EFFECT OF IRRIGATION WATER REGIMES APPLIED VIA SUBSURFACE DRIPPERS ON SOIL WATER DISTRIBUTION AND ON SUGARCANE (Saccharum officinarum L.) GROWTH.

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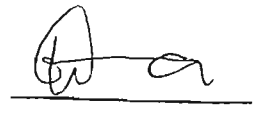
DECLARATION

I Mandla Ernest Gama hereby declare that all the work in this thesis is a result of my own original investigations, except for the assistance that has been acknowledged. It is submitted for the degree of Master of Science, University of Natal, Pietermaritzburg, and has not been submitted previously for any degree or examination at any other University.

Signed: 

ABSTRACT

The effects of different water regimes on sugarcane growth were investigated for subsurface drip irrigation over three seasons. Arbitrary factors (0.5, 0.75, 1.0 and 1.2 of ETc), were applied to adjust the daily estimates of Penman Monteith evapotranspiration (Et). These drip treatments were compared to an overhead sprinkler irrigated (1.0 ETc) block of sugarcane. In the plant and first ratoon crops, the drip plots were irrigated to field capacity, by replenishing an allowable deficit of 10 mm. In the second ratoon however, the soil was irrigated to a 50 % total available moisture (TAM) level. Soil water movement and root distribution adjacent and below emitters was measured.

There was an increase in vertical and lateral soil water movement with increase in irrigation water regime. The rooting density increased with increase in soil water content. However, the root density decreased slightly in the 1.2 ETc treatment below the emitters in the wetter season. There were no differences in cane growth among the drip treatments in the first two seasons, mainly due to the wet weather conditions. In the second ratoon the 1.2 ETc treatment had the tallest stalks, which resulted in the highest cane and sucrose yields (t ha^{-1}). There were no differences in cane and sucrose yields among the other treatments. There were no consistent differences in the plant canopy cover among the drip treatments. The cane growth in the sprinkler block was poor in the plant and first ratoon crops, probably due to the leaching of N, and it was comparable to the drip block in the second ratoon. The crop water use efficiency (CWUE) decreased with an increase in irrigation water regimes, and all drip CWUE treatments were better than that of the sprinkler block in all years.

The study has shown that, a) the estimated daily ETc could be reduced by 50 % while still achieving the Mhlume estate average cane yield of 95 t ha^{-1}, b) rainfall use efficiency, cane and sucrose yields could be increased by using 1.2 ETc at the 50 % TAM level, c) there is a need to re-examine N applications under drip irrigation, particularly where heavy rains occur after leaf samples have been taken.

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GENERAL INTRODUCTION

Mhlume Sugar Company is one of the three large sugarcane growing and milling companies in Swaziland situated in the northern part of the Swaziland Lowveld (32° E, 26° S; altitude 300m). Irrigated sugarcane was first grown at Mhlume in 1958. There has been a progressive decline in productivity over time. Initially high average yields of 120 tonnes cane per hectare (t ha^{-1}) declined rapidly to 77 t ha^{-1} by 1974. The decline was mainly attributed to increased salinity and sodicity levels. Other reasons for the decline in productivity included improper matching of irrigation techniques to soils, the majority of which are classified as marginal and in some cases unsuitable for irrigated sugarcane production. For example, furrow irrigation was implemented without proper land leveling (Workman *et al.*, 1986). By 1974, some 280 ha of land had been abandoned due to waterlogging, and subsequent build-up of associated salinity and/or sodicity problems.

Following a consultant's report (Coulter *et al.*, 1971), a major programme of remedial action was initiated. This consisted of the installation of a comprehensive subsurface drainage system. Most of these drains were laid at an average spacing of 40 m at a depth of 1.2 m. In conjunction, phosphogypsum was applied at rates of up to 10 t ha^{-1} at planting. At the same time major improvements were made to basic agronomic practices, particularly irrigation. As a result, yields increased to the present estate average of 95 t ha^{-1}. Ongoing monitoring of soils in problem areas has shown decreases in both the salinity and sodicity levels to more acceptable levels.

With the soil amelioration programme well established at Mhlume, the focus has shifted to irrigation water management, with an emphasis on optimal water use. Furthermore, the unreliability of rainfall and increasing competition for irrigation water among an increasing number of cane growers have made irrigation efficiency a more important criterion than before. The current development of 7000 ha of small-scale irrigation will put further pressure on water resources in the Komati Basin (Gibb, 1992). Consequently, the main challenge for Mhlume and the sugarcane industry in Swaziland is to investigate ways of improving irrigation efficiencies. This will require the use of more efficient irrigation systems and more accurate scheduling of water applications to optimise cane yields while conserving water.

The area under cane production at Mhlume is 9118 ha, with approximately 61% being furrow irrigated, 31 % overhead sprinkler irrigated and the remainder is either under subsurface drip (478 ha) or center pivot (205 ha) irrigation (Field staff, 2001). Good quality irrigation water is provided by a gravity-fed supply canal from the Komati River. The climate is subtropical with an average annual rainfall of approximately 800 mm (30 year mean) and an annual Class A pan evaporation of approximately 1 900 mm. The annual long-term mean maximum and minimum temperatures are 16 ^{0}C and 28 ^{0}C, respectively. Rainfall occurs mostly in the Summer months, from October to March, with winters being relatively dry. Annual evapotranspiration for sugarcane is estimated to be 1 300 mm, using the Penman - Monteith approach, and effective rainfall estimated at 640 mm (80 % efficiency). The balance of the crop water requirement is met through irrigation.

In the Swaziland sugar industry the estimate of crop water use was historically based on crop factors and the Class A Pan evaporation (Eo). More recently, there has been a move from the Eo to the more accurate Penman – Monteith (PM) approach of estimating evapotranspiration (Richard *et al.*, 1998). With the good correlation between PM and Class A Pan evaporation, correction factors for the Class A Pan evaporation to PM equivalent were developed to enable growers to continue using the Class A Pan.

Drip irrigation is one of the alternatives being considered to improve water use efficiency in sugarcane production. As a result there has been increasing interest in Swaziland in the use of this system as an alternative method to the currently operated furrow or sprinkler irrigation systems. Advantages of drip irrigation include increased irrigation water use efficiency, decreased waterlogging caused by irrigation, reduction of soil surface evaporation, and conservation of soil structure compared to either furrow or overhead irrigation systems. Although drip irrigation has high initial capital costs, its operating costs are relatively low (Nixon and Workman, 1987; Coelho and Or, 1997). This is mainly because of low energy and labour costs.

Water application under drip irrigation can be accurately controlled and plant available water can be maintained at an optimum level (Nixon and Workman, 1987). The higher efficiency is due to reduction of water losses in distribution and application, and by partial wetting of the soil (reduction in soil surface evaporation).

With the increased water use efficiency and the ease with which water application can be controlled under drip irrigation, an interest has developed in establishing the extent to which irrigation water can be reduced without reducing sugarcane yield. The approach to answer some of the questions that arose was to vary the amounts of water applied to the crop.

The overall objective of the research was to determine how to enhance irrigation efficiency of sugarcane using subsurface drip irrigation by studying the effects of varying the amount of irrigation water made available to sugarcane (from surplus to deficit), on the water use efficiency, growth and yield of the crop. The study was implemented by using a set of arbitrary evapotranspiration factors (0.5, 0.75, 1.0 and 1.2 of crop reference evapo-transpiration) applied to Penman – Monteith Et, thereby adjusting the estimates of daily Et, and by comparing these responses to a block of sprinkler irrigated sugarcane.

CHAPTER 1

LITERATURE REVIEW

1.1 Introduction

The principle in drip irrigation is to supply the plant water requirement by maintaining only the rootzone at a high water potential by applying frequent small amounts of water. This is in contrast to the traditional long irrigation cycles under surface or overhead sprinkler irrigation, where a short period of infiltration is followed by a long period of simultaneous redistribution, evaporation, and extraction of water by the growing plant (Bresler, 1978). Under high frequency irrigation, water is supplied to the crop as it is needed, eliminating the need to store water within the entire soil profile. The water holding capacity of the soil becomes less important compared to sprinkler and furrow systems, where the water supplied is based on the water holding capacity of the soil (Rawlins, 1973). Under the latter irrigation systems the soil water potential is high immediately after irrigating, and falls until a subsequent irrigation cycle is applied.

The differences in the irrigation principles and irrigation system's design have a direct bearing on the water movement once in contact with the soil. In the drip system water enters the soil at discrete points (emitters) along a dripper line where it distributes through the soil volume in a pattern determined by the soil properties and volume of water applied. In sprinkler or furrow irrigation the amount to apply is mainly based on the soil water holding capacity, effective rooting depth and evapo-transpiration. The important factors in a drip system design are the emitter spacing, emitter discharge rate, diameter and length of drip lateral together with the understanding of soil - water hydraulic properties.

For a given soil type, the type of irrigation system, total crop water requirement and irrigation scheduling method used to a large extent determines the frequency and how much water to apply per irrigation. This chapter discusses the factors that influence the crop water requirement in a sugarcane crop and the soil physical properties that influence soil water movement under unsaturated soil water conditions in soils with stable soil structure.

1.2 Sugarcane crop water requirement.

Several researchers (Thompson, 1976; Thompson, 1988 and McGlinchey, 1998) have studied sugarcane water use and have used the Penman - Monteith equation to estimate crop water requirement. The PM equation is the recommended standard for evapo-transpiration (Et) estimation (Richard *et al.*, 1998). The Class A Pan, when taking into account costs of equipment and time required to record the various meteorological readings to estimate PM Et and to carry out the calculations, remains the more practical and convenient basis for exercising irrigation controls (Thompson, 1988). However, the advent of automatic weather stations and telecommunications in the capture of weather data, now makes it possible to use sophisticated evaporation and growth models to estimate evapotranspiration without using the Class A Pan (Inman-Bamber *et al.*, 1993).

1.2.1 Relationship between Penman Monteith Et, measured Et and Class A Pan evaporation.

The Penman - Monteith equation uses meteorological data variates, net radiation, maximum and minimum temperatures, run of wind, and relative humidity (Thompson, 1988).

The equations are as follows:

$$\text{Et (Penman)} = \frac{\Delta R_n + \gamma(e_a - e_d)0.26(1+u/160)}{\Delta+\gamma} \quad (1)$$

$$\text{Et (Monteith)} = \frac{\Delta R_n + \gamma(e_a - e_d)B_v}{\Delta+\gamma(1+r_s/r_a)} \quad (2)$$

Where Δ = slope of the saturated vapour pressure curve at air temperature,

R_n = net radiation,

γ = psychrometric constant,

e_a = saturated vapour pressure of air at dry bulb temperature,

e_d = vapour pressure of air at dry bulb temperature,

u = run of wind,

B_v = wind function (Businger, 1956),

r_s = surface resistance (0.75 sec cm^{-1}), and

r_a = aerodynamic resistance (1/0.01437u).

Thompson, (1988), showed that there was a good correlation between the Et measured from lysimeters and the Et calculated from the above equations (r = 0.75 and 0.73 with Penman and Monteith respectively). He also found that there was a good relationship between the Class A Pan and the measured Et. Inman Bamber *et al.*, (1993) found that there was an even better correlation (r^2 = 0.81) between the Penman-Monteith (PM) Et and Class A Pan evaporation. The Penman - Monteith equation used was:

$$Et = \frac{\Delta(R_n - G) + 0.0864 c_p (VPD_2)/r_a}{\Delta + \gamma(1.0 + r_s/r_a)} \qquad (3)$$

Where:

Δ = slope of the saturated vapour pressure – temperature curve,

G = soil heat flux,

c_p = specific heat of air at constant pressure,

VPD_2 = vapour pressure deficit at 10 m,

r_a = canopy aerodynamic resistance

$= Ln((z_2 - d_c)/z\alpha)^2 / (u_2 K^2)$,

r_s = bulk stomatal resistance,

= leaf resistance x leaf area index,

z_α = roughness length for sugarcane,

z_2 = height 10 m above ground,

d_c = zero plane displacement for sugarcane,

R_n = net radiation, and

γ = psychometric constant.

The CANEGRO model developed at the South African Sugar Association Experiment Station and validated in Swaziland was used to develop factors for converting Eo into the Penman - Monteith equivalents (Appendix 1). Using the adjustment factors, the equation for calculating crop reference evapo-transpiration (ETc) was developed as follows:

$$ETc = Eo \times PM\ factor \times Kc. \quad (4)$$

Where: ETc = crop reference evapo-transpiration,
Eo = Class A Pan evaporation,
PM factor = Penman Monteith factor (ET/Eo), and
Kc = crop factor

1.2.2 Plant Available water

The principle of soil water holding capacity as mentioned earlier is relevant in low frequency irrigation, particularly in the traditional overhead sprinkler and furrow irrigation system. In drip irrigation where high frequency irrigation is practiced the critical factor is the estimation of the daily evapotranspiration. The availability of soil water is mainly affected by the soil hydraulic properties. When using soil water content, plant available water (PAW) is characterised using three categories; field capacity (FC), total available moisture (TAM), permanent wilting point (PWP) and effective rooting depth (ERD).

1.2.2.1 Field Capacity

Field capacity is an estimate of the maximum amount of water that can be held by a soil without further loss by drainage (Reeve and Carter, 1991), and is commonly defined as water held at a matric potential of –10 kPa (Ahuja and Nielsen, 1990). Field capacity should be determined in the field by monitoring water content in a draining profile (Salter and Williams, 1965), and if available, to use the water retentivity curve to estimate field capacity.

1.2.2.2 Permanent wilting point

Permanent wilting point defines the lower limit of PAW in the soil, and is normally defined as the water held at a matric potential of –1500 kPa (Ahuja and Nielsen, 1990). However, it has been shown that different plant species have different values of matric potential at PWP (Reeve and Carter, 1991), with ranges from –800 kPa to –3000 kPa. This large range nevertheless usually represents a relatively small change in available water, due to the very gradual change in water content with changing matric potential at higher tensions. Hence the matric potential of –1500 kPa based on wilting studies of sunflowers by Richards and Weaver (1944) produces a reasonable approximation of water content at wilting point as determined by a water retention curve.

1.2.2.3 Total available water capacity

Total available water is the maximum amount of water in the soil profile available for crop water use by transpiration (Annadale *et al.*, 1989). It is normally defined as water content in the soil that is held at a matric potential between FC (–10 kPa) and the PWP (–1500 kPa). Not all water held between field capacity and permanent wilting point is equally available to plants. Water that is held at tensions up to 100 kPa is regarded as being freely available to most crops. A rule of thumb is that the readily available water is one-half to two-thirds of the total available water within the effective rooting depth (Withers and Vipond, 1980; Landon, 1991).

1.2.3 Effective rooting depth

Gosnell and Thompson, (1965) defined effective rooting depth (ERD) under irrigated conditions as that depth of soil from which the crop can remove all the PAW in the field before its growth is materially affected. The PAW is therefore the product between the TAM and the fraction of ERD relative to potential rooting depth. The effective rooting depth is determined in the field by visual inspection of the soil profile and the rooting habit of a crop (Cassel and Nielsen, 1986). Effective rooting depth depends on the stage of growth of the crop, soil type and antecedent soil water.

The dynamism of root growth makes it difficult to accurately estimate effective rooting depth and prediction of effective rooting depth must be accompanied by field investigations (Gosnell and Thompson, 1965). Soil water sensors, radioactive isotope techniques and the neutron probe are some of the non destructive methods that can be used in estimating effective rooting depth during the growing season (Wood and Wood, 1967).

The estimation of the effective rooting depth under drip irrigation is even more difficult, since the soil profile is partially wetted, and the majority of the roots would be expected to be confined within the wetted zones below the emitters. The placement of soil water sensors to monitor soil water movement should therefore be influenced by the size and shape of the wetted zone.

