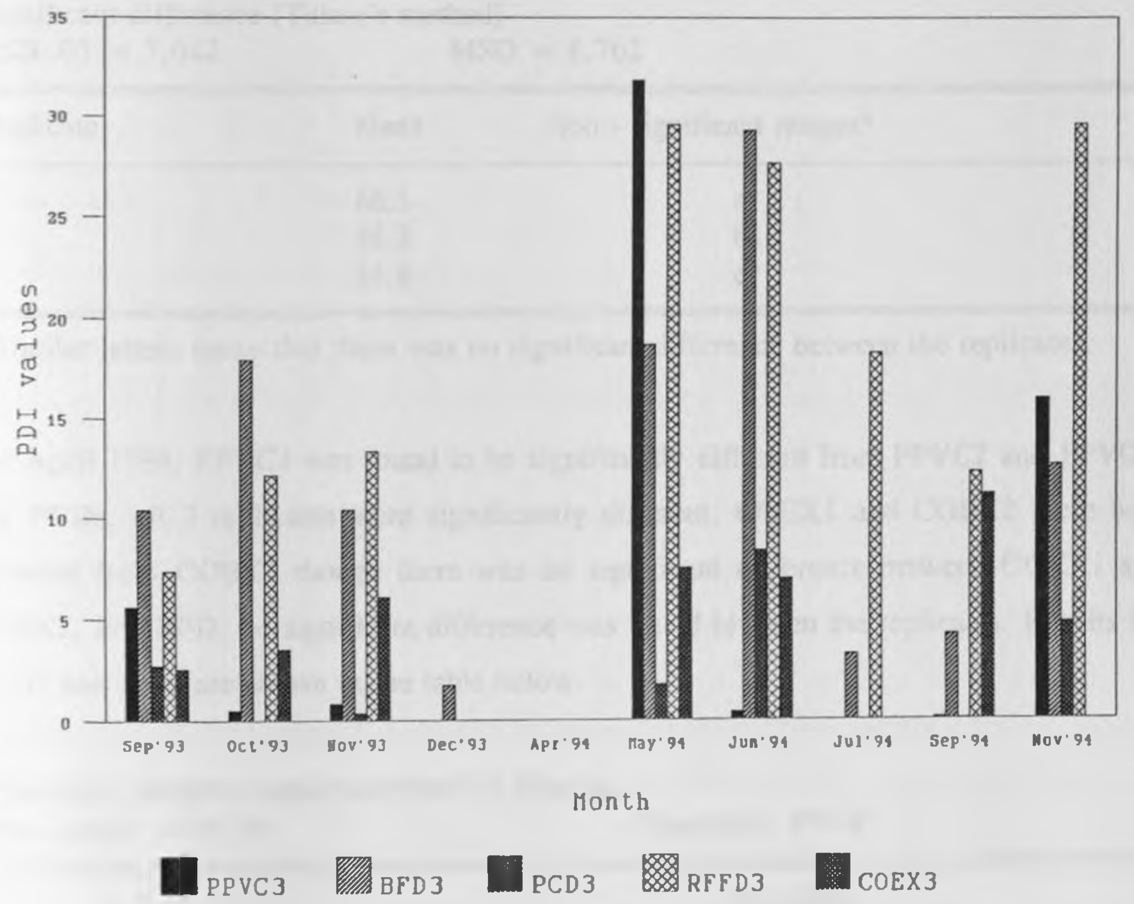


Fig. 4.9 Block 3 - PDI values

Table 4.5a ANOVA table for PCD in OCT/NOV'93.

Time period: Oct/Nov'93 Treatment: PCD

				F-Values		
					Table	
Source of variation	df	SS	MS	calculated	5%	1%
Total	128	59417.43				
Main effects	2	37396.10	18698.05	106.99	3.00	4.61
Error	126	22021.33	174.77			

Calculated F statistic was highly significant.

Table 4.5b Means test for PCD in OCT/NOV '93.

Significant difference (Tukey's method)
LSD .05 = 5.642   MSD = 6.762

Replicate	Mean	Non - significant ranges*
3	66.5	a
2	44.2	b
1	24.8	c

* Similar letters mean that there was no significant difference between the replicates.

For April 1994, PPVC1 was found to be significantly different from PPVC2 and PPVC3. For PCDs, all 3 replicates were significantly different. COEX1 and COEX2 were both different from COEX3 though there was no significant difference between COEX1 and COEX2. For BFD, no significant difference was found between the replicates. Results for PPVC and BFD are shown in the table below.

Table 4.6a ANOVA table for PPVC in APR'94.
Time period: APR'94   Treatment: PPVC

Source of variation	df	SS	MS	F-Values		
					Table	
				calculated	5%	1%
Total	59	34215.19				
Main effects	2	13643.10	6821.55	18.9	2.99	5.12
Error	57	20572.08	360.91			

Calculated F statistic was highly significant

Table 4.6b Means test for PPVC in APR'94.
LSD .05 = 9.822   MSD = 14.458

Replicate	Mean	Non - significant ranges
3	62.7	a
2	61.5	a
1	30.1	b

Table 4.7 ANOVA table for BFD in APR'94.

Time period: APR'94 Treatment: BFD

Source of variation	df	SS	MS	F-Values calculated	Table 5%	Table 1%
Total	59	15749.60				
Main effects	2	589.71	294.85	1.11	2.99	5.12
Error	57	15159.90	265.96			

Calculated F statistic was not significant.

For November 1994, PPVC2 was found to be significantly different from both PPVC1 and PPVC3, though there was no significant difference between PPVC1 and PPVC3. For the BFDs, there was no significant difference between BFD3 and BFD1 and none also between BFD1 and BFD2. However, BFD3 was significantly different from BFD2 at the 5% level. At the 1% level, there was no significant difference between the replicates. For the PCDs, PCD1 was significantly different from PCD2 and PCD3 though the latter were not significantly different from each other. RFFD2 was significantly different from RFFD3 and RFFD1 which were both not different from each other. COEX1 and COEX2 were not significantly different. COEX3 values were not available given that the crop had lodged heavily, rendering the observation pipes inaccessible.

Results for BFD for November 1994 are shown in the tables below.

Table 4.8a ANOVA table for BFD in Nov'94.

Time period: NOV'94 Treatment: BFD

Source of variation	df	SS	MS	F-values calculated	Table 5%	Table 1%
Total	53	8983.928				
Main effects	2	1315.468	657.734	4.374	3.07	5.14
Error	51	7668.461	150.362			

Calculated F statistics was significant at the 5% level.

Results observed from statistical analysis of corresponding discharge events showed no significant differences within the treatments. Some results are also shown.

Table 4.8b Means test for BFD in Nov'94.

LSD 0.05 = 6.3562 LSD 0.01 = 8.4715

Replicate	Mean	Non-significant ranges 5%	1%
3	29.6	a	a
1	23.1	ab	a
2	17.6	b	a

Table 4.9 ANOVA table for PCD in OCT/NOV'93.

Time period: OCT/NOV'93 Treatment: PCD

Source of variation	df	SS	MS	F-Values calculated	Table 5%	1%
Total	128	54.794				
Main effects	2	0.900	0.450	1.052	3.00	4.61
Error	126	53.894	0.428			

Calculated F statistic was not significant.

Table 4.10 ANOVA table for BFD in APR'94.

Time period: APR'94 Treatment: BFD

Source of variation	df	SS	MS	F-Values calculated	Table 5%	1%
Total	128	998.063				
Main effects	2	22.547	11.273	0.797	3.13	4.93
Error	126	975.516	14.138			

Calculated F statistic was not significant.

Results obtained are further dealt with in the discussion.

4.1.5 Statistical analysis of Indices

Results obtained from statistical analysis of PDIs using STATAN are presented in table 4.11. ANOVA computation show that in most cases there were no significant differences between the treatment and within the treatments except in September 1993, November 1993 and April 1994 where block effects were found significant at the 5% level of significance and in November 1993 and September 1994 where treatment effects were found significant, also at the 5% level.

Table 4.11 F - statistic and significance for TSEW45.

	F - VALUES									
	BLOCKS			TREATMENT			SIGNIFICANCE			
	Fcal	Ftab		Fcal	Ftab		Blocks		Treatment	
MONTH		5%	1%		5%	1%	5%	1%	5%	1%
SEP93	4.864		4.46	8.65	0.717	3.84	7.0	*	NS	NS
OCT93	4.301			1.641			NS	NS	NS	NS
NOV93	5.434			4.756			*	NS	NS	NS
DEC93	0.999			0.194			NS	NS	NS	NS
APR94	8.556			1.889			**	NS	NS	NS
MAY94	1.614			0.821			NS	NS	NS	NS
JUN94	1.878			2.108			NS	NS	NS	NS
JUL94	1.985			1.883			NS	NS	NS	NS
SEP94	0.978			3.907			NS	NS	*	NS
NOV94	1.602			1.288			NS	NS	NS	NS

Fcal, Ftab = calculated and tabled values of the F statistic respectively.
* = significant ** = very significant NS = not significant

4.1.6 Cane response data.

Plants were relatively tall, registering on average, plant heights of between 275.7 cm - 294.4 cm. Internode lengths were also large, up to 15.4 cm. Plant populations recorded were high, averaging between 87.7 - 95.0 thousand plants per hectare, compared to the expected plant population for the variety i.e. 66 thousand plants per hectare.

Cane and sugar yields on average ranged between 115 tonnes/ha - 140 tonnes/ha and 14.5 tonnes/ha - 17.0 tonnes/ha respectively. In both cases, lowest values obtained were for RFFD followed by PPVC. PCD had a higher TCH (139) tonnes/ha and TESH (15.2) tonnes/ha than the PPVC. TEST values obtained were highest for RFFD, 1243 Kg/tonne cane and lowest for PCD, 1180 Kg/tonne cane. Actual values obtained are presented in table 4.12.

Table 4.12 Actual crop response data

TRT	PLANT HEIGHT cm	INODE cm	POP * 10^3	AREA ha	TPPLT	TCH	TEST	TESH	TERSH
PPVC1	326	16.1	80.2	0.15	18.3	122	0.124	15.2	1.52
PPVC2	265	14.2	98.3	0.15	16.1	123	0.115	14.1	1.41
PPVC3	264	15.7	84.7	0.12	15.4	129	0.119	15.3	1.53
BFD1	281	14.4	92.8	0.14	18.5	132	0.114	15.1	1.51
BFD2	288	14.5	88.9	0.17	22.2	130	0.116	15.1	1.51
BFD3	265	14.8	95.4	0.15	21.5	143	0.127	18.2	1.82
PCD1	287	14.1	86.5	0.16	23.1	144	0.124	14.2	1.42
PCD2	269	14.9	96.5	0.13	19.1	147	0.120	17.7	1.77
PCD3	271	14.6	96.6	0.12	15.0	125	0.111	13.9	1.39
RFFD1	283	14.0	82.6	0.17	18.2	107	0.129	13.8	1.38
RFFD2	269	14.6	98.7	0.16	19.9	124	0.119	14.8	1.48
RFFD3	281	15.8	93.4	0.16	19.8	123	0.125	15.4	1.54
COEX1	321	16.1	93.0	0.15	20.5	137	0.110	15.1	1.51
COEX2	284	14.2	92.2	0.16	21.9	137	0.123	16.8	1.68
COEX3	277	15.9	99.9	0.14	20.5	146	0.124	18.2	1.82

INODE = Internodes; POP = Population; TPPLT = Tonnage per plot
TCH = Tonnage of Cane per Hectare; TRT = Treatment
TEST = Tonnes of Extractable Sugar per Tonne of cane
TESH = Tonnes of Extractable Sugar per Hectare
TERSH = Tonnes of Extractable and Recoverable Sugar per Hectare

Where cane yields were concerned, PPVC was consistent having almost the same values throughout. Lower values were obtained for PCD3 and RFFD1 as compared to the other replicates of corresponding treatments. Similarly, higher values were obtained for BFD3 and COEX3.

In general cane and sugar yields obtained were good for all treatments being, in most cases higher than the expected cane yields i.e. 95 - 115 t/ha for the particular variety. Differences observed in the various cane response data were, however not statistically significant either between the treatments (treatment effects) or within the treatments (block effects). This was with an exception of plant height for which block effects were significant. Results of the statistical analysis using ANOVAS are summarised in table 4.13.

Table 4.13 F - statistic and significance for crop response data.

	F -VALUES									
	BLOCKS			TREATMENT			SIGNIFICANCE			
	Fcal	Ftab		Fcal	Ftab		Blocks		Treat-ment	
VARIABLE		5%	1%		5%	1%	5%	1%	5%	1%
INTERNODES	1.784	4.46	8.65	0.953	3.84	7.01	NS	NS	NS	NS
POPULATION	2.986			0.702			NS	NS	NS	NS
HEIGHT	5.015			0.750			*	NS	NS	NS
PURITY	2.298			2.610			NS	NS	NS	NS
TCH	0.432			1.023			NS	NS	NS	NS
TESH	1.123			0.546			NS	NS	NS	NS
TEST	0.149			0.354			NS	NS	NS	NS

Fcal, Ftab = calculated and tabled values of the F statistic respectively.
* = significant NS = not significant

4.2 Discussion

4.2.1 Improperly functioning drains

As seen previously, some of the trial drains almost completely failed to discharge i.e. BFD1 and RFFD1. Whilst discharge from PCD1 could not be collected, relatively high water tables experienced in this plot showed that the functioning of the drains was not as efficient as expected. For RFFD it was suspected that the polyfelt got smeared with mud during installations - given that these were carried out during a rainy period. This would have caused the polyfelt to block and interfered with its functioning. The same is suspected to have been the case for PCD1. Blocking of filter material adversely affects permeability in the zone around the drain. A less permeable drain surround increases entrance resistance enormously, and inadmissible values are quickly reached (Dierickx, 1982). For the RFFD, it is also possible that the rock cover may have collapsed, rendering the drains ineffective.

For the bagasse filled drains, it was at first suspected that the bagasse, being an organic material, may have rotted thus failing to execute its function. Organic envelope materials are highly prone to deterioration and their durability is questionable. However, the bagasse used had been obtained from a 15 year old pit (Kamau, 1995), and was still in good condition, being very fibrous and highly pervious with a hydraulic conductivity of 4 m/day (Mutiso, 1993). Also according to King *et al.* (1965), the cane fibre in the bagasse is resistant to decomposition in the soil. Moreover wet conditions in this plot did not favour the decomposition of organic material.

Further investigations of piezometric heads for these drains showed that the drains possibly failed in stage 3, i.e. a failure arising as a result of improper construction / installation. This was thought to be because installations were carried out during the wet period. Poor soil conditions in the filled trenches may have caused high entrance resistance leading to poor drain performance. Backfilling under wet conditions often leads to total drain failure thus necessitating the installation of a complete new system.

4.2.2 Water table depths and discharge

From the observations made, PPVC appeared more efficient both in terms of lowering the water table and in terms of discharge, being quick to start discharging and lowering water tables faster and to generally lower depths than those achieved in the other drained treatments. This was evident from the hydrographs and the indices. PPVC recorded relatively lower values of all indices as compared to the others. Water table depths in this treatment especially in block 3, sometimes went below the bottom of the observation wells. This was also found to be the case for PCD. While the efficiency of a drainage system can be judged by its ability to lower water table sufficiently fast and to low depths, there were doubts as to whether too low water tables attained would not be detrimental to the crop. In this case, the crop would experience a water deficit and would ultimately suffer stress. Also sugarcane is a crop that cannot adjust too rapidly to a falling water table.

Considering that these particular drains performed relatively well, the possibility of adoption of any of the said drains should not be completely ruled out on account of 'over-draining'. A possible solution would be to include subirrigation as a water management practice. Here the drains would be allowed to function normally during the wet periods, but would be blocked once excess water was removed from the main root zone, thus retaining, in situ, a sufficient amount of water for the crops use. Such a practise has its disadvantages in that it may ultimately lead to siltation and other blockages. Another solution would be to design effective depth and spacing of the drains for a set of conditions such as plant root depth, hydraulic conductivity, depth of the impermeable layer and the effective drain diameter. This may in fact be a better solution.

Bagasse filled drains were tried here for the first time in subsurface drainage. Using bagasse as a filter material was thought to be a new and interesting option especially where organic filter materials were concerned. Problems associated with organic filter materials especially limited availability and expense in securing would in this case not have been a problem as bagasse is readily available from the sugar factory.

Results obtained for these drains were, however, disappointing; the block 1 drains almost completely failed to discharge while water tables in the other two blocks, for the same drains, were relatively high. While the behaviour in block 1 can be explained by the installations having been carried out during the wet period, it is difficult to explain the behaviours in block 2 and 3. However, since here the bagasse had been applied to the top of the drains, drain-line ineffectiveness is thought to have been caused by sediment inflow from below rather than the use of ineffective filter material.

The RFFD also proved to be a disappointment with only the RFFD2 performing well. Rock filled French drains have been used previously in the lowlands but with little success. These drains failed in the first instance having been installed too shallow (50 cm) and due to the collapse of their cover which rendered them ineffective (Home, 1991). Such collapsing may also have occurred in the French drains in the experimental field (Plate 4.3). French drains are better suited for localised areas of poor drainage (Smedema and Rycroft, 1983). These drains have a short effective life time and mainly serve as temporary measures (Schwab *et al.*, 1981). It is thought that the use of these drains should not at all be effected for the lowlands of MSC.

Plate 4.3 RFFD1 - Water standing in furrows a few days after a rainfall event. Adjacent fields had already dried out.

Significant differences were observed in water table depths especially between plots in block 1 and those in block 3. Since there were no significant differences within the treatments as far as discharge was concerned, differences observed in water tables were thought to be due to differences in soil types within the experimental field. Further analysis done for periods of falling water table viz December 1993 and July 1994, showed results similar to those previously observed (see Appendix 8). Differences observed in water tables within the blocks could be attributed to differences in soil types within the field.

Generally, the water table problem was not as serious during this experiment as it had been in the past. This was thought to be because the rainfall during the experimental period was unusual, being relatively dry when at least some rainfall was expected and at times being unexpectedly wet e.g. November 1994. A comparison of the rainfall experienced during the crop season with the long term monthly medians for MSC show that the rainfall was somewhat lower than the long term medians in September 1993 to February 1994 (fig. 4.10).

This period covered the first six months of the crops establishment, which according to Doorenbos and Kassam (1979) correspond to the germination and tillering stages of crop growth. These are the critical stages during which the crop would be affected if it was subjected to waterlogging. Water table and discharge measurements made during this period were however sufficient for the performance analysis of the trial drains.

4.2.3 Summation of excess water, SEW

Although mainly PDIs and POs were used for the analysis, variations in the SEW index among the treatments, within the entire experimentation period, were large. This was possibly due to the persistence of high water tables in some plots as compared to others. Annual values obtained for COEX, RFFD and BFD were relatively large meaning that water logging, when it occurred, in these treatments was quite extensive (Table 4.14).

Table 4.14 Average annual SEW values.

TREATMENT	PPVC	BFD	PCD	RFFD	COEX
AVERAGE ANNUAL SEW, cm-days	940.2	2975.8	1703.8	2608.0	3167.1

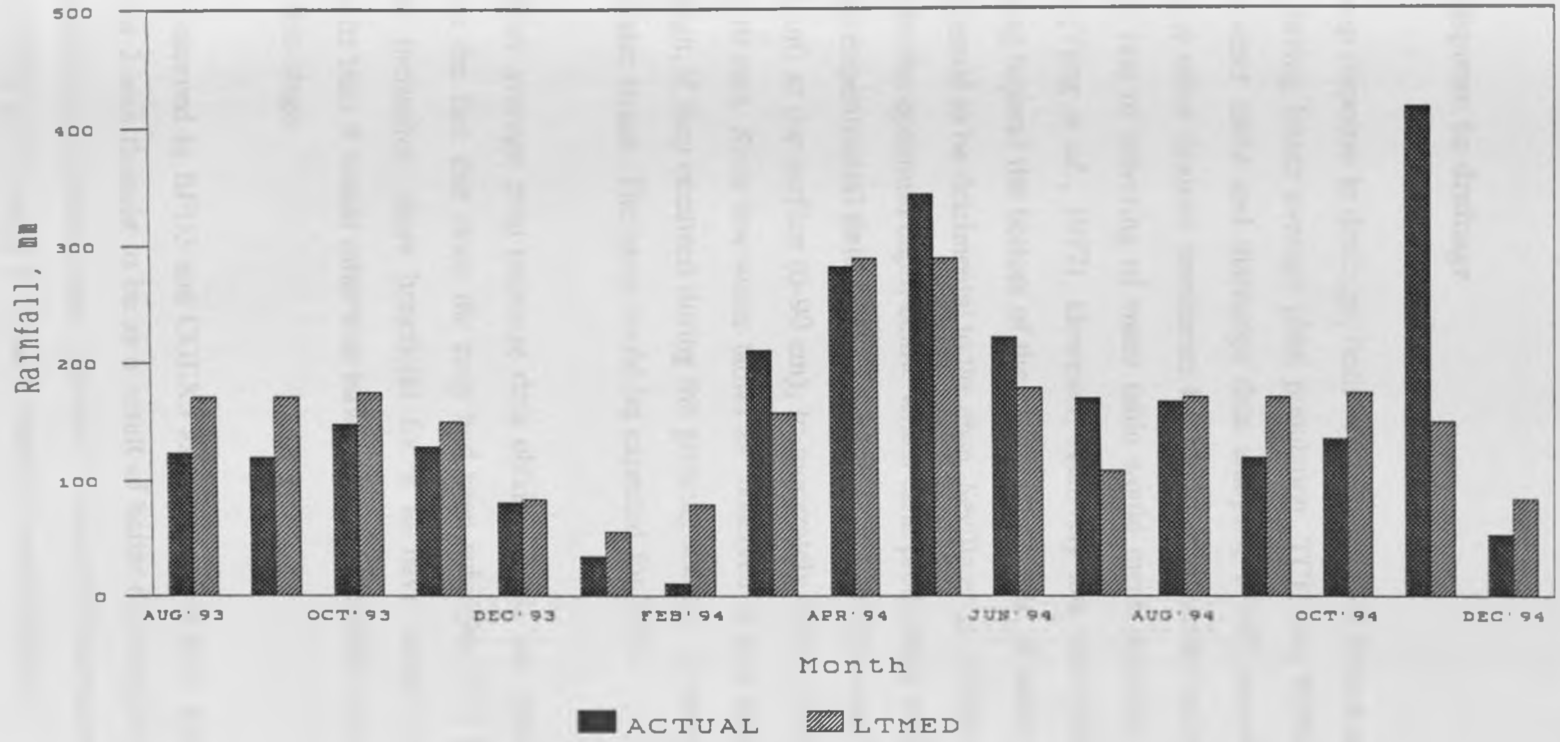


Fig. 4.10 Crop season rainfall (1993/94) versus long term medians (ltmed)

Water tables were at times higher than 45 cm throughout a particular month e.g. for PCD1 in October 1993 (see table 4.2). This implied that for the particular plots, water tables must have, on occasions, remained above the 45 cm depth for more than 14 consecutive days. This is the time period beyond which yields could be severely affected.