1.3 Response of sugarcane to soil water potential

Water moves from the soil, to the plant roots and to the mesophyll cells of the leaf along energy gradients moving from regions of higher water potential to regions of lower water potential. At the leaf, water is evaporated into the atmosphere, the necessary energy for vaporisation being supplied mainly by solar radiation. The evaporated water is removed from the leaf surface by turbulence, convection and by vapour pressure gradients (Gardener, 1960).

The evaporation of water from the leaf mesophyll cells decreases the water potential in the leaf and thus a gradient in matric water potential from the leaf to the roots is established. It is this matric water potential gradient that determines the transpiration rate. As the soil around the roots dries the matric potential of the soil water decreases and thus if a constant transpiration rate is to be maintained to meet evaporative demand of the atmosphere, the matric potential in the roots must decrease (Rawlins and Raats, 1975). As long as the soil matric water potential around the root increases, water moves towards the roots from an area where the soil matric water potential is higher, in response to the established matric potential gradient.

The increase in matric water potential at the plant roots is proportional to the rate of water uptake and is inversely proportional to capillary conductivity (Gardener, 1960).

Changes in soil water content results in corresponding changes in the matric potential gradient between the roots and the surrounding soil (Hill, 1965). Under wet conditions the roots extract water close to the soil surface, and as the profile dries out the depth of water extraction increases. Between long intervals of irrigation a considerable amount of water must be stored within the soil profile. For this water to be used it must be brought into contact with active roots, and for this to happen a matric potential gradient must be established to cause this water to flow towards the roots (Rawlins, 1973). The soil water retention capacity also affects water uptake by roots (Gosnell and Thompson, 1965; Wood and Wood, 1967).

Water deficit during establishment and the early vegetative period (tillering) has an adverse effect on yield as does water deficit in the later growth periods. Water deficit during the vegetative period (stem elongation) and early yield formation causes a lower rate of stalk elongation (Gosnell, 1967). Water deficit during the later part of yield formation forces the crop to ripen. During this stage a low soil water potential is conducive to ripening, however when the plant is exposed to extreme water stress, losses in sucrose content may occur (Doorenbos, 1986).

Crop dry matter accumulation is determined by canopy properties such as the speed of development, size and the duration, as well as the photosynthetic efficiency of the canopy. Leaf growth, stomatal conductance and photosynthesis are all affected by plant water potential. To sustain optimal growth rates the water potentials should be kept at optimum levels in times of natural water deficits by water application (Roberts *et al.*, 1990). Hudson, (1968) indicated that growth rate of a sugarcane plant declined with decreasing soil water potential and ageing root system, and was increased by small showers of rain at night or dull periods during the day.

Water stress increases the rate of leaf senescence and reduces leaf extension rate (Inman-Bamber and de Jager, 1984). Thompson and de Robillard (1968) found that leaf extension rate of the top-most leaf collar of cane growing in drying soils under field conditions fell below maximum when the soil water potential (Ψ_s) was greater than -100 kPa. Inman-Bamber (1986) measured leaf water potential (Ψ_L) to show the effect of increasing Ψ_s or water stress on a sugarcane growth. At a Ψ_L of –0.2 MPa, the plant extension rate falls below its optimal potential, at -0.3 MPa, stomatal resistance starts to rise gradually. Between –0.4

and –0.9 MPa (Ψ_L), the plant extension ceases, and at –0.8 MPa, the youngest unfurled leaves start to roll. Between –1.0 and –1.7 MPa (Ψ_L), green leaf area is reduced, at -1.2 to –1.7 MPa (Ψ_L), stomatal resistance rapidly increases, and finally stomata close between –1.4 and –2.3 MPa. At –2.0 MPa (Ψ_L), the youngest unfurled leaf rolls fully and at –2.8 MPa (Ψ_L), the apical meristem is permanently damaged.

Variation in water use efficiency (WUE) and cane yield of crops under a wide range of conditions have been obtained by researchers and the WUE figures range from 0.074 t ha^{-1} mm^{-1}, (Isobe, 1968), 0.97 t ha^{-1} mm^{-1} (Thompson, 1976) and 0.169 t ha^{-1} mm^{-1} (Teare and Peet, 1983). The WUE values were based on the final yield at harvesting and the total amount of water used between planting or ratooning and harvesting. Inman Bamber (1986), measured stalk mass accumulation thorough out the growth of a sugarcane crop. He found that the stalk mass varied considerably through the crop season and that cane yields increase by more than 1.0 t ha d^{-1} during the hottest months.

1.4 Soil water movement in unsaturated soils

Water movement in the soil may take place in either a saturated or unsaturated state. Saturated flow applies to water movement below a water table or when the infiltration rate at the surface exceeds the rate of saturated hydraulic conductivity of the soil inducing temporary saturation of the surface horizons (Dirksen, 1991). However, most of soil water transport processes such as infiltration, soil evaporation and uptake by plant roots involve flow in an unsaturated state (Hillel, 1980; Ragab and Feyen, 1981).

The movement of water under an unsaturated state is driven mainly by the gradient in matric potential (ψ_m) (Hamblin, 1985). The rate of flow in soils is defined by soil hydraulic properties such as water retention and hydraulic functions (Kravchenko and Zhang, 1998). Darcy's law indicates that the flow of a liquid through a porous medium is in the direction of, and at a rate proportional to hydraulic gradient and also proportional to the property of the conducting medium to transmit the liquid. Hillel, (1980), defines hydraulic conductivity based on Darcy's law as a proportionality factor relating water volume flux density (q) to the hydraulic gradient, as follows:

$$q = K\frac{\Delta H}{L} \tag{5}$$

Where: q = water volume flux density,

$\frac{\Delta H}{L}$ = the change in total hydraulic head (H) per unit length (L) of a soil column = hydraulic gradient

K = hydraulic conductivity

The equation implies that the greater the driving force ($\frac{\Delta H}{L}$), the greater will be the flux density (q). It is constant for conditions under which Darcy's law holds. The Darcy law was originally developed for saturated flow conditions, where K is constant for a particular soil body. The Darcy equation applies only in laminar or non turbulent flow (Fig 1.1). The linear relationship breaks down at high flux where flow becomes turbulent.

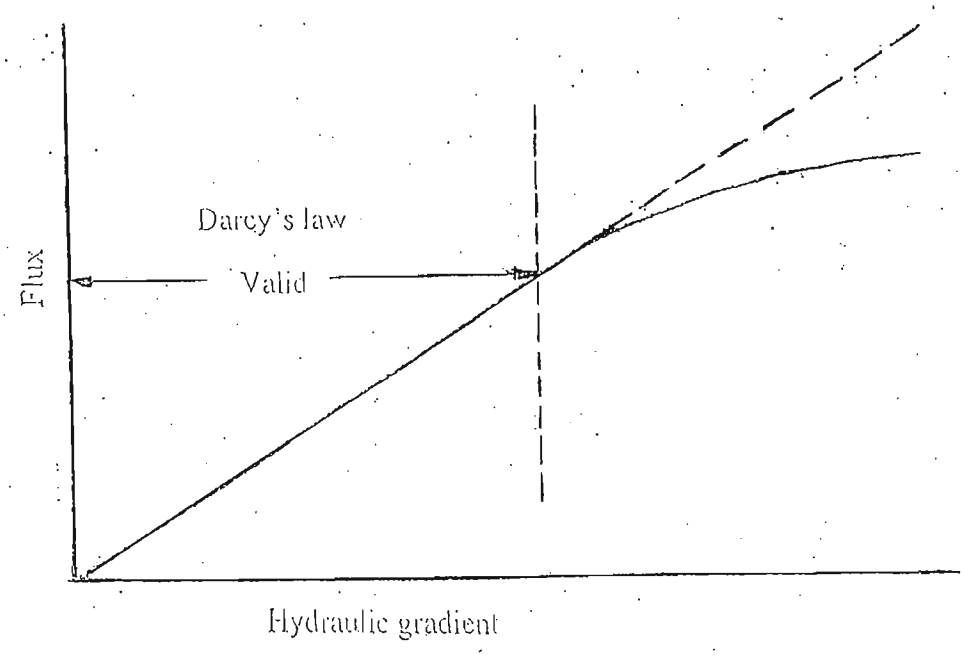


Figure 1.1 Illustration of the deviation of Darcy's law at high flux (Hillel, 1980).

Poiseuille's law has been identified as being more relevant under turbulent flow (Hillel, 1980). The law describes non laminar flow in fine capillaries as follows:

$$Q = \pi r^4 \frac{\Delta P}{8\eta L} \tag{6}$$

where: Q = water volume flow rate,

$\frac{\Delta P}{L}$ = pressure (P) drop per unit distance (L), = pressure gradient

r = radius of tube

η = viscosity.

The above equation indicates that the total flow rate of water through a capillary tube is proportional to the fourth power of the tube radius.

The Darcy law was originally conceived for saturated flow and was extended by Rirchards (1931) to unsaturated flow, with the provision that the conductivity is a function of Ψ_m. The Darcy equation has been combined with the equation of continuity to produce the Richard equation, which is the general equation of flow. The equation of continuity is based on the law of conservation of matter. The Richard equation describes water flow under transient and steady flow (Hillel, 1980). In a one dimensional horizontal flow where gravitational component is negligible, the equation becomes

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}\left(K(\Psi m) \frac{\partial(\Psi m)}{\partial x} \right) \tag{7}$$

Where x is the distance along the direction of flow and $\frac{\Psi_m}{\partial x}$ is the matric potential gradient.

For a vertical system, where the gravitational component is included, the equation is

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(K(\Psi_m) \frac{\partial(\Psi_m)}{\partial z} \right) + \frac{\partial K(\Psi_m)}{\partial z} \tag{8}$$

Where z, is the vertical distance from the soil surface downwards.

1.4.1 Important soil physical factors under unsaturated flow

The hydraulic conductivity of a soil to a great extent depends on the soil texture, pore size distribution and structure (Kunze *et al.,* 1968; Klute, 1986; and Reynolds, 1993). The pore size distribution, which involves the shape, size and arrangement of the primary particles which form compound particles themselves, reflect the nature of soil texture and structure (Sharma and Uehara, 1968). Other important factors affecting hydraulic conductivity include temperature and ionic concentration of the water (Reynolds, 1993).

1.4.1.1 Soil texture

Pore size distribution and soil internal surface area are the main soil factors that influence the hydraulic properties and water retention in the soil (Klute, 1986). For example, the porosity of sandy soils is dominated by large pores and therefore the majority of the water is released at relatively high potentials, i.e. when air entry "pressure" has been exceeded there is rapid release of water with decreasing soil water potential. In clay soil only small amounts of water are released at high potential due to a smaller proportion of large pores and clay soils retain a substantial amount of water at low potentials due to the large surface area available for adsorption (Figure 1.2).

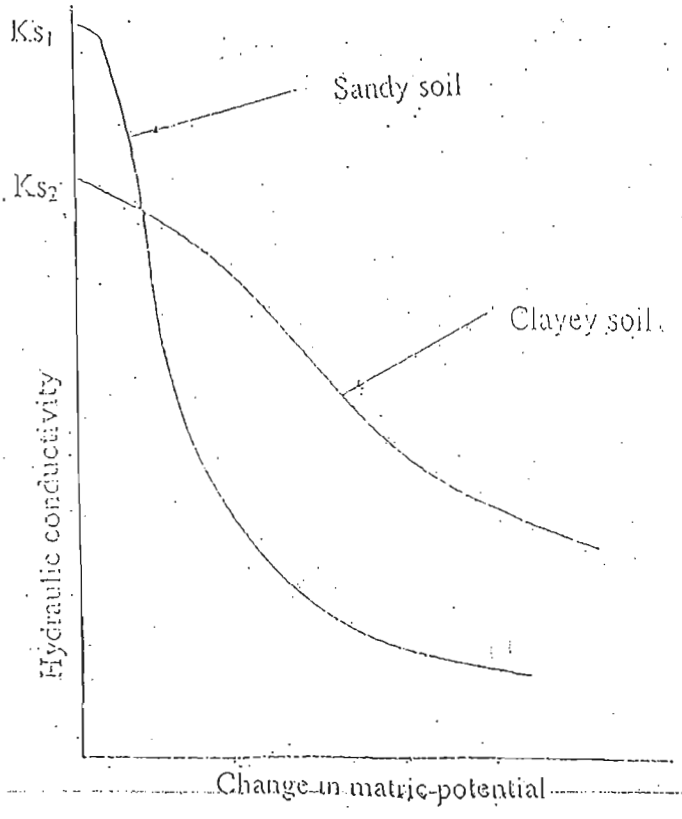


Figure 1.2 Effect of soil

The relationship between pore size and applied suction can be shown by the Kelvin equation (Carter and Ball, 1993).

$$d = 4\gamma \cos\alpha (pgh)^{-1} \qquad (9)$$

Where d = *diameter* of pores,

γ = surface tension of water,

α = contact angle of the water held in the pore (taken as zero),

p = density of water,

g = acceleration due to gravity

h = soil water suction.

The soil must be drained progressively by decreasing the matric potential, otherwise hysteresis influences water content at a given potential (Carter and Ball, 1993).

1.4.1.2 Soil structure

The presence and size of macropores depend on the soil structure, clay mineralogy and soil organic matter content. In well-structured stable soils there are relatively high proportions of large pores, resulting in a more rapid release of water at high water potential than in the non-structured swelling or shrinking clay soils. The continuity of macropores contributes to rapid movement of water and solutes through the soil. Often this flow bypasses the soil matrix resulting in rapid transport of water into the soil profile (Marshal, 1958; Blackwell *et al.*, 1990; and Rawls *et al.*, 1996). Hillel, (1980) demonstrated that an increase in bulk density due to compaction resulted in a decrease in hydraulic conductivity (Figure 1.3).

The organic matter content, due to its hydrophilic nature and improvement in the soil structure, also indirectly or directly contributes to pore size distribution. Incorporation of organic matter improves soil water holding capacity and hydraulic conductivity, reduces bulk density and increases soil porosity (Felton and Ali, 1992).

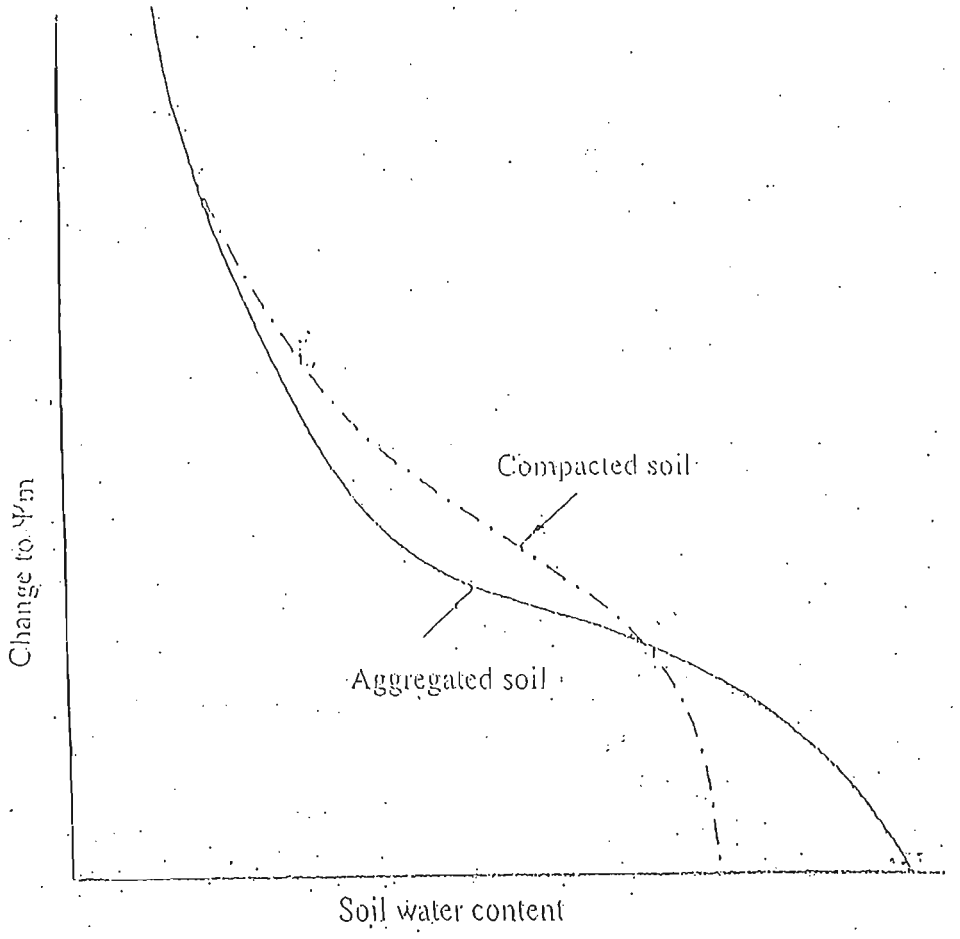


Figure 1.3 Effect of soil structure on water retention (Hillel D, 1980).