4.2.4 Crop response to drainage

Considering crop response to drainage, both PPVC and RFFD do not seem to have favoured crop growth, having lower average plant population, TCH and TESH as compared to the others. From water table and discharge data analysis, PPVC seems to have been more efficient than the other drained treatments having lowered water tables faster and to lower depths. A high rate of lowering of water table would mean preventing crop damage from water logging (Yang *et al.*, 1977). However, relatively low water tables were obtained at times even going beyond the bottom of the observation wells. A water table below a certain optimum is expected to be detrimental to the crop. Sevilla *et al.* (1980), found 140 cm below the surface to be the optimum depth below which cane production was likely to be affected. The soils in the experimental field used by Sevilla *et al.* (1980) varied from medium texture (loam, silty loam) at the surface (0-90 cm), to moderately coarse texture (fine sandy loam) at depth (90-210 cm). Such low water tables as observed in this experiment were thought to be low enough, if they occurred during the growing season, to cause a reduction in yields due to plant water stress. The same could be expected for PCD.

Relatively higher average crop response data obtained from the other treatments could be explained from the fact that since the crop had been subjected to a dry spell in its initial stages it was, thereafter, more beneficial for it to have water remaining at relatively shallower depths than it would otherwise have been had conditions been normal (w.r.t. this field) during this stage.

Higher TCH observed in BFD3 and COEX3 as compared to their corresponding replicates in blocks 1 and 2 was thought to be as a result of better drainage in these replicates given that these occurred in a plinthitic area. Similarly a lower value obtained in PCD3 compared to PCD1 and PCD2 are thought to be as a result of overdraining.

Even though some of the drains were seen to function better than others, differences observed between the treatments where crop response to drainage was concerned were not statistically significant. This could be explained by the fact that the experiment had been affected by a dry spell that occurred in the region shortly after planting. This implied that the cane in all treatments experienced approximately similar drainage conditions in the initial stages of the crops' establishment. Though the crop did not suffer since conditions were not harsh in its initial stages, it is, unfortunately, not possible at this stage to tell how the crop would respond to this behaviour under normal conditions. It is, however suspected that future stands and stand longevity are likely to be affected provided the crop does not again undergo a dry period during the resprouting of the stubble crop. It is also expected that the crop would respond favourably to good water table management during years of above normal rainfall.

Camp and Carter (1983) working on sugarcane in Louisiana found no significant differences during the plant crop. This was attributed to the fact that during the season, water table depth was never high enough to cause damage to the crop. Significant treatment differences were however observed for the ratoon crops.

4.2.5 Importance of observing proper installation procedures

The implementation of subsurface drainage requires careful consideration and, as seen, prior experimentation to ensure that any subsurface drainage works are appropriate for the field concerned.

A lot of capital is invested in experimentation and even more would eventually be invested in the actual installations. It would then prove disastrous if so carefully tested a system should fail to perform well, due to improper installation. Improper installation is a major cause of drain failure.

In this particular case, a few of the drains were reported as failed; failure being associated with installation under wet conditions. Rands (1987) argues that the timing of installation has no significant effect on subsequent drain performance provided there was a good standard of workmanship. It has, however, been reported that installation under wet conditions could lead to complete failure as far as drainage systems are concerned (Cavelaars, 1974; Raadsma, 1974; Schultz *et al.*, 1990).

According to Dierickx (1982), the performance of an envelope material is greatly dependent on the soil moisture conditions at the time of installation. Clogging and blocking of filter material is a world wide problem (Stuyt, 1982) but such a situation is likely to be aggravated by installations under wet conditions.

Backfilling under wet conditions would also ultimately lead to drain failure. It is thus important that the backfilling of a trench with puddled soil be avoided.

Timing of installation is thus important for subsequent drain performance. This is, however, not the only cause of drain failure that is associated with improper installation. Others include improper alignment, uneven grade, etc. These have been discussed in detail in sec. 2.3.1.

Considering the above discussed points, it is evident that the importance of observing correct installation procedures, to ensure the efficient functioning of the drains, cannot be overemphasised.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Despite the fact that many experimental results from other areas have shown an increase in cane and sugar yields after the installation of subsurface drainage systems, no significant difference was found between the treatments in this case. This was attributed to the fact that the water table was never high enough, during the critical period, to cause adverse conditions.

From the cane and sugar yield stand point, therefore, there appears to be no advantage among the various treatments based upon the results obtained. This implies that no material can be justifiably recommended for adoption at this stage.

However, considering the hydraulic performance of the drains, perforated PVC pipes (PPVC) and porous concrete drains (PCD) showed better performance, lowering the water table faster and to lower depths than the other drained treatments. Rock filled French drains (RFFD) performed poorly. These drains have been tried before on the lowlands and have been found ineffective. Their use should therefore not be effected for the MSC lowlands. Relatively poor performance of the bagasse filled drains (BFD) could be attributed to improper placement of filter material rather than the use of ineffective material.

The possibility of increasing crop production through drainage should not be ruled out, given the weather conditions during the experimental period. The economic and financial implications of installing a subsurface drainage system are big. For the sugar industry, the use of drains must be justified by increased cane and sugar production. Further monitoring of ratoon crops would be necessary in order to reveal more results from which further comparisons can be made where crop response to drainage is concerned.

5.2 Recommendations

Following the performance analysis of the different subsurface drainage materials installed in the lowlands of MSC, the following recommendations have been made.

i, It is necessary that a material to be adopted for the lowlands be justifiably recommended. It follows, therefore, that this experiment must run for a considerable number of years so as to sample an adequate range of crop / seasonal weather variation interaction. In this context:

a) Further monitoring of subsequent ratoon crops is necessary. Crop response data to be collected may be the same as that collected during this experiment, viz cane and sugar yields, plant population, plant height and internode lengths.

b) Missing observation pipes should be replaced to facilitate further monitoring of water table fluctuations.

c) A cost benefit analysis based on yields obtained over the entire crop period is necessary in order to ascertain the cost effectiveness of the material to be recommended.

ii, For the future success in monitoring at this experiment, it is necessary that the drains be cleaned out to remove silt deposits. The accumulation of these could eventually render the drains ineffective. Methods that could be used are such as push rods with an attached scraper or flushing out with a water jet. The collector drain, which quickly gets overgrown with weeds, would also need periodic cleaning.

iii, The status of the collector drain has, on many occasions, hindered data collection and drain performance as the banks frequently collapse causing water to stagnate and submerge the drain outlets. It is thought that bank stabilisation would do a lot to alleviate this problem. A close growing grass such as Paspalum, which is available on the estate, would serve the purpose adequately.

iv, Further research needs to be conducted to ascertain the following:-

a) Threshold SEW values beyond which there is likely to be a decrease in cane yields need to be determined. These could be determined by monitoring long term yields in relation to water table depths. In establishing the SEW threshold, natural decline in cane yields in subsequent stubble crops should not be ignored as this is likely to complicate the SEW - yield correlations.

b) The effect of different water table depths on yields may be investigated by setting up an experiment on gently sloping land. Alternatively, the same could be studied under lysimeter tank conditions. Here the water table could be maintained at various depths, being kept constant at each depth using drains installed at appropriate depths. Results obtained here can also be used in obtaining the SEW threshold mentioned above, other than using long term yield results.

c) The effect of drainage conditions in the various treatments on trafficability.

d) The interaction between envelope and soil material and its effect on envelope permeability.

v, Considering that some discrepancies were observed in the results, these being attributed to the inhomogeneities of the soils within the experimental field, it is suggested that drainage experiments be preceded by a thorough investigation of the soils within the proposed experimental field. This would minimise the likelihood of setting up an experiment within an area in which soils differ appreciably. Differences observed could then be attributed only to treatment effects provided all other factors, e.g. cultural and agronomic treatment of the sugarcane, were held constant .

REFERENCES

Amer, M.H. and B. Lesaffre, 1990. Cost benefit analysis. In: B. Schultz, Ed., Guidelines on the Construction of Horizontal Subsurface Drainage Systems. ICID: 155 - 181.

Anon, 1970. Control of sediment flow into subsurface drains. Trans. of the ASCE, 96(IR4): 437 - 449.

Barnes, A.C., 1974. The Sugar Cane. Leonard Hill Books.

Beltràn, J.M., 1978. Drainage and Reclamation of Salt affected Soils. Bardenas Area, Spain. ILRI publication 24: 258 - 289.

Bengston, R.L., C.E. Carter, H.F. Morris and J.G. Kowalczuk, 1983. Subsurface drainage effectiveness on alluvial soils. Trans. of the ASAE, 26(1): 423 - 425.

Blackburn, F., 1984. Sugarcane. Longman - London / New York.

Borin, M. and A. Berti, 1991. Testing and statistical analysis of the performance of a pipe drainage system - A case study of North -Eastern Italy. Irrigation and Drainage Systems, 5: 165 - 182.

Bouwer, H., 1974. Developing drainage design criteria. In: J. Van Schilfgaarde, Ed., Drainage for Agriculture. Am. Soc. of Agronomy 17: 67 - 81.

Brokensha, M.A., S. King and J.P. Lamusse, 1976. Evaluation of the press method for cane analysis under South African conditions. Proc. of the fiftieth annual congress, SASTA: 212 - 219.

Camp, C.R. and C.E Carter, 1983. Sugarcane yield response to subsurface drainage for an alluvial soil. Trans. of the ASAE (SW), 26(1): 1112 - 1116.

Carter, C.E., 1987. Subsurface drainage increases sugarcane yields and stand longevity. Drainage Design and Management. Proc. of the Fifth National Drainage Symposium. ASAE: 159-167.

Carter, C.E. and C.R. Camp, 1983. Subsurface drainage of an alluvial soil increased sugarcane yields. Trans. of the ASAE, 26(1): 426 - 429.

Carter, C.E. and C.R. Camp, 1994. Drain spacing effects on water table control and cane sugar yields. Trans. of the ASAE, 37(5): 1509 - 1513.

Carter, C.E., J.E. Irvine, V. McDaniel and J. Dunkelman, 1985. Yield response of sugarcane to stalk density and subsurface drainage treatments. Trans. of the ASAE, 28(1): 172 - 178.

Carter, C.E. and J.M. Floyd, 1973. Subsurface drainage and irrigation for sugarcane. Trans. of the ASAE, 16(2): 279-282.

Carter, C.E., J.L Fouss and V. McDaniel, 1988. Water management increases sugarcane yields. Trans. of the ASAE, 31(2): 503 - 507.

Carter, C.E., R.L. Bengston, C.R. Camp, J.L. Fouss and J.S. Rogers, 1992. Crop yield increases required to justify subsurface drainage installation costs in the Lower Mississippi Valley. Drainage and Water table Control. Proc. of the Sixth International Drainage Symposium ASAE: 428 - 439.

Cavelaars, J.C., 1974. Subsurface field drainage systems. Drainage Principles and Applications. ILRI publication 16, vol.IV:1-65.

Chieng, S., J. King and M.G. Driehuyzen, 1987. Effect of subsurface drainage and subirrigation on the yields of four crops. Canadian Agricultural Engineering, 29(1): 21 - 26.

Crécy, J. De, 1982. Structural behaviour of heavy soils and drainage systems. In: M.J. Gardiner, Ed., Land Drainage. A seminar in the EC Programme of Coordination of Research on Land Use and Rural Resources. A.A. Balkema / Rotterdam: 73 - 84.

Dewey, F.J. and J.A. George, 1988. The use of a sand envelope for subsurface drainage within the South African sugar industry. Proc. of the sixty second annual congress, SASTA: 208 - 213.

Dieleman, P.J., 1974. Deriving soil hydrological constants from field drainage tests. Drainage Principles and Applications. ILRI publication 16, vol. III: 329 - 351.

Dieleman, P.J., 1979. Drainage knowledge and research needs in developing countries. In: J. Wesseling, Ed., Proc. of the International Drainage Workshop. ILRI publication 25: 291 - 310.

Dierickx, W. and H. Yüncüoglu, 1982. Factors affecting the performance of drainage envelope materials in structurally unstable soils. Agricultural Water Management, 5: 215 - 225.

Dierickx, W., 1982. Drainage research for better drainage efficiency. In: M.J.Gardiner, Ed., Land drainage, a seminar in the EC Programme of Coordination of Research on Land Use and Rural Resources. A.A. Balkema / Rotterdam: 253-268.

Dierickx, W., 1993. Research and development in selecting subsurface drainage materials. Irrigation and Drainage Systems 6: 291-310.

Doorenbos, J. and A.H. Kassam, 1979, Yield Response to Water. FAO Irrigation and Drainage paper No. 33.

El-Mowelhi., N.A. El-Bershamgy, G.J. Hoffman and A.C. Chang, 1988. Enhancement of crop yields from subsurface drains with various envelopes. Agricultural Water Management, 15: 131 - 140.

Escolar, R.P., W.F. Allison and J. Juarez, 1971. The effect of water table depth on the yield of sugarcane. ISSCT XIV congress: 722 - 726.

Fausey, N.R., G.S. Taylor and G.O. Schwab, 1986. Subsurface drainage in a fine textured soil with impaired permeability. Transaction of the ASAE, 2(6): 1650 - 1653.

Fausey, N.R., 1983. Shallow subsurface drain performance in Clermont soil. Trans. of the ASAE(SW), 26(1): 782 - 784.

FAO, 1980. Drainage Design Factors, FAO Irrigation and Drainage paper NO. 38.

Gayle, G.A., R.W. Skaggs and C.E. Carter, 1987. Effects of excessive soil water conditions on sugarcane yields. Trans. of the ASAE, 30(4): 993 - 997.

Gittinger, J.P., 1971. Economic Analysis of Agricultural projects. Economic Development Institute. International Bank for Reconstruction and Development.

Goor, G.A.W. Van De, 1979. Plant growth in relation to drainage. Drainage Principles and Applications. ILRI publication 16, vol I: 90 - 121.

Gosnell, J.M., 1971. Effect of water table level on growth of sugarcane. ISSCT XIV congress: 841 - 849

Gumbs, F.A. and L.A. Simpson, 1981. Influence of flooding and soil moisture content on elongation of sugarcane in Trinidad. Expl. Agric. 17: 403 - 406.

Home, P.G. 1991. Drainage of Lowland Sugarcane Fields: Mumias - Kenya. MSc. Thesis unpublished. Department of Agricultural Engineering, University of Nairobi.

Humbert, R.P., 1968. The Growing of Sugarcane. Elsevier Publishing Company, Amsterdam.

Hwang, R.B, J.N Luthin and G.S. Taylor, 1974. Effect of backfill on drain flow in layered soils. Trans. ASCE, 100(IR3): 267 - 276.

ICNR (India Committee on National Resources), 1963. Study on Waste Lands Including Saline, Alkali and Waterlogged Lands and Their Reclamation Measures. New Delhi.

Irvine J.E., C.A. Richard, C.E. Carter and J.W. Dunckelman, 1984. The effect of row spacing and subsurface drainage on sugarcane yields. Sugarcane No 2: 3 - 5.

Jansen, F.P., 1974. Economic evaluation of water management projects. Drainage Principles and Applications. ILRI publication 16, vol. IV: 432 - 451.

Kamau, J.N., 1995. Research and Development Engineer, MSC. Personal Communication.

Kessler, J., 1979. Field drainage criteria. Drainage Principles and Applications. ILRI publication 16, vol II (revised edition): 130 - 164.

King, N.J., R.W. Mungomery and C.G. Hughes, 1965. Manual for Sugarcane Growing. American Elsevier publishing company, inc. New York.

Knops, J.A.C., F.C Zuidema, C.L. Van Someren and J. Scholten, 1979. Guidelines for the selection of envelope materials for subsurface drains. In: J. Wesseling, Ed., Proc. of the International Drainage Workshop. ILRI publication 25: 14 - 38.

Knops, J.A.C. and W. Dierickx, 1979. Drainage materials. In: J. Wesseling, Ed., Proc. of the International Drainage Workshop. ILRI publication 25: 439 - 450.

Little T.M. and F.J. Hills, 1978. Agricultural Experimentation. Design and analysis. John Wiley and Sons, New York.

Makatiani, D. and P.W. Toywa, 1994. Mumias Sugar Company: A sure success story for both locals and internationals. The Kenya Sugar. KSSCT, X(1): 7 - 13.

McIntosh, G.E., 1977. Grower solutions to drainage problems in the Victoria mill area. QLDSSCT, 44: 119 - 124.

Milburn, P., 1987. The performance of a subsurface drainage system on a New Brunswick silt loam soil. Canadian Agricultural Engineering, 29(1): 27 - 34.

Mirjat, M.S. and R.S. Kanwar, 1992. Evaluation of subsurface drain installation methods using water table and drain outflow data. Trans. of the ASAE, 35(5): 1483 - 1488.

MSC, 1994. Mini report. Agronomy section.

Mutiso, P.S., 1993. Bagasse as a drainage material. Habari MUSUCO. MSC, (Special edition): 25.

Nyongesa, C., 1994. Field supervisor, Agronomy section, MSC. Personal communication.

Ochieng, A., 1995. Performance of two varieties recommended for commercial cultivation. Agronomy section SONY Sugar Company, Unpublished.

Owende, P.M.O., 1990. Development and Performance of a Toolframe for Mechanical Sugarcane Stool Destruction. MSc. Thesis, Unpublished. Department of Agricultural Engineering, University of Nairobi.

Perez, O., 1984. Using plastic pipes properly in conservation structures. Agricultural Engineering, 65(3): 6 - 8.

Purseglove, J.W., 1972. Tropical Crops - Monocotyledons 1. Longman Group Limited.

Raadsma, S., 1974. Current drainage practices in flat areas of humid regions in Europe. In: J. Van Schilfgaarde, Ed., Drainage for Agriculture. Am. Soc. of Agronomy, 17: 67 - 81.

Rands, J.G., 1987. The effects of installing drain tubes under differing soil moisture conditions by the trenched and trenchless method. Drainage Design and Management. Proc. of the Fifth National Drainage Symposium. ASAE: 310-318.

Schultz, E., G. Westland and J.B. Summers, 1990. Operations and management. In: B. Schultz, Ed., Guidelines on the Construction of Horizontal Subsurface Drainage systems. ICID: 125 - 153.

Schwab, G.O., R.K. Frevet, T.W. Edminster and K.K. Barnes, 1981. Soil and Water Conservation Engineering, 3rd Edition. John Wiley and Sons, Inc. New York.

Sevilla J.C., E. Angula and J.E. Paz-Vergara, 1980. Effect of water table level on cane production. ISSCT XVII congress. Agricultural Engineering technical paper.

Shafer, F.F., 1940. Causes of failure in tile drains. Agricultural Engineering. ASAE.

Smedema, L.K., 1987. Field drainage for dry foot crops in the (Semi-) humid tropics. In: J. Vos, Ed., Proc. Symposium 25th International Course on Land Drainage. ILRI publication 42: 42 - 55.

Smedema, L.K., 1988. Water table control indices for drainage of agricultural land in humid climates. In: J.W. Van Hoorn, Ed., Agrohydrology Recent Developments. Elservier, Amsterdam. 69 - 77.

Smedema, L.K. 1993. Drainage performance and soil management. Soil Technology, Catena verlag, Vol. 6: 183 - 189.

Smedema, L.K. and D.W. Rycroft, 1983. Land Drainage: Planning and design of agricultural drainage systems. Batsford Academic and Educational Limited, London.

Steel, R.G.D. and J.H. Torrie, 1980. Principles and Procedures of Statistics. A biometrical approach. McGraw-hill International.

Stuyt, L.C.P.M., 1982. A new approach in research into drainage materials. In: M.J. Gardiner, Ed., Land Drainage. A seminar in the EC Programme of Coordination of Research on Land Use and Rural Resources. A.A. Balkema / Rotterdam: 223 - 248.

Summers, J.B., B. Lesaffre and K.G.A. Smith, 1990. Drainage materials. In: B. Schultz, Ed., Guidelines on the Construction of Horizontal Subsurface Drainage Systems. ICID: 48 - 65.

USDA - SCS, 1971. Drainage of Agricultural Land. National Engineering Handbook, Section 16.

Vuuren, W. van and H. Jorjani, 1984. Estimating yields for a cost benefit analysis of subsurface drainage in southern Ontario. Canadian Agric. Engineering, 26(1): 27-34.

Walker, P.N. and J.D. Wells, 1983. Pipe drainage of heavy soils. Trans. of the ASAE(SW), 26(1): 112 - 115, 122.

Wesseling, J., 1972. Drainage materials - a provisional report of the experience gained in the Netherlands. Drainage Materials. FAO, Irrigation and Drainage paper, No.9.

Wesseling, J., 1974. Crop growth and wet soils. In: J. Van Schilfgaarde, Ed., Drainage for Agriculture. Am. Soc. of Agronomy 17: 32 - 37,

Wesseling, J., 1979. Subsurface flow to drains. Drainage Principles and Applications. ILRI publication 16, vol. II (Revised edition): 1-56.

Yang, S.J., P.L. Wang, Y.T. Chang and T.C. Yang, 1977. The performance of subsurface drainage and its effect on sugarcane growth on fine textured soils in Taiwan. Taiwan sugar: 378 - 384.

Yang, S.J.and P.L. Wang, 1980. Soil aeration, nutrient uptake and yield of sugarcane as affected by tile drainage. ISSCT XVII congress. Agricultural Engineering paper:1-16.

APPENDICES

Appendix 1A Sample rainfall data for Mumias Sugar Company zone (1993/94)

DAY	SEP'93	NOV'93	JAN'94	FEB'94	MAY'94	SEP'94
1	10.9	4.2	0.0	0.0	10.0	4.4
2	0.0	4.5	0.0	0.0	1.4	11.4
3	4.2	44.4	0.0	0.0	10.0	15.0
4	2.0	7.0	0.1	0.0	0.0	18.1
5	30.4	0.5	0.6	0.0	37.2	3.9
6	25.0	1.0	0.0	0.0	0.0	12.8
7	10.8	4.9	2.2	0.0	28.2	31.1
8	0.0	18.3	0.0	0.0	0.0	1.6
9	0.0	0.0	0.0	0.0	0.2	0.0
10	0.0	7.1	3.2	3.3	3.2	0.0
11	0.0	0.4	0.0	0.3	15.8	0.0
12	1.7	7.7	4.1	0.0	0.3	4.0
13	0.0	3.6	0.0	0.0	10.9	0.0
14	1.8	1.1	0.0	0.0	15.2	1.6
15	4.1	0.0	0.0	0.0	6.5	3.6
16	12.4	0.0	24.8	0.0	1.4	0.0
17	1.6	17.4	0.0	0.0	19.5	0.0
18	0.0	0.0	0.0	0.0	7.4	0.0
19	0.0	0.0	0.0	0.0	19.0	0.0
20	0.0	0.7	0.0	0.0	16.2	1.0
21	0.0	0.0	0.0	0.4	6.5	0.0
22	0.0	0.0	0.0	25.1	2.3	1.5
23	0.0	0.0	0.0	30.5	0.5	0.0
24	0.0	0.0	0.0	0.0	5.0	1.0
25	13.5	0.0	0.0	0.0	0.5	0.0
26	1.5	0.0	0.0	0.0	4.1	6.9
27	0.0	0.8	0.0	0.0	0.0	0.0
28	0.0	3.5	0.0	0.0	34.0	0.0
29	0.0	0.0	0.0		20.1	0.0
30	0.0	1.1	0.0		9.3	3.4
31			0.0		0.0	