1.4.1.3 Soil water content

As the soil dries or decreases in water potential, there is a corresponding decrease in hydraulic conductivity (Hillel, 1980; Ghildyal and Tripathi, 1987). The decrease is caused by a number of factors, which include the reduction in effective porosity and reduction in pore conductivity due to withdrawal of water from macropores. The water has to move through micropores, which offer considerable resistance to water flow. Air filled pores are not effective channels for the flow of water in that they increase tortuosity in the path of flow. This is particularly evident in unstable soils where there is a reduction in the size of the pores because of shrinkage during drying and this increases the capillary pressure (Figure 1.3).

1.4.1.4 Electrolyte status

In swelling clays the composition and concentration of the soil solutes influence the hydraulic conductivity of the soil. The swelling and dispersion of clays increase when the ionic concentration in the soil solution decreases or when the solution Na:Ca ratio increases (McNeal and Coleman, 1966; Pupisky and Shainberg , 1979; Oster *et al.*, 1980). The swelling and dispersion of clays result in the reduction of macropores and clogging of conducting pores respectively (McNeal *et al.*, 1968). Under such soil conditions the hydraulic conductivity of the soil is reduced. The hydraulic conductivity of a sandy loam is related to total salt concentration of the soil solution and to the soil's exchangeable sodium percentage (ESP) (Figure 1.4).

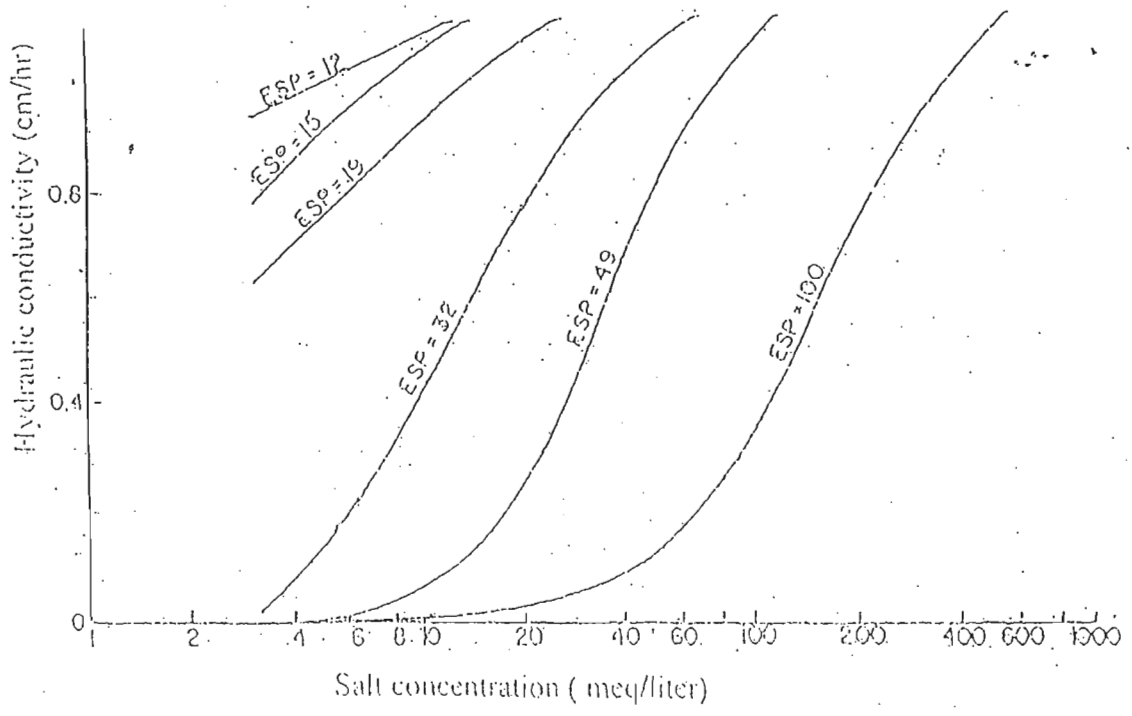


Figure 1.4. Effect of total salt concentration and soil exchangeable sodium percentage (ESP) on hydraulic conductivity (McNeal and Coleman, 1966).

1.4.1.5 Temperature

Soil temperature increase affects the density, viscosity and surface tension of water. An increase in soil temperature results in an increase in hydraulic conductivity (Figure 1.5). However the effect of temperature is more pronounced above the soil water content corresponding to 33 kPa (Ghildyal and Tripathi, 1987).

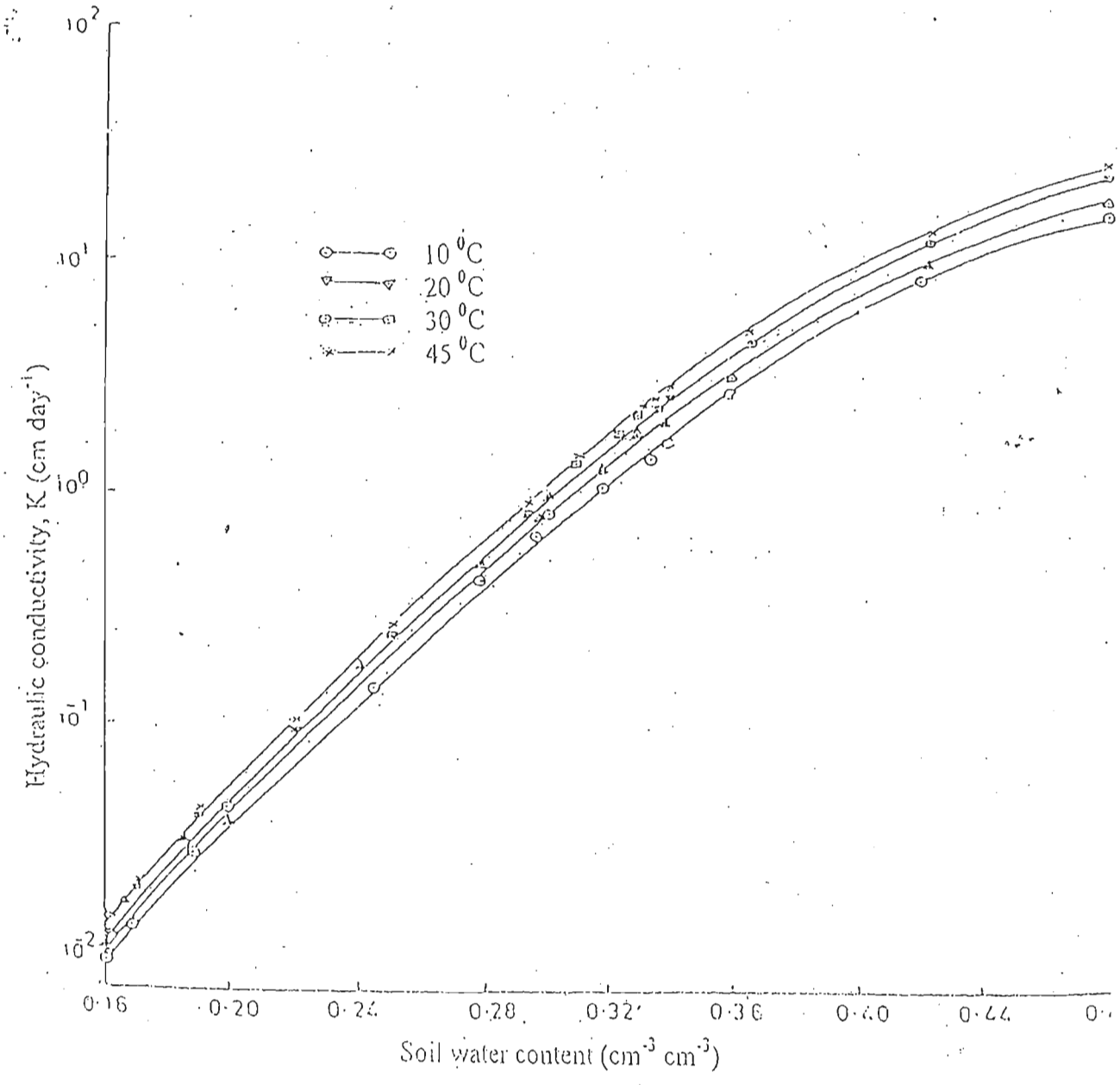


Figure 1.5. Effect of temperature on hydraulic conductivity (Ghildyal and Tripathi, 1987).

1.5 Factors influencing the soil wetting pattern under drip irrigation.

Drip irrigation system design mainly involves the selection of a proper combination of emitter discharge rate, emitter spacing, diameter and length of the lateral system for any given set of soil, crop and the climatic conditions (Bresler, 1978). In addition the application uniformity is dependent on the pressure variations caused by elevation changes and friction head losses through the pipe network, the sensitivity of emitters to pressure, temperature variations and the degree and extent of emitter clogging (Mizyed and Kruse, 1989).

1.5.1 Effect of soil texture on water movement

The soil texture is an important characteristic feature that is considered in irrigation design (Balogh, 1985). The shape of the wetted volume below an emitter depends mainly on capillary and gravitational forces (Baars, 1976). In soils with fine texture the capillary force is strong and that of gravity almost negligible. The wetting pattern in such soils has the shape of a bulb (Figure 1.6). In contrast, for sandy soils gravity forces exert a greater influence than capillary forces. Consequently, the vertical component of the flow is deeper and the horizontal component is narrower, which causes a more elongated shape of the wetted pattern (Bresler, 1978).

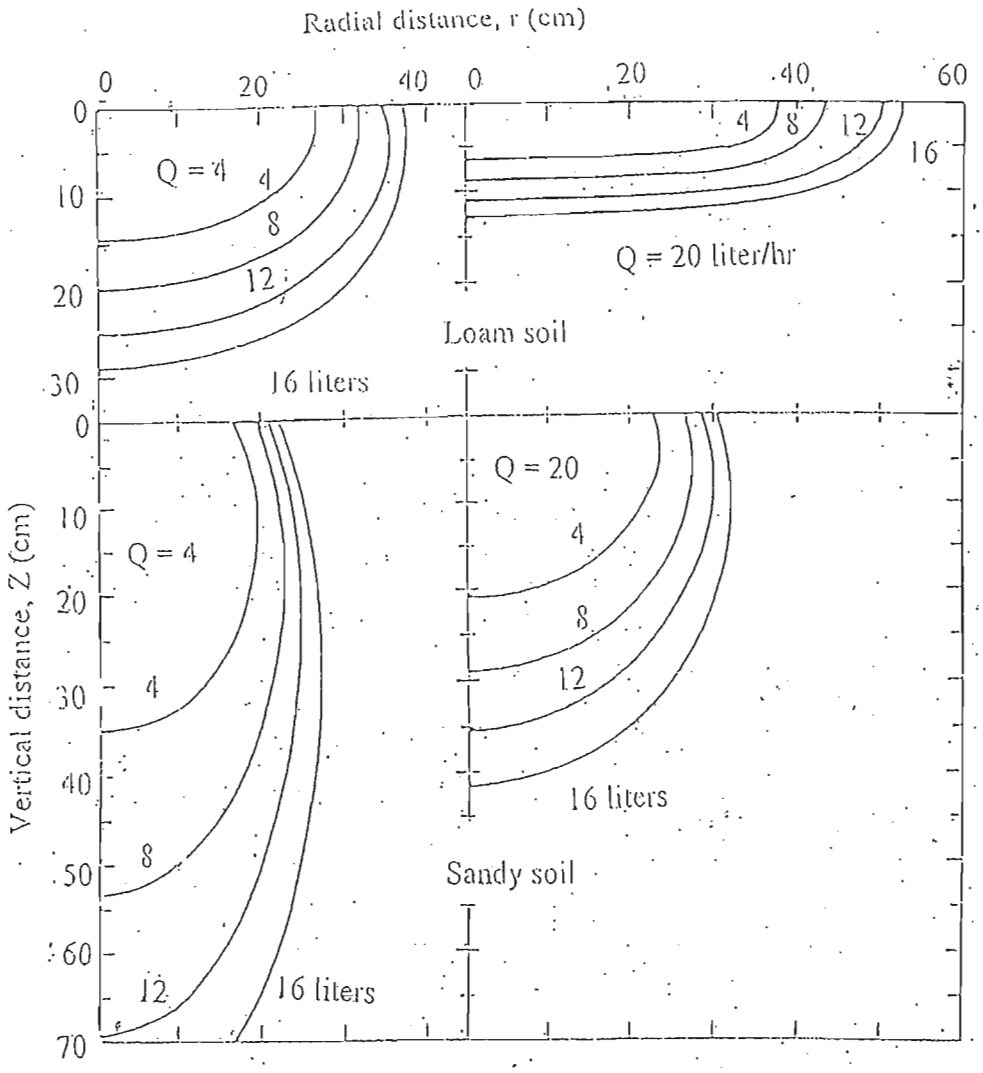


Figure 1.6. Effect of soil texture and emitter discharge rate (Q = emitter discharge rate in l hr^{-1}) on soil wetting pattern. The numbers on the curves refer to total quantities of water applied (Bresler, 1978).

1.5.2 Effect of duration of application and emitter discharge rate on soil wetting pattern.

Increasing the duration of water application or emitter discharge rate in clay soils results in an increase in both vertical and lateral water movements (Figure 1.7). In sandy soils however, an increase in the duration of water application and emitter discharge rate result in relatively more vertical water movement and very insignificant change in lateral water movement (Figure 1.8).