Appendix 1B Sample water table and discharge data

WATER TABLE DATA

DAY	WTPPVC1	WTPCD3	WTCOEX1	WTBFD3	WTRFFD1
1/8/93	-79.8	-91.0	-68.0	-98.0	-27.2
2	-55.5	-45.7	-35.2	-39.2	0.2
3	-31.0	-69.0	-47.5	-95.2	-10.7
4	-37.7	-55.0	-56.2	-59.0	-18.5
6	-23.5	-37.0	-23.2	-23.0	10.0
7	-6.5	-23.0	-3.5	-23.7	10.7
8	-0.3	-34.3	5.2	-4.7	11.7
9	-8.5	-54.7	-8.5	-19.2	9.7
10	-23.0	-58.7	-13.7	-24.2	6.7
11	-22.2	-66.7	-15.5	-34.2	-6.2
13	-44.5	-69.3	-40.0	-33.0	-8.0
14	-48.2	-60.7	-46.0	-39.0	-9.3
15	-49.7	-74.3	-48.7	-31.7	-10.7
16	-49.5	-71.0	-46.2	-38.5	-19.0
17	-35.2	-66.7	-25.7	-33.5	-5.0
18	-45.5	-41.3	-37.7	-34.0	-14.2
20	-63.2	-79.0	-50.5	-41.0	-24.2
22	-51.0	-89.2	-55.0	-42.5	-36.5
24	-84.2	-46.7	-61.0	-40.7	-41.2
25	-84.0	-64.0	-70.7	-46.5	-43.7
27	-51.7	-32.2	-55.5	-44.7	-32.2
31	-64.7	-79.0	-69.0	-51.5	-48.5

WT= water table, therefore WTPPVC1 stands for watertables for PPVC in block 1, WTPCD3 stands for watertables for PCD in block 3 etc.

DISCHARGE DATA

DAY	DPPVC2	DPPVC3	DBFD2	DBFD3	DPCD2	DRFFD2	DRFFD3
1/8/93	0.00	0.00	0.00	0.00	3.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	5.14	5.57	1.82	1.37	5.23	1.74	1.03
6	5.42	2.23	0.38	6.52	3.05	0.81	0.00
7	1.41	0.00	0.12	0.48	1.41	0.00	0.00
8	0.22	0.00	0.00	0.55	0.00	0.00	0.00
9	0.65	0.31	0.00	0.55	0.46	0.00	0.00
10	0.21	0.00	0.00	0.27	0.00	0.00	0.00
11	0.12	0.00	0.00	0.20	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.04	0.00	0.00	0.00
16	0.00	0.00	0.00	0.04	0.00	0.00	0.00
17	0.00	0.00	0.00	0.04	0.00	0.00	0.00
18	0.00	0.00	0.00	0.04	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	0.00	0.00	0.00	0.00	0.00	0.00	0.00

D= discharge and therefore DPPVC1 stands for discharge for PPVC in block 1 and so on.

Appendix 2A INDCOM Programme listing

```
*COMPUTES INDICES FOR WATER TABLE ANALYSIS
STORE "          " TO mINFILE, mOUTFILE, mANFIELD
STORE 0 TO NX, SEWX
CLEAR
@ 7,7 SAY "Input the names of files and field to be analyzed."
@ 8,7 GET mINFILE
@ 9,7 GET mOUTFILE
@ 10,7 GET mANFIELD
READ
SELECT 1
USE &mINFILE
SELECT 2
USE &mOUTFILE
GO TOP
STORE 0 TO CNX. CSEWX
DO WHILE .NOT. EOF()
SELECT 1
IF 45.0>&mANFIELD
NX=1
ELSE
NX=0
ENDIF
IF 45.0>&mANFIELD
SEWX=(45.0-&mANFIELD)
ELSE SEWX=0
ENDIF
SELECT 2
REPLACE N11 WITH NX
REPLACE SW11 WITH SEWX
CNX=CNX+N11
CSEWX=CSEWX+SW11
REPLACE CN11 WITH CNX
REPLACE CSW11 WITH CSEWX
SKIP
SELECT 1
SKIP
ENDDO
CLEAR ALL
```

Appendix 2B INDCOM - data output (June 1994)

```
Record#  N11 CN11  SW11 CSW11 N12 CN12  SW12 CSW12 N13 CN13  SW13 CSW13
      1    1    1  11.0  11.0   0    0   0.0   0.0   1    1   5.2   5.2
      2    1    2  23.8  34.8   0    0   0.0   0.0   1    2   3.8   9.0
      3    1    3  14.4  49.2   0    0   0.0   0.0   0    2   0.0   9.0
      4    1    4  19.6  68.8   0    0   0.0   0.0   0    2   0.0   9.0
      5    1    5  29.4  98.2   0    0   0.0   0.0   0    2   0.0   9.0
      6    1    6  29.6 127.8   0    0   0.0   0.0   0    2   0.0   9.0
      7    1    7  36.2 164.0   0    0   0.0   0.0   0    2   0.0   9.0
      8    1    8  29.4 193.4   0    0   0.0   0.0   0    2   0.0   9.0
      9    1    9  26.0 219.4   0    0   0.0   0.0   0    2   0.0   9.0
     10    1   10  21.8 241.2   0    0   0.0   0.0   0    2   0.0   9.0
     11    1   11  20.6 261.8   0    0   0.0   0.0   0    2   0.0   9.0
     12    1   12  17.4 279.2   0    0   0.0   0.0   0    2   0.0   9.0
     13    1   13   7.4 286.6   0    0   0.0   0.0   0    2   0.0   9.0
     14    1   14   6.0 292.6   0    0   0.0   0.0   0    2   0.0   9.0
     15    1   15   4.8 297.4   0    0   0.0   0.0   0    2   0.0   9.0
     16    1   16   3.0 300.4   0    0   0.0   0.0   0    2   0.0   9.0
     17    0   16   0.0 300.4   0    0   0.0   0.0   0    2   0.0   9.0
     18    1   17  36.8 337.2   0    0   0.0   0.0   0    2   0.0   9.0
     19    1   18  18.6 355.8   0    0   0.0   0.0   0    2   0.0   9.0
     20    0   18   0.0 355.8   0    0   0.0   0.0   0    2   0.0   9.0
     21    0   18   0.0 355.8   0    0   0.0   0.0   0    2   0.0   9.0
     22    0   18   0.0 355.8   0    0   0.0   0.0   0    2   0.0   9.0
     23    0   18   0.0 355.8   0    0   0.0   0.0   0    2   0.0   9.0

Record#  N21 CN21  SW21 CSW21 N22 CN22  SW22 CSW22 N23 CN23  SW23 CSW23
      1    1    1  30.3  30.3   1    1  22.8  22.8   1    1  38.1  38.1
      2    1    2  30.5  60.8   1    2  28.5  51.3   1    2  41.0  79.1
      3    1    3  31.2  92.0   1    3  29.3  80.6   1    3  42.4 121.5
      4    1    4  36.3 128.3   1    4  30.0 110.6   1    4  43.1 164.6
      5    1    5  36.7 165.0   1    5  33.2 143.8   1    5  43.8 208.4
      6    1    6  41.5 206.5   1    6  40.7 184.5   1    6  43.2 251.6
      7    1    7  41.2 247.7   1    7  40.7 225.2   1    7  43.4 295.0
      8    1    8  32.8 280.5   1    8  35.8 261.0   1    8  44.0 339.0
      9    1    9  34.0 314.5   1    9  36.8 297.8   1    9  43.6 382.6
     10    1   10  35.2 349.7   1   10  37.8 335.6   1   10  26.7 409.3
     11    1   11  35.0 384.7   1   11  38.3 373.9   1   11  24.7 434.0
     12    1   12  34.3 419.0   1   12  36.8 410.7   1   12  33.2 467.2
     13    1   13  33.2 452.2   1   13  36.2 446.9   1   13  32.6 499.8
     14    1   14  33.3 485.5   1   14  35.5 482.4   1   14  33.0 532.8
     15    1   15  28.2 513.7   1   15  32.5 514.9   1   15  42.0 574.8
     16    1   16  25.7 539.4   1   16  31.0 545.9   1   16  11.2 586.0
     17    1   17  26.5 565.9   1   17  31.2 577.1   1   17  13.0 599.0
     18    1   18  34.7 600.6   1   18  35.0 612.1   1   18  26.6 625.6
     19    1   19  32.0 632.6   1   19  37.8 649.9   1   19  28.2 653.8
     20    1   20   9.0 641.6   1   20  18.8 668.7   1   20  11.4 665.2
     21    1   21   2.0 643.6   1   21  16.8 685.5   1   21   2.2 667.4
     22    1   22   0.4 644.0   1   22  16.2 701.7   1   22   5.2 672.6
     23    1   23   4.6 648.6   1   23  17.3 719.0   1   23   2.4 675.0
```

Record#	N31	CN31	SW31	CSW31	N32	CN32	SW32	CSW32	N33	CN33	SW33	CSW33
1	1	1	35.4	35.4	1	1	17.0	17.0	1	1	15.1	15.1
2	1	2	40.3	75.7	1	2	17.3	34.3	1	2	18.7	33.8
3	1	3	42.2	117.9	1	3	14.3	48.6	1	3	20.5	54.3
4	1	4	44.0	161.9	1	4	11.3	59.9	1	4	22.2	76.5
5	1	5	44.3	206.2	1	5	16.0	75.9	1	5	18.2	94.7
6	1	6	44.3	250.5	1	6	21.0	96.9	1	6	13.3	108.0
7	1	7	44.0	294.5	1	7	25.3	122.2	1	7	16.8	124.8
8	1	8	31.0	325.5	1	8	8.7	130.9	1	8	17.0	141.8
9	1	9	31.7	357.2	1	9	8.7	139.6	1	9	16.0	157.8
10	1	10	32.3	389.5	1	10	8.7	148.3	1	10	13.8	171.6
11	1	11	29.7	419.2	1	11	7.7	156.0	1	11	7.6	179.2
12	1	12	32.3	451.5	1	12	8.7	164.7	1	12	5.0	184.2
13	1	13	27.0	478.5	1	13	2.3	167.0	1	13	4.0	188.2
14	1	14	27.0	505.5	1	14	2.0	169.0	1	14	3.6	191.8
15	1	15	24.0	529.5	0	14	0.0	169.0	0	14	0.0	191.8
16	1	16	16.3	545.8	0	14	0.0	169.0	0	14	0.0	191.8
17	1	17	17.3	563.1	0	14	0.0	169.0	0	14	0.0	191.8
18	1	18	39.7	602.8	0	14	0.0	169.0	0	14	0.0	191.8
19	1	19	39.0	641.8	1	15	9.7	178.7	0	14	0.0	191.8
20	0	19	0.0	641.8	0	15	0.0	178.7	0	14	0.0	191.8
21	0	19	0.0	641.8	0	15	0.0	178.7	0	14	0.0	191.8
22	0	19	0.0	641.8	0	15	0.0	178.7	0	14	0.0	191.8
23	0	19	0.0	641.8	0	15	0.0	178.7	0	14	0.0	191.8