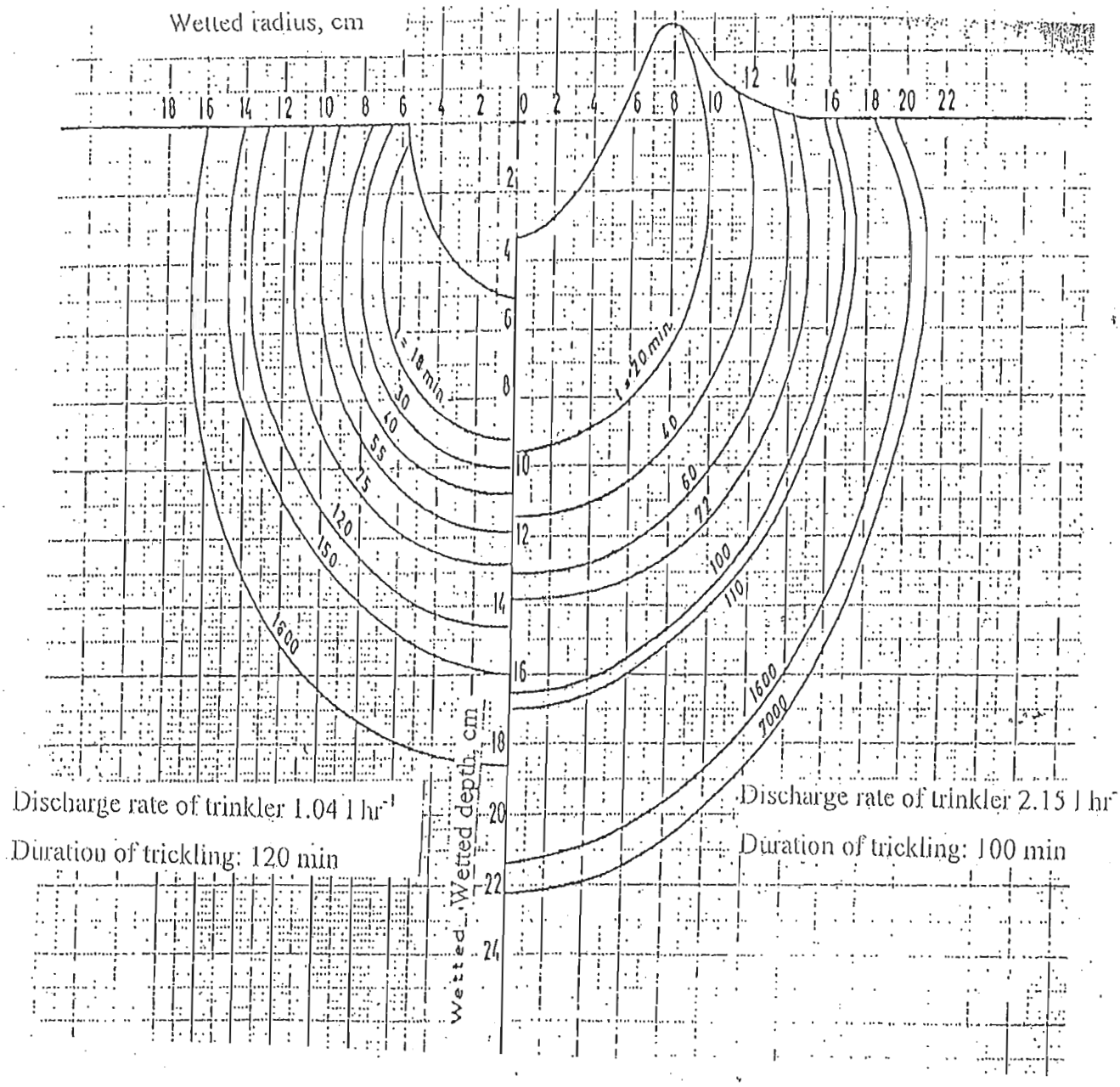


Figure 1.7. Effect of duration of application and emitter discharge rate on the wetting pattern in a clay soil (Baars, 1976).

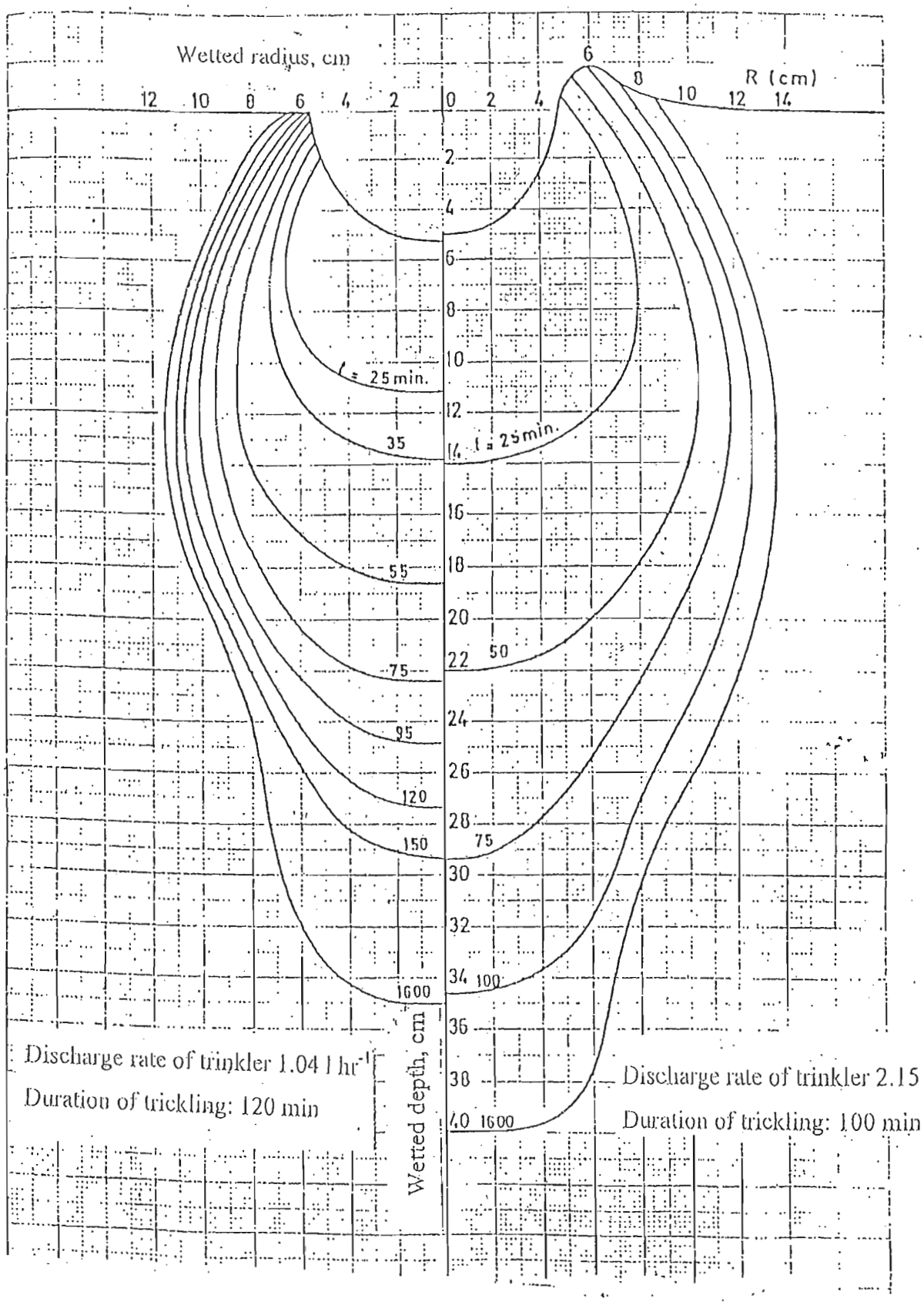


Figure 1.8. Effect of duration of application and emitter discharge rate on the wetting pattern in a sandy soil (Baars, 1976).

1.6 SUMMARY AND CONCLUSIONS

The principle of high frequency irrigation under drip irrigation is to supply water requirements of the crop by replenishing daily water losses from evapotranspiration, and thus maintaining the rootzone at a high water potential. Under such soil water conditions the soil water holding capacity becomes less important because water is supplied to the crop as it is needed.

In the drip system, water enters the soil at discrete points (emitters) along a dripper line and is then distributed through the soil volume in some pattern. The size and shape of the wetted pattern is largely controlled by the hydraulic properties of that soil. In sandy soils, water tends to move more vertically than horizontally, whereas in clay soils the horizontal component is relatively more pronounced.

The important factors in drip irrigation are the emitter spacing and discharge rate. In a drip irrigation system design, a combination of these factors is used to design the drip system to meet the soil water hydraulic properties. The choice of a drip system must be based on the soil hydraulic properties to achieve effective rootzone wetting.

This chapter has summarised some of the fundamental principles governing high frequency irrigation and control of soil water regimes. Sound knowledge of soil water movement and crop water requirement are as important as the irrigation system design. The methods used to determine the crop water requirement and the irrigation scheduling parameters have a significant effect on efficiency of a drip system. These methods have a direct bearing on the soil wetting patterns, as they dictate the frequency and duration of irrigation water application. It follows that good management, sound irrigation scheduling techniques and an efficient irrigation system are the key to increasing crop water use efficiency.

CHAPTER 2

EXPERIMENTAL METHODS

2.1 Introduction

The experiment was designed to study the effects of different water regimes on sugarcane growth and yields under subsurface drip irrigation. It was also hoped that the results would provide information that could be used to optimise the limited available water resource per unit area of land. The experiment was established on the 18th November 1998 in a field that was previously under overhead sprinkler irrigation. The duration of the experiment was three years, i.e., from plant cane to the second ratoon cane. The normal estate cultural practices under drip irrigation were followed and some water application levels were varied as required per treatment.

An observational sprinkler block was also established next to the drip experiment. The purpose of this block was to compare cane growth and crop water use efficiency in this block with the drip treatments.

2.2 Site Description

The experiment was located in a field (527/3) which had been under sprinkler irrigation for 13 years. The soils are mainly the Rondspring series (Murdoch, 1972; Nixon *et al.*, 1986). The properties of this soil correspond to the Glendale series of the South African Binomial System (MacVicar *et al.*, 1977). The texture of the A horizon ranges from a clay to clay loam and overlies a dark red to reddish brown structured clay loam to clay B horizon (Plate 2.1 and Table 2.1). The B-horizon comprises mainly gravel and weathering rock at depth. Despite having a shallow soil depth, these soils are among the most productive soils in the Swaziland sugar industry. Some physical and chemical properties of these soils are given (Table 2.1). These results were determined on representative samples taken from field 527/3 using the methods described by The Non-Affiliated Soil Analysis Work Committee (1990).

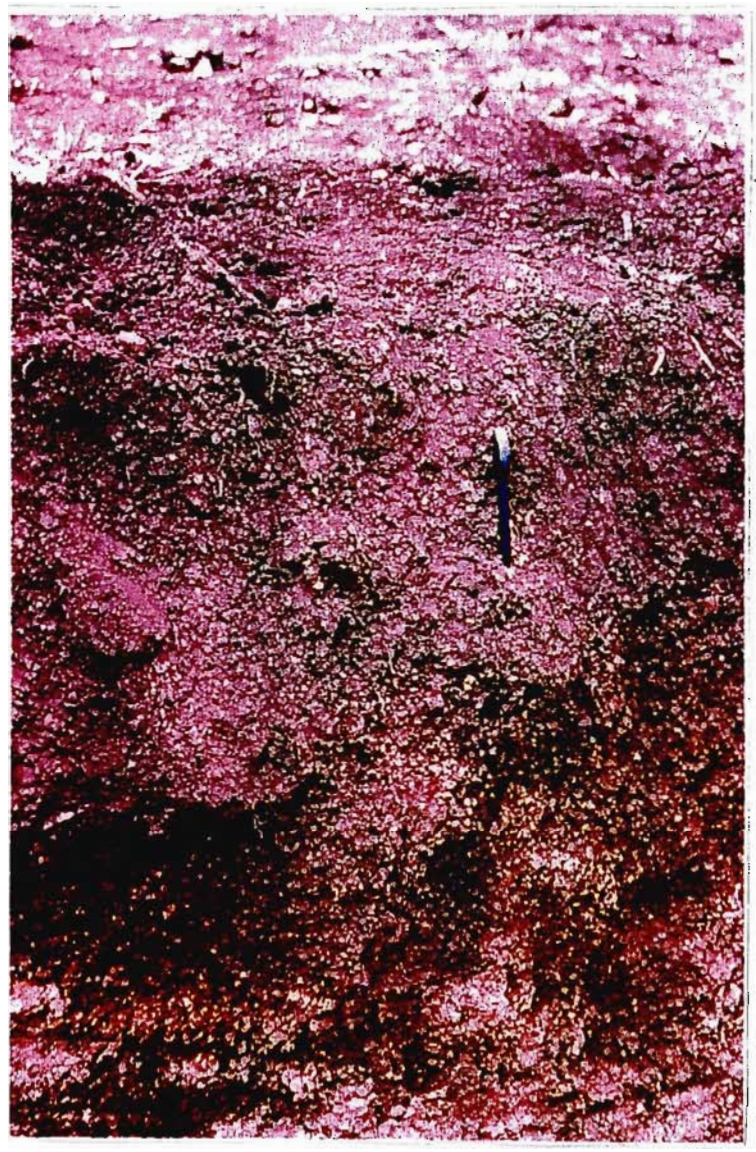


Plate 2.1: A Rondspring soil series profile, showing the characteristic horizons. (Scale: the pen indicated is 0.14 m long).

Table 2.1. Physical and chemical properties of the Rondspring soil at the experimental site.

Depth (m)	Bulk Density (Kg m^{-3})	Porosity (%)	RAM (mm m^{-1})	AWC (mm m^{-1})	TEXTURE (%)			pH (H_2O)	Cations (mmol$_c$ L^{-1})			Ec_e	SAR_e (mmol$_c$ $L^{-1})^{1/2}$
					Sand	Clay	Silt		Na	Mg	Ca	(mS m^{-1})	
0.15	1610	38	94	145	42	45	13	6.2	1.03	1.32	1.16	23	0.92
0.45	1500	42	80	136	36	53	11	6.6	0.55	0.64	0.70	12	0.67
0.75	1480	39	98	142	38	53	9	6.5	0.63	0.50	0.66	12	0.83

Key: RAM = Readily Available Moisture, AWC = Available Water Capacity,

SAR_e = Exchangeable Sodium Adsorption Ratio

2.3 Experimental Design

The design of the drip experiment was a randomised complete block design with four treatments and five replications (Appendix 2). Each plot had 10 rows spaced 1.5 m apart and 20 m in length. The net plot was the middle 6 rows of 16 m lengths (2 m discards from both ends of each row).

The irrigation water regime treatments were 0.5, 0.75, 1.0 and 1.2 crop reference evapotranspiration (ETc). The objectives of the irrigation water regimes were: for the 0.5 ETc water regime to apply only 50 % of the estimated crop water requirement so that the soil became progressively drier, the 0.75 ETc to apply only 75 % of the estimated crop water requirement. The 1.0 ETc to apply the normal daily estimated crop water requirement and the 1.2 ETc to apply 20 % more than the normal estimated crop water requirement in case the current water regimes were less than the optimal growing conditions.

The treatment plots were irrigated once the treatment deficit reached 10 mm to bring the soil water content back to field capacity. With the wet weather conditions experienced in the plant crop and first ratoon, it was clear that for treatment effects to be significant in the second ratoon, the soil water balance had to be maintained below field capacity. Hence, in the second ratoon the soil water levels were lowered to 50 % total available moisture (TAM) in all treatments. To achieve this the 1.0 ETc treatment was used to lower the soil water balance figures in each treatment until the 50 % TAM was reached and thereafter the treatments were applied. The treatment plots were then irrigated once the deficit reached 10 mm to bring the soil water balance to 50 % TAM level instead of field capacity (100% TAM). The amount applied was therefore constantly 10 mm in all treatments and only the frequency of irrigation between treatments varied. The irrigation intervals were expected to be longest in the driest treatment (0.5 ETc) and shortest in the wettest treatment (1.2 ETc). Replicates for each treatment were irrigated simultaneously.

In the sprinkler block 40 mm was applied in each irrigation and the 1.0 ETc factors were used to estimate daily crop water use. Irrigations were carried out in each treatment once the 40 mm was depleted to bring the soil back to field capacity.

Effective rainfall was the estimated rainfall that was stored and was available for crop use. The upper limit of the effective rainfall was determined by the soil water deficit at the time of irrigation. In drip irrigation effective irrigation was taken as the total irrigation water applied in each treatment. Water losses through deep percolation and soil surface evaporation were assumed to be negligible. Only the standard 1.0 ETc treatment was used in the sprinkler block. The objective of having this block was to have a commercial sprinkler block to compare with the drip system under similar growing conditions.

2.4 Land Preparation

Following harvesting of the sugarcane crop in 1998 the field was prepared for planting. Mechanical operations carried out were aimed at cane stool eradication, fine tilth formation and land leveling. Old sugarcane stools were eradicated by a shallow cultivation using a medium disc harrow (0.80 m disk diameter). The soil was then ripped to a depth of at least 0.40 m. Two discing operations followed in order to produce a good tilth. The first was carried out with a heavy disc harrow (0.90 m disk diameter) and the second with a light disc harrow (0.60 m disk diameter).

2.5 Planting

The experiment was planted with sugarcane variety NCo 376 in November, 1998. Furrows were drawn at a spacing of 1.5m and were 0.20 m deep, which is the standard practice in Swaziland. Prior to planting, Netafim Super Typhoon 125 (inside diameter: 17 mm) dripper lines (laterals) were placed in the planting furrow at a depth of 0.15 – 0.20 m using a tractor mounted dripper insertion rig (Plate 2.2). The emitter spacing was 0.6m, and the delivery rate was 1.75 Lh^{-1}, which gave an average application of 2 mmh^{-1}. During installation the tapes were laid with the emitters facing upwards. This ensured that particles that settle after irrigation did not block the emitters. A tractor was used to haul bundles of seedcane into the field. Two parallel rows of NCo 376 were placed end to end alongside and outside the furrows, where they were first cut into approximately 0.40 m setts before being placed onto the furrows. This was done to avoid cutting the dripper tapes that were already in the furrows.

Double stalk planting was used to ensure good plant populations at emergence. This planting procedure resulted in a planting density of about 8.0 t ha^{-1} of seedcane. The seedcane was mechanically covered to form a ridge, approximately 0.2 m high, on top of the seedcane (Plate 2.3).

Plate 2.2: A tractor mounted dripper insertion implement

Plate 2.3: Ridging implement used to cover planted cane

2.6 Irrigation system layout

The subsurface drip experiment and overhead sprinkler observation block were located adjacently on the same soil type in the field (Appendices 2 and 3). Irrigation water was pumped from a nearby storage dam. The dam helped to reduce the amount of sediment reaching the filtration system thereby minimising filtration requirements. For the sprinkler system water was pumped from the dam directly to the field.

Downstream of the pump station the drip system consisted of 3 main components; the filtration plant, main and submains, and infield network of laterals. The filtration station consisted mainly of a series of sand and disc filters that provided primary and secondary filtration, respectively. The pumped water in the supply mainline first passed through Conn 40 sand filters and then through synthetic disc filters. The filters used an automatic back-flushing system based on time and pressure differential.

The underground supply mainline from the filtration station delivered water to four underground submains in the drip experiment (Plate 2.4 and Appendix 2). This was designed to correspond to the number of treatments. Each of the individual submains had a separate valve with its own flow meter. All dripper lines from similar treatment plots were connected to one submain.

Plate 2.4: Underground submain layout in the drip block.

A sprinkler observation block (an 18 x 18m grid, sprinkler type: RB14070, nozzle size: 4.37 x 2.38 mm) was also established 130 m from the drip block (Appendix 2). The system delivered on average 4.78 mm hr^{-1}, which was less than the system's design specification of 5.19 mm/hr. The net application was adjusted accordingly. The block had one flow meter to measure the volume of water applied.

2.7 Source and quality of irrigation water

The Mhlume Sugar Company obtains water from the Komati River via the Mhlume Water Canal. An analysis of the water (Table 2.2) confirms the findings of Johnston (1976) and Ndlovu (1993), and indicates that the water has low salinity and sodicity hazard for irrigation purposes.

Table 2.2 Analysis of water from the Komati River (March, 1999)

Cations ($mmol_c\ L^{-1}$)			pH	ECe ($mS\ m^{-1}$)	SARe $(mmol_c\ L^{-1})^{1/2}$
Na	Mg	Ca			
0.4	0.4	2.2	8.02	10	0.35

2.8 Irrigation and daily crop water requirement

The good correlation found between Class A pan evaporation (Eo) and crop reference evapotranspiration (ETc) from the Penman Monteith equation (McGlinchey *et al.*, 1996) made it possible to develop factors for converting Eo to the Penman Monteith equivalent. Mhlume irrigation scheduling is based on equation (4). The ETc and crop factors (Kc) used are shown in Appendix 1.

2.9 Irrigation system maintenance

Drip systems maintenance standards and procedures used at Mhlume were followed during the growing season. The main operations involved the use of independent chlorine and trifluralin flush treatments. The chlorine treatment involved chemigation with swimming pool chlorine (HTH) with a 68 % concentration of calcium hypochlorite. The treatment was done to clean the system by destroying algae, bacteria and bacterial slimes. The intermittent application method was used and 15 ppm of the HTH in irrigation water was used.

A herbicide (Trifluralin 5) injected at a rate of 1.1 l ha^{-1}, into the drip irrigation system was used to prevent root intrusion into emitters. Both maintenance treatments were independently applied immediately after harvesting, at six months after planting or re-growth and at the beginning of dryoff. In addition, to these treatments the drip systems had to be flushed at the beginning of each irrigation by opening the flush valves on each plot. This was done to remove any dirt that may have settled within the system. The flushing process was done continually until the flush-water was clean.

2.10 Fertiliser Application

The nutrient requirements for the experiment were based on soil analysis and established local industry nutrient threshold levels. Fertiliser in the drip experiment was applied by fertigation, and broadcast by hand in the sprinkler block. The total nutrient application for both the sprinkler and drip block was similar. In the plant crop the total nutrient application was 120 kg N ha^{-1}, 55 kg P ha^{-1} and 200 kg K ha^{-1}. In the subsequent ratoons the application was 140 kg N ha^{-1}, 0 kg P ha^{-1} and 200 kg K ha^{-1}. For the drip system, urea ammonium nitrate (UAN), phosphoric acid and $KCl_{(11)}$ were used as sources of N, P and K, respectively.

Split N application was done only in the drip system, where half of the N requirement was applied within two months of planting or ratooning (equal amounts at intervals of about 2 weeks). The balance of N (60 kg ha^{-1}) was applied in equal amounts at monthly intervals up to the age of 4 months.

For the sprinkler block the fertiliser was hand applied in a granular form as a blend of $UREA_{(46)}$, $DAP_{(38)}$ and $KCL_{(50)}$, respectively. At planting, 60 kg N ha^{-1}, 55 kg P ha^{-1} and 200 kg K ha^{-1} was hand applied in the furrows as basal fertiliser. The balance of N (60 Kg N ha^{-1}) was applied in March (after 3 months) in the form of urea.

2.11 Weed Control

The operations carried out followed the herbicide policy used at Mhlume. The primary method for controlling weeds was herbicide spraying using knapsacks. For plant cane the treatment used as pre-emergence was 3L ha^{-1} Sencor 480 plus 3L ha^{-1} Gesapax within two weeks of planting. Post emergence treatment was 3L ha^{-1} MSMA plus 3L ha^{-1} Gesapax. In ratoon cane, early post-emergence treatment was used, and this was 2.8 L ha^{-1} Herricane DF plus 3L ha^{-1} Gesapax 500. Hand-hoeing was used where weeds had not been killed by the herbicides.

2.12 Ripener Application

In order to avoid ripener and treatment interactions no ripener was applied in this experiment.

2.13 Data Measurements

2.13.1 Soil wetting pattern under drip irrigation

Soil samples were taken in the winter months (May –July) where there was no interference from precipitation. As such only the second ratoon data is presented because it was the only season that had relatively dry weather conditions and therefore no interference from rainfall.

2.13.1.1 Gravimetric soil water content distribution

Gravimetric soil samples were taken using a 2.5 mm inner diameter auger at distance intervals of 0.15 m from a selected emitter starting from the emitter to the mid point (0.75 m) of the interrow. At each distance soil samples were taken at depth intervals of 0.15 m to a maximum depth of 0.90 m where possible. A total of 42 samples per treatment were

taken. The samples were taken 0800 hours before, and 24 hours after irrigation, in each treatment. The soil samples were placed in airtight tin containers until the whole batch per treatment was complete. Thereafter the samples were immediately taken to the laboratory to be analysed for soil water content by oven drying at 105^0C for 48 hours.

The gravimetric soil water content (%) data was plotted using a Survey Package (SURPAC) version 5.04 for Windows 98, to show the wetting pattern obtained in each treatment before and after irrigation. The package uses a least squares regression to fit isolines.

2.13.1.2 Matric potential distribution

For many soil studies, soil water content information is of primary interest. However, for studies involving water transport and storage in soils and soil–water–plant relationships, the energy status of the soil water is more important (Cassel and Klute, 1986). Tensiometers have been used in a number of studies to measure the energy status of soil water. As part of this study 36 tensiometers were setup and designed in the laboratory (Plate 2.5). The principles, preparation and testing of the tensiometers were as discussed by Cassel and Klute, (1986).

The distribution of soil water potentials across a cane row was monitored using an array of nine tensiometers per plot. The array consisted of three profiles of tensiometers spaced 0.375 m apart from the emitter position to the middle of the interrow (0.750 m). Each profile consisted of three tensiometers which were placed at depths of 0.15, 0.60 and 0.90 m. The tensiometers were read in the morning at about 0700 hrs, prior to, and 24 hrs after, each irrigation. The matric potential results were then plotted using the Survey Package (SURPAC) version 5.04 for Windows.

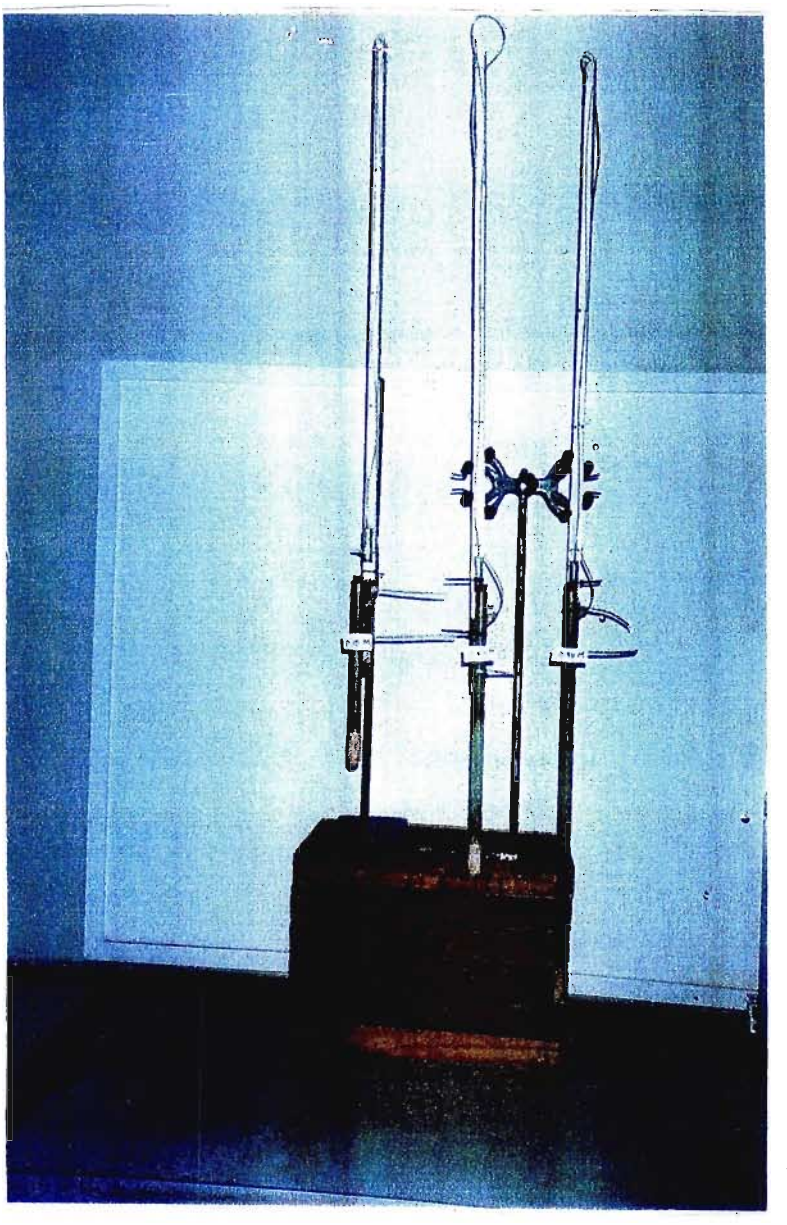


Plate 2.5: Mercury tensiometer used to measure soil water potential

2.13.2 Growth Measurements

2.13.2.1 Stalk height, canopy assessment and stalk population

Both stalk height and stalk population were measured monthly, usually on the same day but always within the same week of each month until harvest. Stalk height measurements were taken from ten marked stalks, randomly selected, on two selected cane rows per plot.

Stalks were sampled at 2 m intervals per cane row (5 stalks per row). A peg was driven into the ground at the base of each stalk with 0.20 m above ground level. Stalk height measurements were made from the top of this peg to eliminate measuring from an uneven soil surface. However, the first month of growth, when the cane was too young (< 0.20 m), measurements were taken from the ground. Stalk height was estimated by measuring the distance from the peg or ground level to the topmost visible dewlap of the uppermost fully extended leaf. The stalk populations were taken from a total of four randomly inserted sample plots on each treatment plot. The size of each sample plot was 2 metres by one row. Stalk counts from these sample plots were then used to estimate stalk population on each plot.

On the stalks selected for height measurements the number of green leaves were recorded monthly until harvest. Also, the length of a selected third leaf selected from the top, was measured weekly to determine the growth response relative to crop water stress. The measurements on leaf length were carried out from the third month until full leaf extension.

2.13.2.2 Root distribution.

Soil samples were taken using a root auger (auger volume: 557 cm^3) after harvesting at 0.000, 0.375 and 0.750 m distances away from a selected emitter, in one guard row per treatment plot. At each distance, root samples were taken at depths 0-0.10, 0.10-0.20, 0.20-0.30, 0.30-0.40, 0.40-0.50, 0.50-0.60, 0.60-0.70, 0.70-0.80 and 0.80–0.90 m, where soil depth permitted. The mass of the roots in each sample was determined in the laboratory by first washing the soil through a sieve (size of mesh: 2 mm), oven drying the extracted roots at 55 °C and weighing them.

The root mass density figures were then plotted using the Survey Package (SURPAC) version 5.04 for Windows to generate root density isolines below the emitters.

2.13.2.3 Leaf nutrient content

Leaf samples were taken four months after planting in plant cane and four months after harvesting in ratoon crops. The objective of leaf sampling was to compare crop nutrient uptake between the drip and the sprinkler block. Hence, treatment plots were sampled as one unit in the drip block. Sampling was carried out across two diagonals in each block. The third leaf down the stalk was sampled, the first leaf being the one that was at least one-half unrolled. A total of about 40 leaves were sampled per block and these were bundled together and taken to the laboratory for macro nutrient content (N, P, K, Ca and Mg) determination. The leaf sampling was done at a crop age of three months in each growing season.

2.13.3 Harvesting

The plant crop was harvested in October 1999 at the age of 11 months. The first and second ratoons were harvested in October 2000 and September 2001 at the ages of 12 and 11 months, respectively. The plant and second ratoon crops were harvested at a younger age because of profuse flowering observed in the field.