Record#	N41	CN41	SW41	CSW41	N42	CN42	SW42	CSW42	N43	CN43	SW43	CSW43
1	1	1	34.0	34.0	1	1	0.9	0.9	1	1	32.8	32.8
2	1	2	37.0	71.0	1	2	0.1	1.0	1	2	46.2	79.0
3	1	3	34.5	105.5	0	2	0.0	1.0	1	3	44.8	123.8
4	1	4	32.0	137.5	0	2	0.0	1.0	1	4	44.1	167.9
5	1	5	34.0	171.5	0	2	0.0	1.0	1	5	43.4	211.3
6	1	6	35.5	207.0	1	3	7.3	8.3	1	6	43.2	254.5
7	1	7	35.5	242.5	1	4	0.5	8.8	1	7	40.8	295.3
8	1	8	42.5	285.0	0	4	0.0	8.8	1	8	39.6	334.9
9	1	9	44.5	329.5	0	4	0.0	8.8	1	9	39.6	374.5
10	1	10	46.5	376.0	0	4	0.0	8.8	1	10	35.0	409.5
11	1	11	44.5	420.5	0	4	0.0	8.8	1	11	33.6	443.1
12	1	12	40.5	461.0	0	4	0.0	8.8	1	12	29.2	472.3
13	1	13	37.0	498.0	0	4	0.0	8.8	1	13	29.6	501.9
14	1	14	36.5	534.5	0	4	0.0	8.8	1	14	30.6	532.5
15	1	15	27.5	562.0	0	4	0.0	8.8	1	15	12.2	544.7
16	1	16	26.5	588.5	0	4	0.0	8.8	1	16	8.8	553.5
17	1	17	27.5	616.0	0	4	0.0	8.8	1	17	6.4	559.9
18	1	18	42.5	658.5	0	4	0.0	8.8	1	18	22.0	581.9
19	1	19	41.0	699.5	0	4	0.0	8.8	1	19	23.6	605.5
20	1	20	15.0	714.5	0	4	0.0	8.8	1	20	13.6	619.1
21	1	21	6.0	720.5	0	4	0.0	8.8	1	21	12.4	631.5
22	0	21	0.0	720.5	0	4	0.0	8.8	1	22	5.0	636.5
23	1	22	2.0	722.5	0	4	0.0	8.8	0	22	0.0	636.5

Record#	N51	CN51	SW51	CSW51	N52	CN52	SW52	CSW52	N53	CN53	SW53	CSW53
1	1	1	27.0	27.0	1	1	37.7	37.7	1	1	23.7	23.7
2	1	2	42.7	69.7	1	2	50.7	88.4	1	2	34.0	57.7
3	1	3	37.7	107.4	1	3	51.4	139.8	1	3	22.9	80.6
4	1	4	39.3	146.7	1	4	51.7	191.5	1	4	11.8	92.4
5	1	5	55.3	202.0	1	5	53.7	245.2	1	5	12.8	105.2
6	1	6	56.0	258.0	1	6	53.7	298.9	1	6	13.5	118.7
7	1	7	56.0	314.0	1	7	52.7	351.6	1	7	11.0	129.7
8	1	8	44.3	358.3	1	8	47.0	398.6	1	8	12.8	142.5
9	1	9	44.5	402.8	1	9	47.3	445.9	0	8	0.0	142.5
10	1	10	44.7	447.5	1	10	47.7	493.6	1	9	2.3	144.8
11	1	11	43.7	491.2	1	11	46.7	540.3	1	10	2.5	147.3
12	1	12	42.7	533.9	1	12	45.3	585.6	0	10	0.0	147.3
13	1	13	39.0	572.9	1	13	45.7	631.3	0	10	0.0	147.3
14	1	14	39.0	611.9	1	14	45.7	677.0	1	11	0.3	147.6
15	1	15	33.7	645.6	1	15	35.3	712.3	0	11	0.0	147.6
16	1	16	29.0	674.6	1	16	33.3	745.6	0	11	0.0	147.6
17	1	17	29.0	703.6	1	17	35.0	780.6	0	11	0.0	147.6
18	1	18	44.0	747.6	1	18	45.3	825.9	0	11	0.0	147.6
19	1	19	37.4	785.0	1	19	38.7	864.6	1	12	12.8	160.4
20	1	20	16.4	801.4	1	20	22.0	886.6	0	12	0.0	160.4
21	1	21	10.7	812.1	1	21	17.0	903.6	0	12	0.0	160.4
22	1	22	4.7	816.8	1	22	12.0	915.6	0	12	0.0	160.4
23	1	23	11.3	828.1	1	23	14.0	929.6	0	12	0.0	160.4

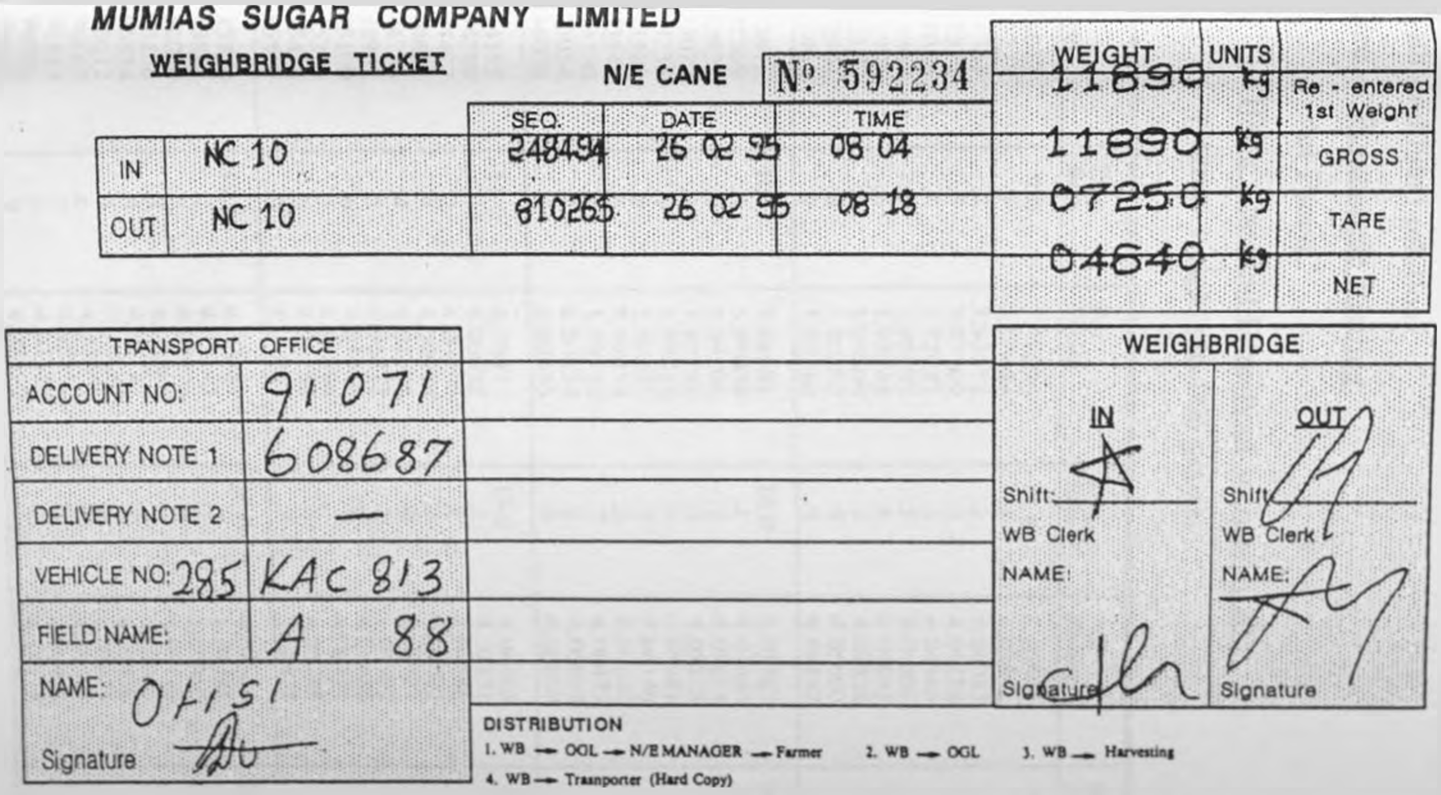
Appendix 3A STATAN programme listing

```
*PERFORMS THE ANOVA PROCEDURE
STORE 0 TO CT, SSA, SSB, SSE, MSB, MST, MSE, FB, FT, CFLD1, CFLD2, CFLD3,
SQFI, SQF2, SQF3
STORE "            " TO IFILE, OFILE
READ
SELECT 1
USE &OFILE
SELECT 2
USE &IFILE
GO TOP
SELECT 1
STORE 2 TO i
STORE FIELD(I) TO MFLD
STORE FIELD(i+1) TO MFLD2
STORE FIELD(i+2) TO MFLD3
SUM ALL &MFLD TO CFLD1
SUM ALL (&MFLD)^2 TO SQF1
SUM ALL &MFLD2 TO CFLD2
SUM ALL (&MFLD2)^2 TO SQF2
SUM ALL &MFLD3 TO CFLD3
SUM ALL (&MFLD3)^2 TO SQF3
CT=((CFLD1+CFLD2+CFLD3)^2)/15
SSB=(((CFLD1)^"+(CFLD2)^2+(CFLD3)^2)/5)-CT
MSB=SSB/2
GO TOP
RC1=&MFLD+&MFLD2+&MFLD3
SKIP
RC2=&MFLD+&MFLD2+&MFLD3
SKIP
```

```
RC5=&MFLD+&MFLD2+&MFLD3
SST=(((RC1)^2+(RC2)^2+(RC3)^2+(RC4)^2+(RC5)^2)/3)-CT
MST=SST/4
SSA=(SQF1+SQF2+SQF3)-CT
SSE==SSA-SSB-SST
MSE=SSE/8
FB=MSB/MSE
FT=MST/MSE
SELECT 2
REPLACE SSS3 WITH SSA
SKIP
REPLACE SSS3 WITH SSB
REPLACE MSS3 WITH MSB
REPLACE FCS3 WITH FB
SKIP
REPLACE SSS3 WITH SST
REPLACE MSS3 WITH MST
REPLACE FCS3 WITH FT
SKIP
REPLACE SSS3 WITH SSE
REPLACE MSS3 WITH MSE
CLEAR ALL
```

Appendix 3B STATAN - data output

```
d#  SVARN  DF       SSS3        MSS3    FCS3
 1  TOTAL  14  485453.58
 2  BLOCK   2  229274.83    114637.4    4.86
 3  TRT     4  67614.137    16903.53    0.71
 4  ERROR   8  188564.61    23570.58

d#  SVARN  DF       SSO3        MSO3    FCO3
 1  TOTAL  14  475433.60
 2  BLOCK   2  176515.51    88257.76    4.30
 3  TRT     4  134741.30    33685.33    1.64
 4  ERROR   8  164176.78    20522.10

i#  SVARN  DF       SSN3        MSN3    FCN3
 1  TOTAL  14  526282.26
 2  BLOCK   2  150946.72    75473.36    5.43
 3  TRT     4  264223.78    66055.95    4.75
 4  ERROR   8  111111.76    13888.97

i#  SVARN  DF       SSD3        MSD3    FCD3
 1  TOTAL  14    2545.95
 2  BLOCK   2     472.20      236.10    0.99
 3  TRT     4     183.13       45.78    0.19
 4  ERROR   8    1890.61      236.32

#   SVARN  DF       SSA4        MSA4    FCA4
 1  TOTAL  14   67829.58
 2  BLOCK   2   35530.40    17765.20    8.55
 3  TRT     4   15687.96    3921.991    1.88
 4  ERROR   8   16611.21    2076.402

#   SVARN  DF      SSMG4       MSMG4   FCMG4
 1  TOTAL  14  720183.95
 2  BLOCK   2  160210.87    80105.44    1.61
 3  TRT     4  163027.09    40756.77    0.82
 4  ERROR   8  396945.98    49618.25

#   SVARN  DF     SS.JN4      MS.JN4  FC.JN4
 1  TOTAL  14  1505749.2
 2  BLOCK   2  280072.32    140036.2    1.87
 3  TRT     4  629005.08    157251.3    2.10
 4  ERROR   8  596671.80    74583.98
```



MUMIAS SUGAR COMPANY LIMITED

WEIGHBRIDGE TICKET

N/E CANE

№ 592234

		SEQ.	DATE	TIME	WEIGHT	UNITS	
					11890	kg	Re - entered 1st Weight
IN	NC 10	248494	26 02 95	08 04	11890	kg	GROSS
OUT	NC 10	810265	26 02 95	08 18	07250	kg	TARE
					04640	kg	NET

TRANSPORT OFFICE	
ACCOUNT NO:	91071
DELIVERY NOTE 1	608687
DELIVERY NOTE 2	—
VEHICLE NO:	285 KAC 813
FIELD NAME:	A 88
NAME: OHISI Signature	

WEIGHBRIDGE	
IN	OUT
Shift:	Shift:
WB Clerk NAME:	WB Clerk NAME:
Signature	Signature

DISTRIBUTION

1. WB → OGL → N/E MANAGER → Farmer 2. WB → OGL 3. WB → Harvesting
4. WB → Transporter (Hard Copy)

① PLOT No. I

Cane weights data from weigh bridge tickets

Appendix 5A Conversion tables for sucrose analysis

Table of factors for the calculation of Pol per cent Juice from Pol Reading for use in Dry Lead method with undiluted solutions.