Prior to harvest the cane was dried off for 35 days. This was done to ensure that the soil was dry for infield trafficking and also to enhance sucrose content. In each growing season the crop was burnt a day before harvest. The experimental net plots were cut separately by hand and weighed in the field using a tractor–mounted boom scale (Martin – Decker). The weighed cane per plot was used to calculate cane yield per plot (t ha^{-1}). Cane from the whole experiment was then cut and removed by standard commercial methods to the mill.

2.13.4 Sugarcane Yield and Quality

For cane quality, 16 stalks were taken at random in each plot and sent for laboratory analysis. Analyses involved shredding the sugarcane samples, determination of water content by loss in mass following oven-drying, and sucrose content by polarimetry (SASTA, 1985). From these measurements the sucrose content was calculated. Sucrose yield was then computed from the sucrose percentages and sugarcane yields for each plot.

CHAPTER 3

RESULTS AND DISCUSSION

Results from the plant crop to the second ratoon crop are presented and include water application, soil water measurements, crop growth and yield.

3.1 Water application

The effect of irrigation scheduling in the three growing seasons is shown in Figures 3.1 – 3.3 for irrigations scheduled at 0.5, 0.75, 1.0 and 1.2 of estimated Penman – Monteith (PM) evapo-transpiration under drip irrigation, and at 1.0 ETc for sprinkler irrigation. The results show that soil water depletion patterns were similar in the plant crop (Figure 3.1) and the first ratoon (Figure 3.2). In both seasons the soil water content was maintained close to field capacity in all treatments within the first five months after crop establishment. This was a result of the heavy rains that were received during this period. In the plant crop (1999) and first ratoon (2000) more than normal rainfall was received within the first five months of establishment (Appendix 3). A total of 544 mm (82 % of mean annual rainfall) in 1999 and 966 mm (85 % of mean annual rainfall) in the year 2000 was received during these months in the plant and first ratoon crops respectively. The wet conditions during these periods affected response to irrigation. Thereafter, there was progressive drying of the soil until harvesting of the 0.5 ETc and 0.75 ETc treatments. The 1.0 ETc and 1.2 ETc treatments were maintained close to field capacity in both seasons.

With progressive drying of the soil in the 0.5 ETc and 0.75 ETc treatments there was an increase in rainfall efficiency compared to the wetter treatments (Appendix 3). The high rainfall efficiency in these treatments is explained by the soil being relatively dry, so that the rainfall that occurred in these treatments resulted in an increased net water intake by the soil. As expected, there was a general increase in the frequency of water application and net irrigation water application (Appendix 4) from the driest treatment (0.5ETc) to the wettest treatment (1.2ETc). The intervals between irrigations was of longer duration in the sprinkler than in the drip treatments, because of the higher net water application of 30 mm as opposed to 10 mm in the drip plots.

In the second ratoon, the 0.5 ETc and the 0.75 ETc treatments had the whole profile dry (negative soil water balance) at 3 and 6 months after harvesting, respectively (Figure 3.3). The low soil water levels achieved in these treatments suggest that the crop was severely water stressed and the water stress symptoms were confirmed by field observations. The 1.0 ETc treatment was continuously maintained at the 50 % TAM level and the 1.2 ETc marginally above this level. The net irrigation water application (Appendix 4) increased from the driest to the wettest treatment. The rainfall efficiency was higher in the second ratoon than in previous crops in all treatments because the soil water content in year 2000/2001 was kept below field capacity and thus the net effective rainfall was higher than in the other seasons.

The total net water use (i.e., sum of the net irrigation applied and net rainfall) results are shown in Appendix 5. In the plant crop and first ratoon only the 1.2 ETc treatment had the total net water use figure marginally above the total crop water requirement of 939.80 mm and 1075. 99 mm respectively. The low net water use in the plant crop and first ratoon is attributed to low effective rainfall, because of the higher than normal rains that were received within the first five months of growth. In most cases after heavy rains, water had to be physically drained out of the plots using spades. In the second ratoon all treatments had total net water applications below the annual crop water requirement of 995.23 mm, and the water applications were lower than in the other seasons. The low water application in this ratoon is mainly attributed to deliberate delays in irrigation when adjusting the soil water balance from field capacity to the 50 % TAM and also due to the low total rainfall received during the season.

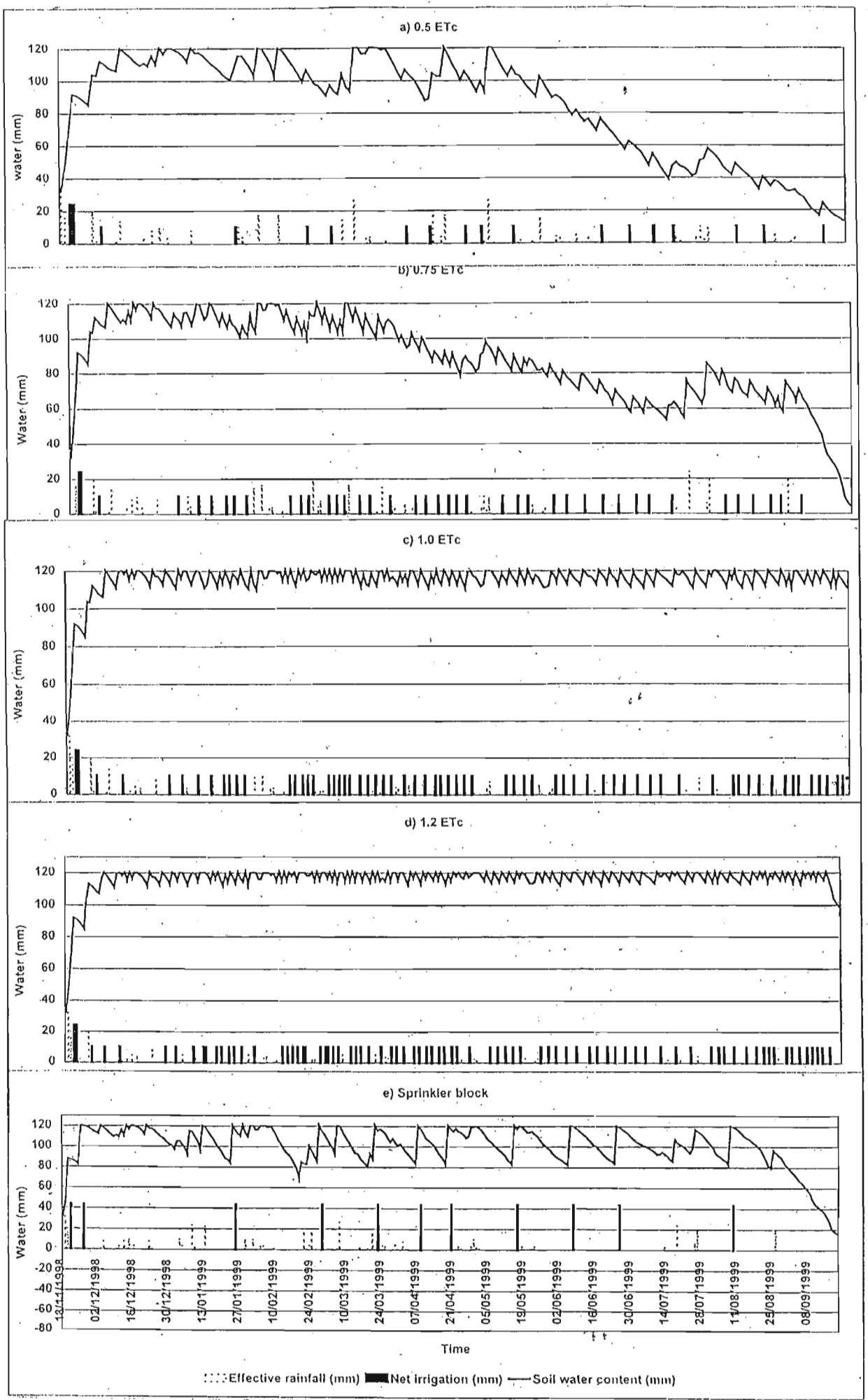


Figure 3.1: Effect of irrigation scheduling on the soil water balance in the plant crop, (a to d represent irrigation scheduled at 0.5, 0.75, 1.0 and 1.2 ETc under drip irrigation, and e is sprinkler irrigated at a schedule based on 1.0 ETc).

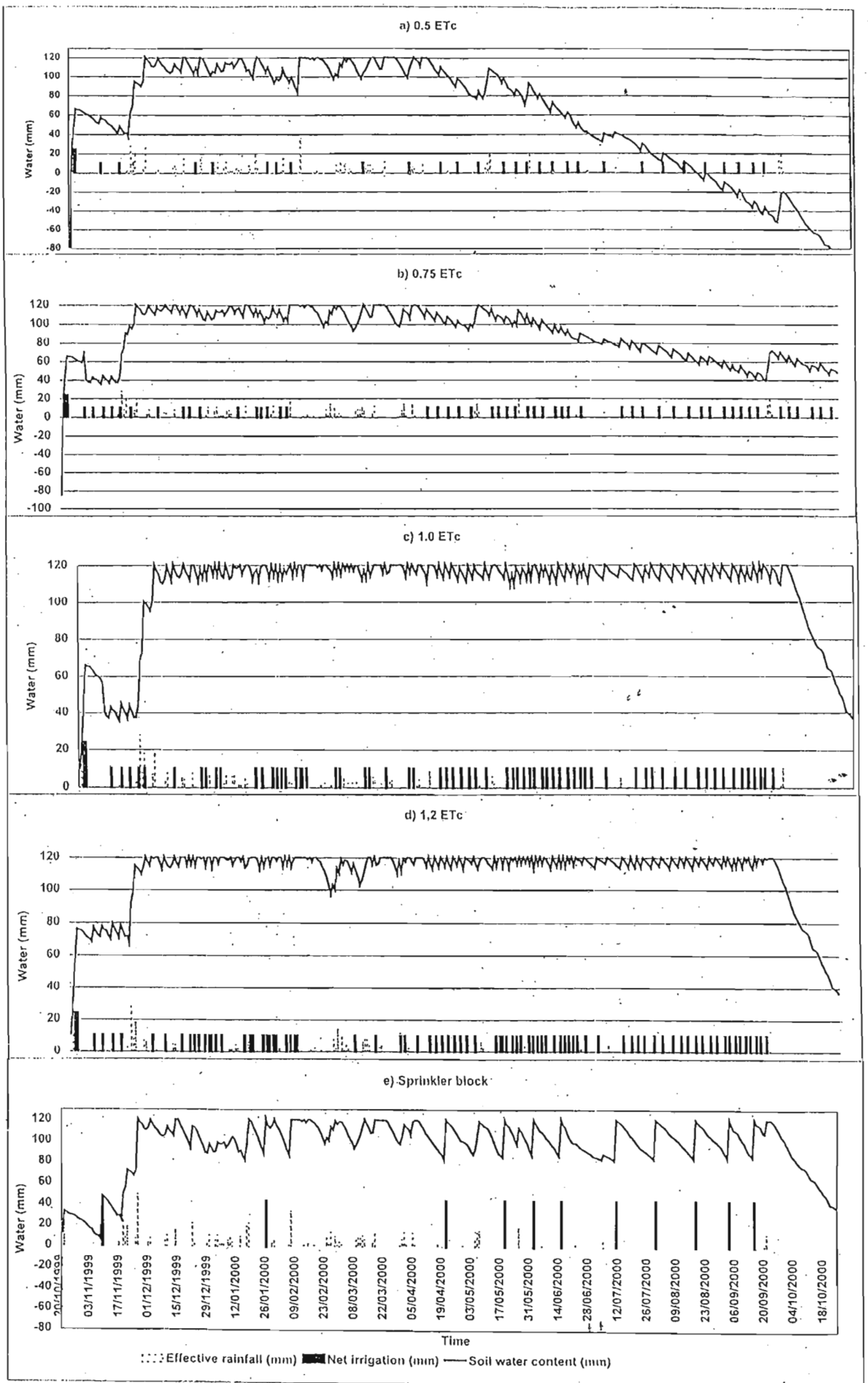


Figure 3.2: Effect of irrigation scheduling on the soil water balance in the first ratoon crop, (a to d represent irrigation scheduled at 0.5, 0.75, 1.0 and 1.2 ETc under drip irrigation, and e is sprinkler irrigated at a schedule based on 1.0 ETc).

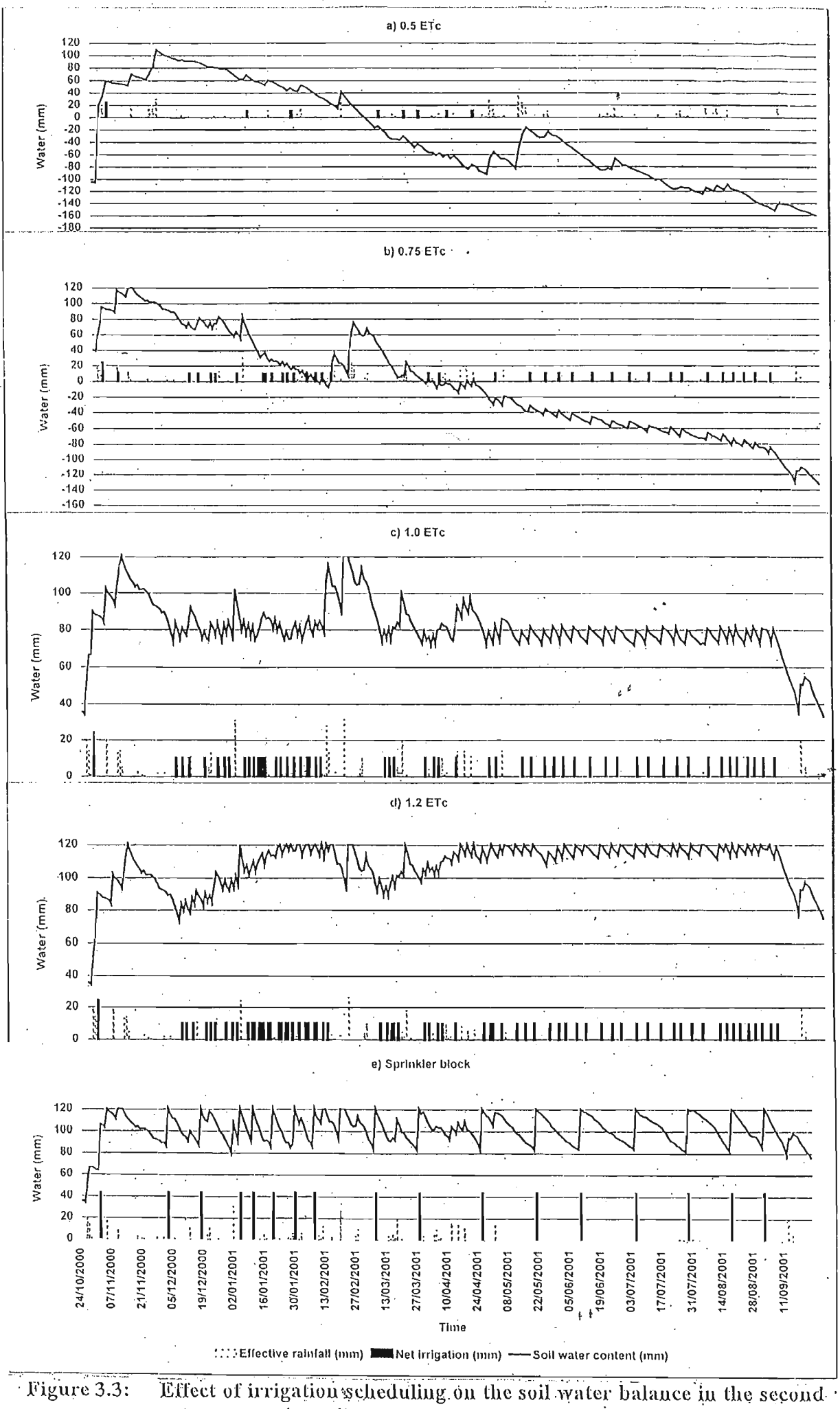


Figure 3.3: Effect of irrigation scheduling on the soil water balance in the second ratoon crop, (a to d represent irrigation scheduled at 0.5, 0.75, 1.0 and 1.2 ETc under drip irrigation, and e is sprinkler irrigated at a schedule based on 1.0 ETc).

3.2 Effect on soil water and rooting distribution

Two methods were used to characterise the soil wetting patterns below the emitters in all four drip treatments. The wetted pattern was characterised using soil gravimetric samples and by mercury tensiometers to measure soil matric potential. The soil water content and soil water potential distributions were plotted after each irrigation in all treatments using Survey Package (SURPAC) version 5.04 for Windows, 1998. The cross section of the soil water content and potential patterns were plotted from the emitter to the center of the interrow (0.75 m) on both sides, and to a soil depth of 0.90m (Figures 3.4 and 3.5). To eliminate the effects of rainfall when interpreting the data, only the results in the winter months in the second ratoon, where the surrounding soil water conditions were dry, are discussed.

3.2.1 Soil water distribution

3.2.1.1 Gravimetric method

The average soil water content decreased with an increase in the distance away from the emitter (Figure 3.4). The soil water content distribution increased from the driest treatment (0.5 ETc) to the wettest treatment (1.2 ETc). In the 0.5 ETc treatment the only significant change in soil water content that occurred after irrigation was below the emitter to a soil depth of 0.30 m (Figure 3.4). Due to the presence of gravel and weathering rock, the maximum auger depth was 0.30 m in this treatment plot. There was basically no change in soil water content in the interrow.

In the 0.75 ETc treatment (Figure 3.4 b.), the soil water content increased after irrigation only below the emitter. From the 0.15 m to the center of the interrow the results on average show a decrease in soil water content after irrigation which suggests that the wetting front did not reach 0.15 m away from the emitters. The pre - irrigation soil water content was on average higher than that in the 0.5 ETc treatment, which suggests that the 0.75 ETc was a wetter treatment.

In the 1.0 ETc (Figure 3.4 c) and 1.2 ETc (Figure 3.4 d) treatments, there was better lateral water movement compared to the 0.5 and 0.75 ETc treatments. This can be seen by the increase in soil water content between 0.20 – 0.30 m into the interrow after irrigation.

In the 1.2 ETc treatment there was on average more lateral and vertical water movement. Vertical water movement reached more than 0.80 m deep. Interestingly soil wetting in the top 0.20 m was poor towards the center of the interrow in all treatments.

The increase in both lateral and vertical water movement with increase in irrigation water regimes confirms the theory that hydraulic conductivity increases with increase in soil water content (Hillel, 1980).

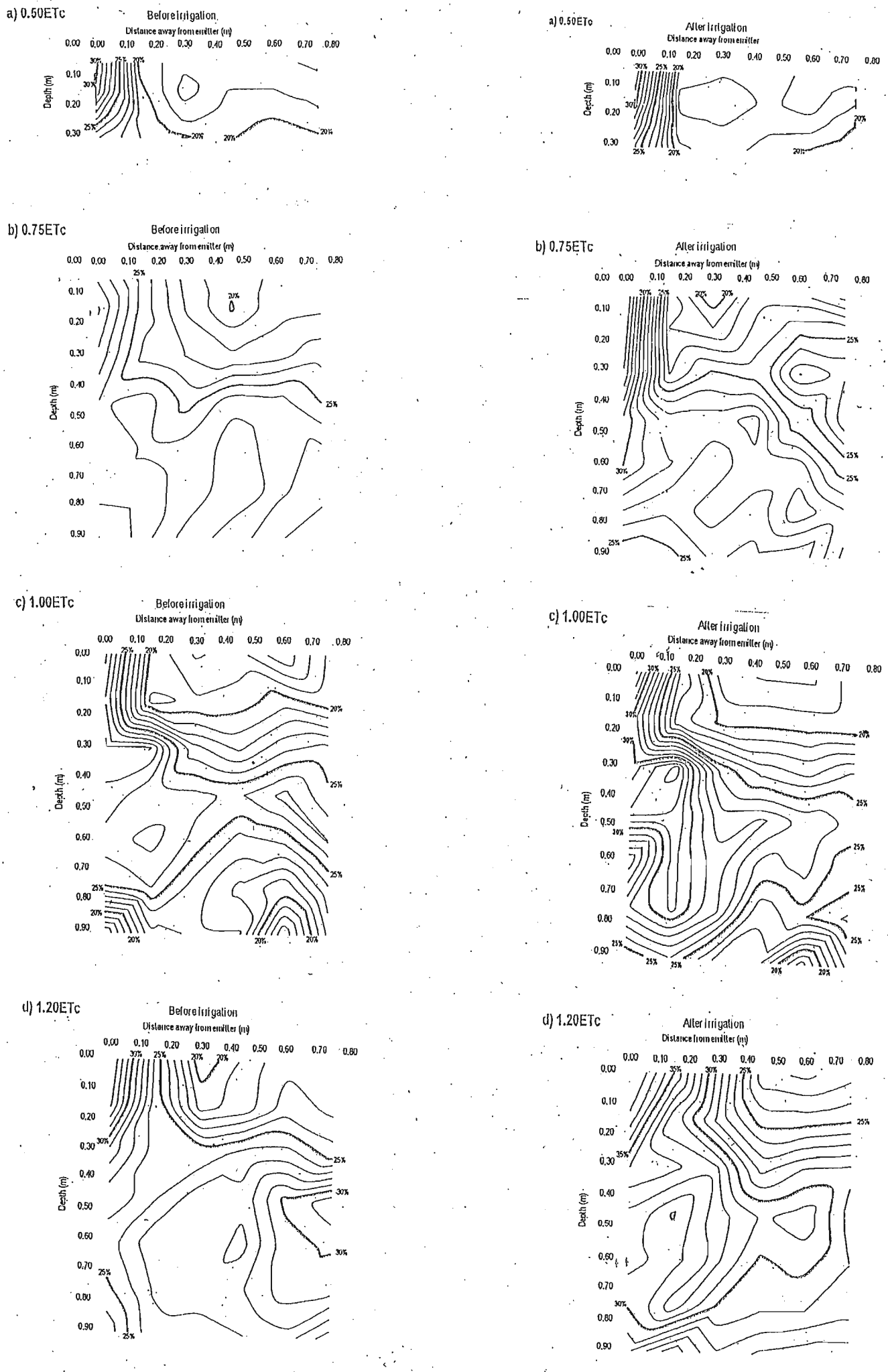


Figure 3.4 Two – dimensional schematic illustrations of the effect of the irrigation regimes on **gravimetric soil water content** (%) isolines below and adjacent to the emitter for 10 mm irrigations in the second autumn crop

3.2.1.2 Tensiometer method

Generally, the results resembled the gravimetric soil water content patterns where there was better soil water distribution after irrigation in the wetter treatments (Figure 3.5). However, the change in soil water potential after irrigation in the dry treatments (0.5 and 0.75 ETc) was not as definite as in the gravimetric soil water results, probably because the soil was too dry for the tensiometers to be fully operational. In practice, the maximum limit of most tensiometers is at a matric potential of 80 kPa (Hillel, 1980). The matric potential results for the driest treatment (0.5 ETc) indicate that the soil was at its driest (-50 to -90 kPa), and there was little change in matric potential after irrigation in the interrow (Figure 3.5a). In this treatment, the highest soil water potential was reached directly below the emitter and it ranged between –20 to –30 kPa. The 0.75 ETc treatment was wetter compared to the 0.5 ETc treatment. The difference in matric potential can be attributed to the higher frequency of water applied compared to the 0.5 ETc treatment.

In both the 1.0 ETc and 1.2 ETc treatments the matric potential results show that soil water was held at higher water potentials compared to the drier treatments both before and after irrigation compared to the 0.5 and 0.75 ETc treatments. Even in the wet treatments, the results show that on average the soil water potential was highest below the emitter and diminished with distance away from the emitter both prior to and after irrigation. As expected, the wettest treatment (1.2 ETc) had the highest water potentials below and away from the emitter. As with the gravimetric soil water data, the matric potential patterns confirm that soil water increased from the driest treatment (0.5 ETc) to the wettest treatment (1.2 ETc). This applies to both vertical and lateral distribution patterns.

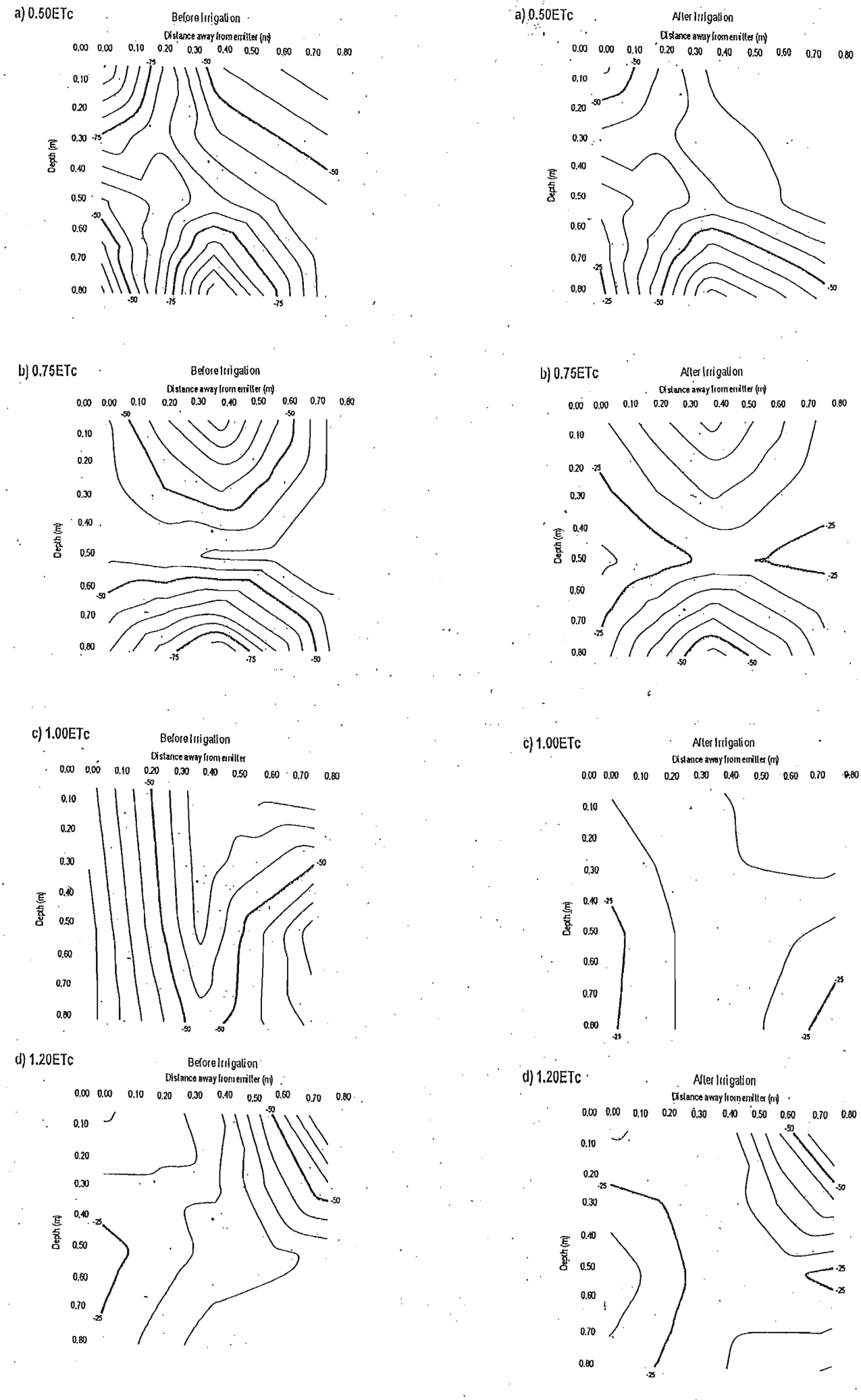


Figure 3.5 Two – dimensional schematic illustrations of the effect of the irrigation regimes on **soil water potential** (-kPa) isolines below and adjacent to the emitter for 10 mm irrigations in the **second ratoon crop**, scheduled for

3.2.2 Effect on root distribution patterns.

Root distribution patterns were determined immediately after harvesting, below and adjacent to emitters in the first and second ratoon crops. This data was used to generate root density isolines (Figures 3.6 and 3.7, Appendix 6.5). Bulk density in the experimental block (Table 2.1) decreased with depth. This suggests soil physical properties were not limiting. Attempts were made to auger to a depth of 0.9 m, however in the first ratoon few samples were obtained below a depth of 0.5 m due to the presence of gravel and rocks, and data below 0.5 m (Figure 3.6) was therefore excluded. In the second ratoon root samples were obtained to a depth of 0.8 m (Figure 3.7).

There was an increase in root mass towards the drip line (Figure 3.4). The higher root density distributions (Table 3.1a) in areas close to the drip line were due to the high soil water content in these areas, since soil strength declines and root elongation increases as soil water content increases (Michelakis *et al.*, 1993). In the first ratoon, the root density (Figure 3.6, Appendix 6.5) and relative root distribution (Table 3.1 a) on the cane row was lower in the wettest treatment (1.2 ETc) compared to the other treatments. The lower density of roots below the emitters (Figure 3.6 and Table 2) in the wettest treatment (1.2 ETc) suggests that the soil was constantly waterlogged and thus the roots grew in the adjacent areas where the soil conditions were conducive for root growth. The rooting patterns between the 1.0 ETc and the drier treatments were similar (Figure 3.6, Appendix 6.5). The similarity in rooting distribution between these treatments suggests that the soil water conditions were not sufficiently different between these treatments to influence rooting behaviour.

In the second ratoon there was an increase in root density (Figure 3.7, Table 3.1b), and also improved root density distribution (Table 3.1b) compared to the first ratoon crop in all treatments. The increase in rooting density could be attributed to normal increase root biomass with crop age. The highest root density was obtained in the 1.2 ETc treatment. With the dry weather conditions experienced in the second ratoon the root growth behaviour in the 1.2 ETc treatments suggests that there was better wetting of the soil profile with depth compared to the other drier treatments. Baran *et al.* (1974) and Kingston (1978) showed that short irrigation intervals, which prevent surface soil from drying, encourage a higher percentage of roots to develop near the soil surface.

Extended irrigation intervals resulted in more extensive rooting at depth. The roots in the other treatments were predominantly found above 0.3 m depth (Figure 3.7, Appendix 6.5), and there was a sharp decline in rooting density with depth. The decline in the rooting density with depth in the drier treatments indicates that soil was relatively dry in these treatments with increase in soil depth.

The rooting distribution increased with increase in the area wetted by the emitters and was influenced by the soil volume wetted by rainfall events. In a dry season, the rooting distribution was confined to the area wetted by emitters, and in wet seasons, the rooting distribution was evenly distributed and the emitter position had very little influence on rooting distribution. However, the rooting density was reduced in the 1.2 ETc treatment in the wet season because of waterlogging conditions below the emitters. The rooting behaviour has implication on nutrient placement and crop uptake. Maintaining the soil water content at field capacity, increases chances of the soil below the emitters becoming waterlogged and thus reducing root growth in that area. The results therefore suggest that irrigating to maintain the soil water content at field capacity may limit nutrient uptake below the emitters. However irrigating to keep the soil water levels below field capacity, may improve rooting below the emitters and thus nutrient uptake.