Pol per cent juice = Polariacede Reading
Pol Factor.

Pol Factor = 100 x Apparent Density of sucrose at 20°c
Normal weight (26.000 grams)

Deg. Brix	Pol Factor	Deg. Brix	Pol Factor	Deg. Brix	Pol Factor	Deg. Brix	Pol Factor
5.0	3.91077	9.0	3.97296	13.0	4.03696	17.0	4.10285
.1	3.91227	.1	3.97434	.1	4.03858	.1	4.10450
.2	3.91381	.2	3.97612	.2	4.04023	.2	4.10619
.3	3.91535	.3	3.97769	.3	4.04158	.3	4.10785
.4	3.91688	.4	3.97927	.4	4.04346	.4	4.10954
.5	3.91842	.5	3.96088	.5	4.04508	.5	4.11119
.6	3.91996	.6	3.98246	.6	4.04675	.6	4.11288
.7	3.92150	.7	3.98404	.7	4.04835	.7	4.11454
.8	3.92304	.8	3.98562	.8	4.05000	.8	4.11623
.9	3.92462	.9	3.98719	.9	4.05162	.9	4.11792
6.0	3.92615	10.0	3.98881	14.0	4.05327	18.0	4.11962
.1	3.92769	.1	3.99038	.1	4.05488	.1	4.12127
.2	3.92923	.2	3.99196	.2	4.05654	.2	4.12296
.3	3.93077	.3	3.99358	.3	4.05815	.3	4.12465
.4	3.93235	.4	3.99515	.4	4.05981	.4	4.12635
.5	3.93388	.5	3.99677	.5	4.06146	.5	4.12804
.6	3.93542	.6	3.99835	.6	4.06308	.6	4.12973
.7	3.93700	.7	3.99996	.7	4.06473	.7	4.13142
.8	3.93954	.8	4.00154	.8	4.06638	.8	4.13312
.9	3.94008	.9	4.00335	.9	4.06800	.9	4.13481
7.0	3.94165	11.0	4.00473	15.0	4.06965	19.0	4.13650
.1	3.94319	.1	4.00635	.1	4.07131	.1	4.13819
.2	3.94477	.2	4.00796	.2	4.07296	.2	4.13988
.3	3.94631	.3	4.00954	.3	4.07462	.3	4.14158
.4	3.94788	.4	4.01116	.4	4.07627	.4	4.14327
.5	3.94942	.5	4.01277	.5	4.07792	.5	4.14496
.6	3.95100	.6	4.01435	.6	4.07958	.6	4.14669
.7	3.95254	.7	4.01596	.7	4.08123	.7	4.14838
.8	3.95412	.8	4.01758	.8	4.08288	.8	4.15008
.9	3.95569	.9	4.01935	.9	4.08454	.9	4.15181
8.0	3.95723	12.0	4.02081	16.0	4.08619	20.0	4.15350
.1	3.95881	.1	4.02242	.1	4.08785	.1	4.15519
.2	3.96038	.2	4.02404	.2	4.08950	.2	4.15692
.3	3.96196	.3	4.02565	.3	4.09115	.3	4.15862
.4	3.96354	.4	4.02727	.4	4.09285	.4	4.16035
.5	3.96612	.5	4.02885	.5	4.09450	.5	4.16204
.6	3.96665	.6	4.03050	.6	4.09615	.6	4.16377
.7	3.96883	.7	4.03212	.7	4.09785	.7	4.16596
.8	3.96981	.8	4.03373	.8	4.09930	.8	4.16719
.9	3.96938	.9	4.03535	.9	4.10115	.9	4.16872

Source: MSC, Agronomy section.

TABLE FOR CALCULATING AVAILABLE POL% IN TRIALS AND COMMERCIAL FIELDS

Fibre %	Ratio I	Fibre %	Ratio I	Purity	Ratio II	Purity	Ratio II
8.0	.82	18.5	.61	70	.72	91	.90
8.5	.81	19.0	.60	71	.73	92	.91
9.0	.80	19.5	.59	72	.74	93	.92
9.5	.79	20.0	.58	73	.75	94	.92
10.0	.78	20.5	.57	74	.76	95	.93
10.5	.77	21.0	.56	75	.77	96	.94
11.0	.76	21.5	.55	76	.78	97	.95
11.5	.75	22.0	.54	77	.79	98	
12.0	.74	22.5	.53	78	.80		
12.5	.73	23.0	.52	79	.81		
13.0	.72	23.5	.51	80	.82		
13.5	.71	24.0	.50	81	.83		
14.0	.70	24.5	.49	82	.83		
14.5	.69	25.0	.48	83	.84		
15.0	.68	25.5	.47	84	.85		
15.5	.67	26.0	.46	85	.86		
16.0	.66	26.5	.45	86	.87		
16.5	.65	27.0	.44	87	.87		
17.0	.64	27.5	.43	88	.88		
17.5	.63	28.0	.42	89	.89		
18.0	.62			90	.89		

Pol % juice * ratio I * ratio II = available pol % cane

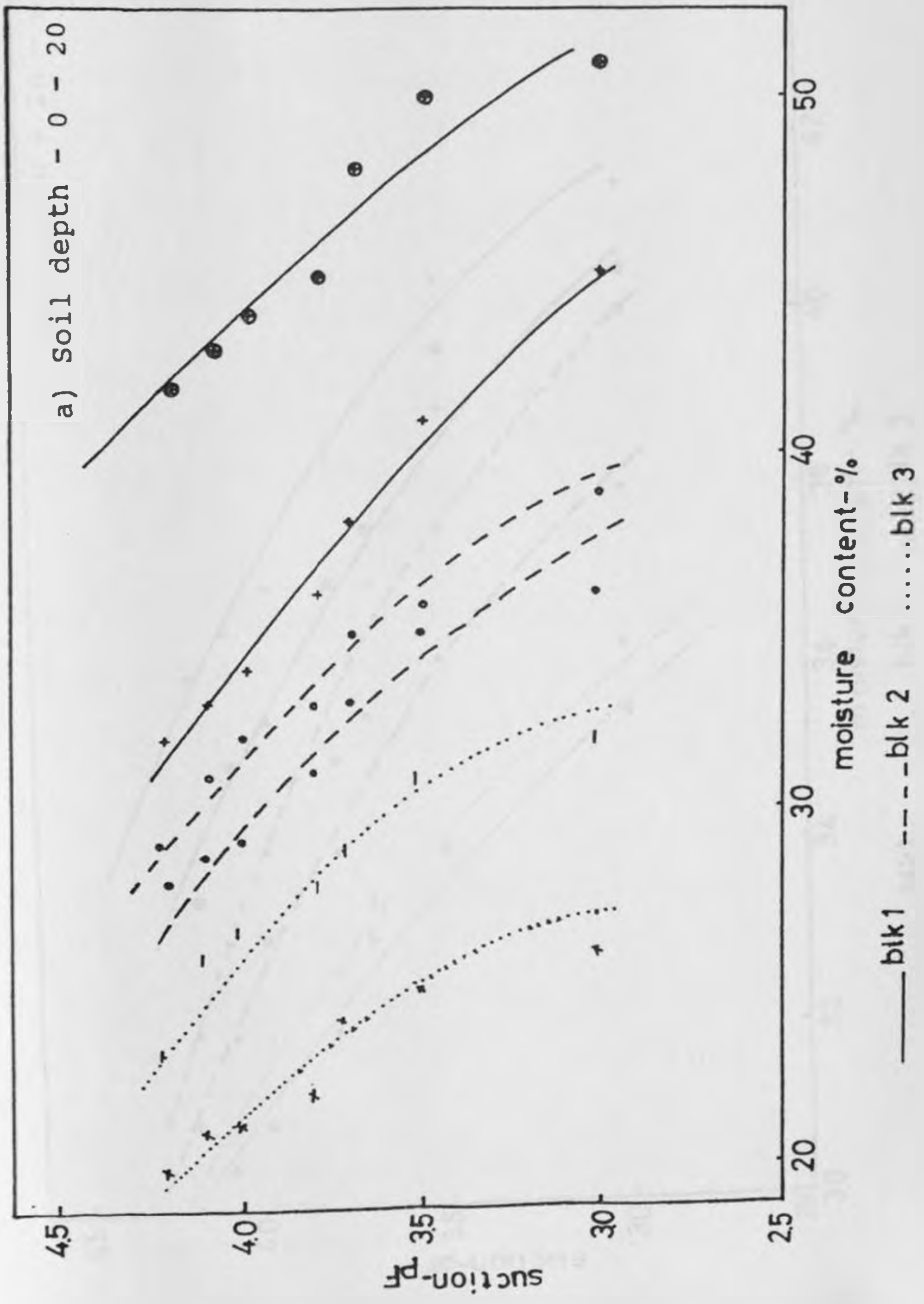
Pol % juice * ratio I = extracted pol % cane

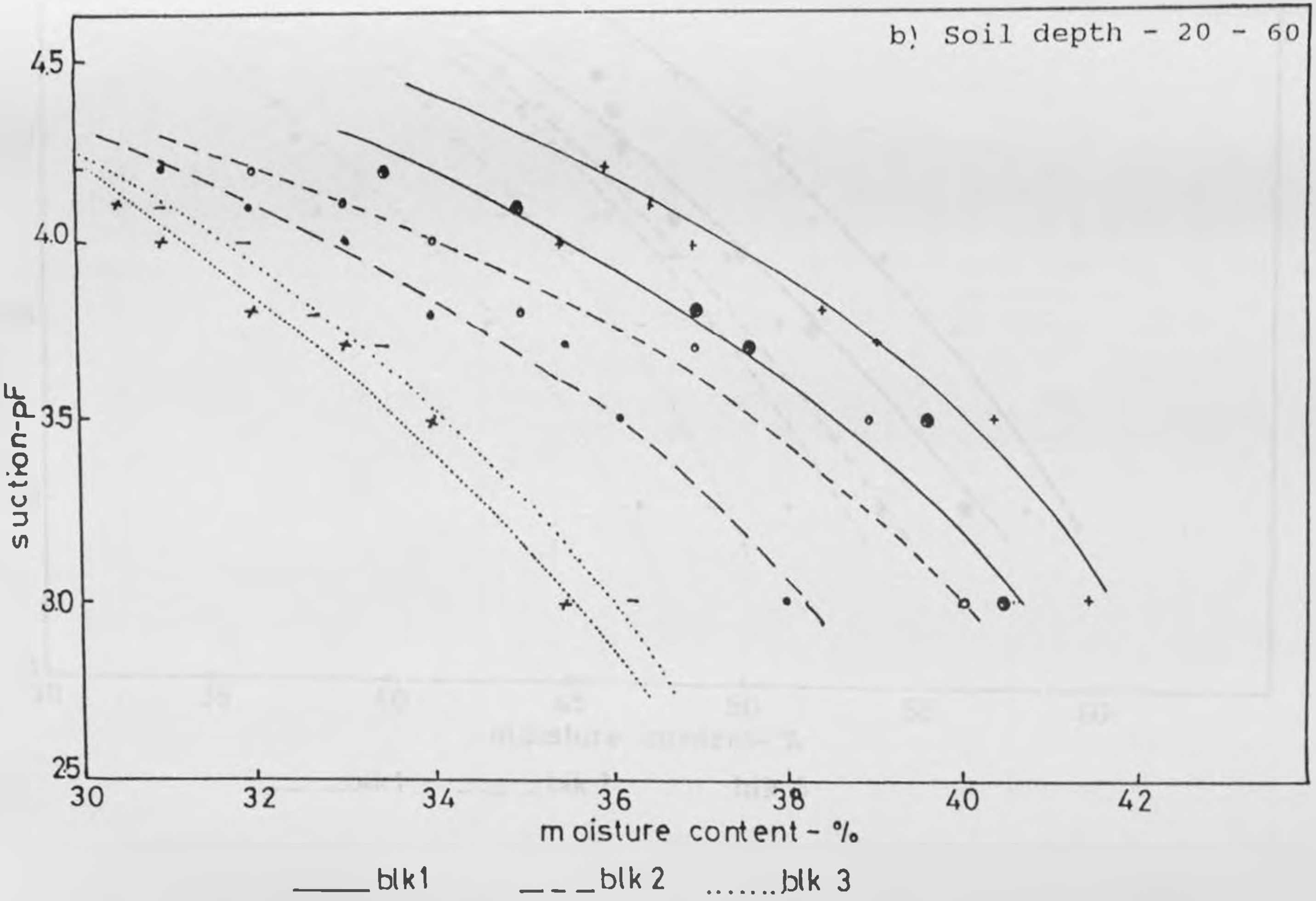
Tonnes available pol/hectare = TCH * available pol % cane/100

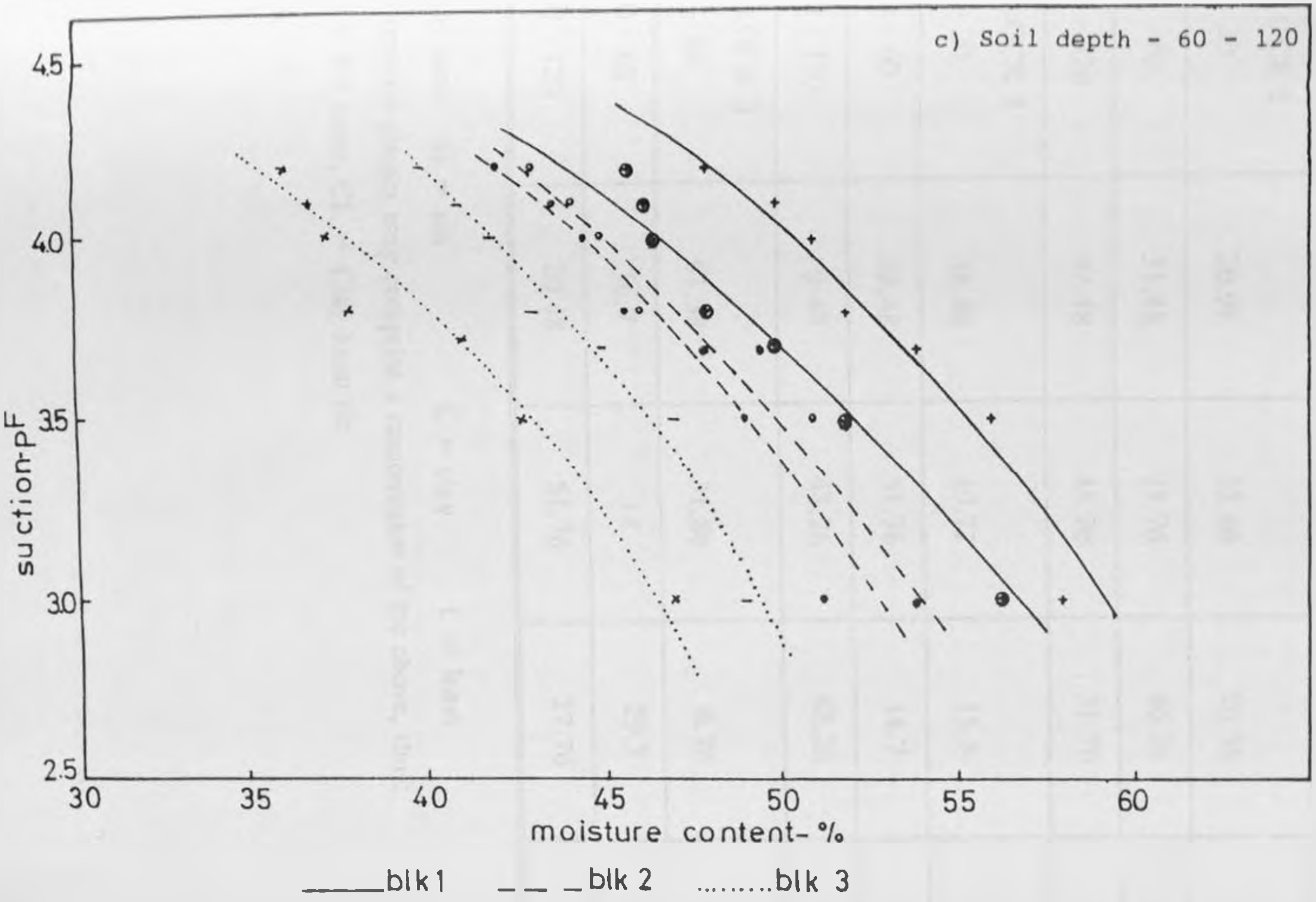
Appendix 5B Sucrose analysis - preliminary results

TREATMENT	CORRECTED BRIX	POL %	PURITY	FIBRE %	AVAILABLE POL %
BLOCK 1					
PPVC	22.38	20.15	90.0	14.7	12.4
BFD	21.98	19.37	88.1	15.7	11.4
PCD	22.58	20.16	89.3	14.8	12.4
RFFD	22.58	20.80	92.1	15.1	12.9
COEX	20.38	18.06	88.6	14.6	11.0
BLOCK 2					
PPVC	21.34	18.43	86.4	13.3	11.5
BFD	20.74	18.28	88.1	13.4	11.6
PCD	21.94	19.44	88.6	13.7	12.1
RFFD	21.74	19.45	89.5	14.8	11.9
COEX	21.54	19.18	89.0	13.2	12.3
BLOCK 3					
PPVC	22.69	20.16	88.8	15.8	11.9
BFD	22.69	20.02	88.2	12.7	13.1
PCD	20.89	18.84	90.2	16.1	11.1
RFFD	21.99	19.75	89.8	13.6	12.5
COEX	23.30	20.78	89.20	15.7	12.4

Appendix 6 Suction / moisture content relationships for soils in the experimental field




b) Soil depth - 20 - 60
suction-pF
4.5
4.0
3.5
3.0
2.5
30
32
34
36
38
40
42
moisture content - %
_____ blk1
_ _ _ blk 2
.... blk 3



c) Soil depth - 60 - 120

Appendix 7 Soil textural analysis - results for the experimental field

Soil depth	% sand	% silt	% clay	Textural class
BLOCK 1				
0 - 20	26.98	52.46	20.56	SiL
20 - 60	31.48	21.76	46.76	C
60 - 120	22.48	45.76	31.76	CL
BLOCK 2				
0 - 20	38.48	49.72	15.8	SiL
20 - 60	33.48	51.76	14.7	SiL
60 - 120	9.48	48.26	42.26	SiC
BLOCK 3				
0 - 20	61.38	31.86	6.76	SL
20 - 60	56.7	14	29.3	SCL
60 - 120	20.48	51.76	27.76	CL

* S = sand Si = silt C = clay L = loam

The textural classes may comprise a combination of the above, thus:

SiL = Silt loam, CL = Clay loam etc

ppendix 8 ANOVA tables for water tables during recession periods

Time period:- DECEMBER 1993
Treatment:- PCD

Source of variation	df	SS	MS	F values Calculated	5%	1%
Total	56	12427.63				
Main	2	6234.44	3117.22	27.18	3.16	5.02
Error	54	6193.18	114.69			

Calculated F statistic was highly significant.

Means test:- LSD .05 = 5.544 MSD = 8.374

Replicate	Mean	Non-significant ranges*
3	82.4	a
2	66.9	b
1	57.1	c

Treatment:- COEX

Source of variation	df	SS	MS	F values Calculated	5%	1%
Total	56	12126.21				
Main	2	1778.43	889.21	4.64	3.16	5.02
Error	54	10347.78	191.63			

Calculated F statistic was significant.

LSD .05 = 7.16 MSD = 10.82

Replicate	Mean	Non-significant ranges*
3	78.0	a
1	76.3	a
2	65.4	b

* Similar letters imply that no significant differences were found between the corresponding replicates.

Time period:- JULY 1994
Treatment:- PPVC

Source of variation	df	SS	MS	F-values Calculated	5%	1%
Total	53	10277.10				
Main	2	5260.90	2630.45	26.74	3.18	5.05
Error	51	5016.20	98.35			

Calculated F statistic was highly significant.

LSD .05 = 5.14 MSD = 7.98

Replicate	Mean	Non-significant ranges
3	75.8	a
2	74.8	a
1	54.4	b

Treatment:- BFD

Source of variation	df	SS	MS	F-values Calculated	5%	1%
Total	53	8086.60				
Main	2	5362.45	2681.22	50.20	3.18	5.05
Error	51	2724.15	53.41			

Calculated F statistic was highly significant.

LSD .05 = 3.79 MSD = 5.88

Replicate	Mean	Non-significant ranges
3	46.1	a
2	24.0	b
1	23.8	b

Appendix 9 Installation of the trial drains - an overview

For the installations, alignment was done using quick set levels. Trenches, 45 cm wide, were dug and graded at 1% slope, after which the subsurface drains were installed in the graded trenches. The laying of the drains was done manually.

The perforated P.V.C., porous concrete drains and loose rock for the rock filled French drains, were wrapped in polyfelt which is a filter material. Backfilling was then done with base material to a height of 25 cm, then with sand and then top soil (from excavations) for the final 30 cm.

The bagasse filled drains were installed by filling the trench with bagasse and then compressing it by passing over with a shovel tractor.

The treatments were separated by polythene sheets. Influence of the adjacent field, A87 (see fig.1.2) was prevented by means of a terrace drain separating the two fields.

For the collector drain, a topographic - survey was done along the already existing collector drain. The downstream end was dug to 1.8 m. This was considered a substantial depth to allow for the measurement of discharge from the drains using a measuring cylinder.

Some problems, however, occurred during installation, which was done during a wet period. In some cases, the polyfelt got smeared with mud, thus rendering it ineffective in its water conducting function. This, though, affected only a few of the drains.