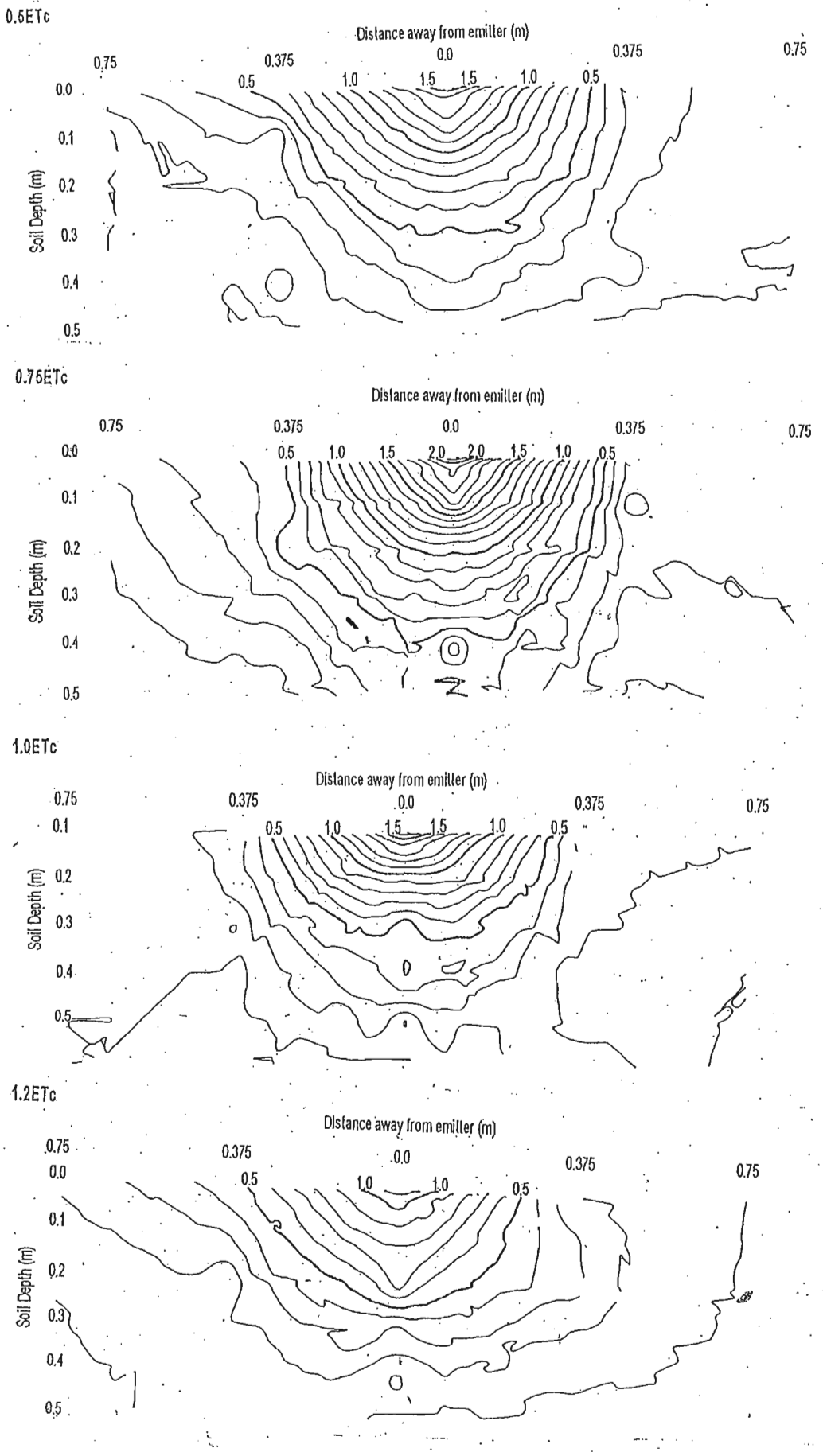


Figure 3.6 Two – dimensional schematic illustrations of the effect of the irrigation regimes on **root density distribution** (mg cm^{-3}) isolines below and adjacent to the emitter for 10 mm irrigations in the **first ratoon crop**

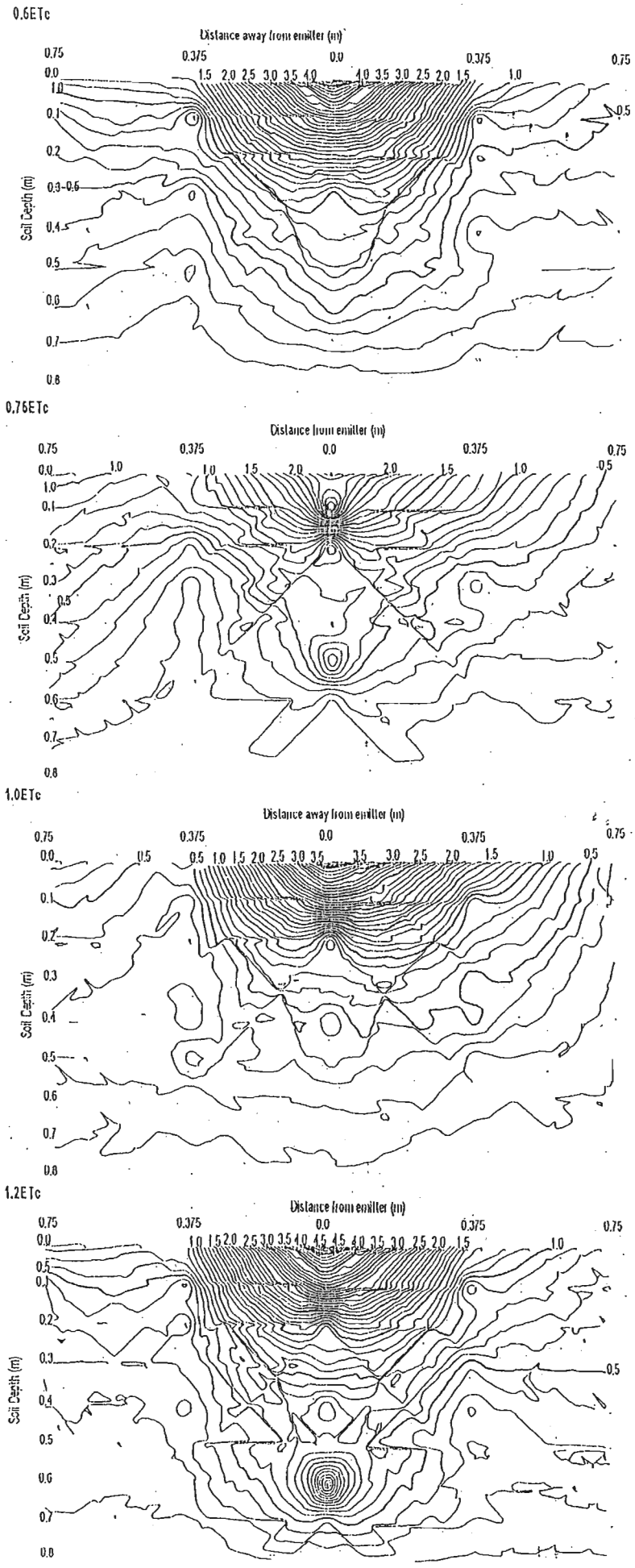


Figure 3.7. Two -- dimensional schematic illustrations of the effect of the irrigation regimes on **root density distribution** (mg cm^{-3}) isolines below and adjacent to the emitter for 10 mm irrigations in the **second ratoon crop**, scheduled for 0.5, 0.75, 1.0 and 1.2 of estimated ETc.

Table 3.1: Relative root distribution (% by root mass) below an emitter.

a) First ratoon

		Distance from the center of the cane row (m)					
Treatment:	Depth	0.75m	0.375m	0m	0.375m	0.75m	Total
0.50 ETc	0.0	2.72	6.25	18.45	2.82	1.40	31.63
	0.1	0.36	2.58	13.72	3.31	1.61	21.58
	0.2	2.92	2.70	8.58	2.41	1.16	17.78
	0.3	1.30	1.54	5.42	1.71	1.74	11.71
	0.4	0.79	0.53	4.72	3.08	1.51	10.62
	0.5	1.64	0.90	2.63	0.61	0.91	6.68
	Total	9.74	14.50	53.52	13.93	8.31	100.00
0.75 ETc		0.75m	0.375m	0m	0.375m	0.75m	Total
	0.0	2.31	4.21	20.88	2.09	2.77	32.27
	0.1	1.20	3.68	16.16	1.16	1.44	23.65
	0.2	1.14	5.05	9.33	2.41	1.39	19.31
	0.3	0.69	2.71	6.90	1.29	0.44	12.02
	0.4	0.48	1.14	1.89	1.69	0.18	5.37
	0.5	0.03	0.42	4.96	0.47	1.48	7.38
	Total	5.85	17.22	60.12	9.11	7.71	100.00
		0.75m	0.375m	0m	0.375m	0.75m	Total
1.0 ETc	0.0	2.53	2.96	25.51	3.84	3.01	37.85
	0.1	2.25	3.61	13.07	3.12	1.32	23.36
	0.2	1.48	1.29	6.02	2.98	1.42	13.18
	0.3	1.53	1.00	7.27	1.90	0.35	12.04
	0.4	0.86	1.04	1.15	1.69	0.38	5.13
	0.5	1.45	0.94	1.29	4.24	0.52	8.43
	Total	10.09	10.83	54.31	17.78	6.98	100.00
		0.75m	0.375m	0m	0.375m	0.75m	Total
1.2 ETc	0.0	3.21	6.64	17.96	2.74	1.42	31.96
	0.1	2.10	4.36	12.52	4.70	2.75	26.42
	0.2	1.97	1.62	11.04	4.89	1.51	21.04
	0.3	1.10	2.72	3.73	2.59	0.09	10.23
	0.4	0.30	1.56	0.99	1.74	0.47	5.06
	0.5	0.42	2.58	1.18	0.58	0.52	5.29
	Total	9.10	19.48	47.43	17.24	6.76	100.00

Table 3.1 (continued).

b) Second Ratoon

		Distance from center of cane row (m)					
Treatment:	Depth (m)	0.75	0.375	0	0.375	0.75	Total
0.5 ETc	0	4.89	5.12	18.43	4.45	2.18	35.07
	0.1	2.69	2.15	11.73	1.72	0.82	19.12
	0.2	2.36	2.67	7.33	1.46	1.27	15.09
	0.3	1.80	1.10	3.81	1.51	1.23	9.46
	0.4	1.79	0.85	3.77	0.69	0.33	7.43
	0.5	2.25	0.28	3.11	1.39	0.07	7.10
	0.6	0.99	0.26	2.24	0.91	0.45	4.85
	0.7	0.30	0.00	0.91	0.27	0.20	1.68
	0.8	0.00	0.00	0.12	0.00	0.09	0.20
	Total	17.08	12.44	51.45	12.40	6.64	100.00
		0.75	0.375	0	0.375	0.75	Total
0.75 ETc	0	6.4	4.2	13.7	6.9	2.4	33.58
	0.1	4.9	1.9	14.3	5.9	1.7	28.70
	0.2	2.6	1.4	2.4	3.3	1.0	10.69
	0.3	3.2	0.2	3.7	1.4	1.9	10.43
	0.4	1.3	0.0	2.7	2.3	0.7	7.02
	0.5	1.0	0.1	5.4	0.8	0.0	7.29
	0.6	0.2	0.0	0.4	0.3	0.0	1.00
	0.7	0.3	0.1	0.4	0.4	0.0	1.24
	0.8	0.1	0.0	0.0	0.0	0.0	0.05
	Total	20.1	8.0	42.9	21.3	7.7	100.00
		0.75	0.375	0	0.375	0.75	Total
1.0 ETc	0	4.6	1.7	21.6	8.9	1.5	38.2
	0.1	2.5	1.2	12.7	4.3	2.4	23.0
	0.2	1.1	1.0	3.4	3.8	0.9	10.2
	0.3	1.8	1.1	3.5	2.1	1.0	9.6
	0.4	0.7	0.6	1.6	2.8	0.5	6.2
	0.5	0.4	2.4	2.4	0.6	0.0	5.8
	0.6	1.2	0.6	1.2	1.0	0.0	4.0
	0.7	0.8	0.7	0.7	0.1	0.0	2.2
	0.8	0.3	0.0	0.4	0.0	0.0	0.8
	Total	13.5	9.3	47.4	23.6	6.3	100.0
		0.75	0.375	0	0.375	0.75	Total
1.2 ETc	0	3.8	2.8	18.5	5.2	2.9	33.2
	0.1	1.0	1.0	11.9	2.8	1.4	18.1
	0.2	1.3	0.7	5.3	3.4	1.3	12.1
	0.3	1.8	1.2	4.6	1.5	2.5	11.6
	0.4	1.1	0.7	2.0	0.7	0.9	5.4
	0.5	1.0	0.9	2.8	0.7	0.4	5.8
	0.6	0.8	0.6	6.8	0.9	0.5	9.5
	0.7	0.4	0.2	1.5	0.6	0.3	3.0
	0.8	0.2	0.0	0.6	0.2	0.3	1.4
	Total	11.5	8.0	54.0	16.0	10.5	100.0

3.3 Leaf Nutrients

The leaf nutrient analysis results indicate that in the plant cane and first ratoon crops the leaf nutrient levels in the sprinkler block were lower than nutrient levels in the drip block. In the second ratoon the nutrient levels were similar between the sprinkler and drip block (Table 3.2). However according to the Swaziland sugarcane industry nutrient thresholds, all the nutrients were above the threshold levels in all three growing seasons.

Table 3.2 Leaf nutrient analysis (% dry matter) results from the three growing seasons

		Nutrient	Drip Block			Sprinkler Block		
Month	Macro nutrients	Threshold % Levels	Plant cane	First Ratoon	Second Ratoon	Plant cane	First Ratoon	Second Ratoon
March (4 months)	N	1.7	2.84	2.24	2.38	2.48	1.95	2.37
	P	0.19	0.33	0.27	0.30	0.23	0.25	0.29
	K	0.8	1.24	1.27	1.21	1.18	1.05	1.25

3.4 Effect on cane growth

3.4.1 Stalk height

Generally, the results indicate that there was normal increase in stalk height with age in all treatments in the 3 growing seasons (Figure 3.8, Appendix 6.1). However, there were no statistical differences (p=0.05) at any stage of growth between the drip treatments in the plant crop and first ratoon (Appendices 6.1a and 6.1b.). The lack of response among the treatments could be attributed to the high rainfall that was received during the first five months of crop establishment. The frequent rains tended to level the treatment effects during this critical crop growth stage.

The average stalk height for the drip treatments in the plant cane and first ratoon crop was higher than in the sprinkler observational block throughout the growing season (Figure 3.8).

The irrigation water application results show that the sprinkler block comparatively received adequate water. The early season rainfall in the plant cane and first ratoon crops could have leached out nitrogen from the rootzone, as reflected by the lower N levels (Table 3.2), which might explain the lower stalk heights in the sprinkler block. The drip treatments were moderated by the split application of the N fertiliser source.

In the second ratoon, cane growth in the 1.2 ETc treatment was significantly better than in any other treatment from 4 months of age (Figure 3.8, Appendix 6.1 c). The stalk height for the sprinkler block was comparable to that of cane grown under the drip treatments. The improvement in cane growth in the sprinkler block confirms that there was adequate soil nutrients (Table 3.2) without the leaching potential caused by excessive rainfall. Due to the comparatively drier season in the second ratoon, there was very little, if any, leaching out of nutrients out of the soil profile.

3.4.2 Plant population

The results show that in the plant cane and first ratoon crops there were no significant differences in plant cane population among the drip treatments (Figure 3.9, Appendix 6.2). The lack of treatment response could be attributed to the excessive early rainfall that was received in the two seasons. The sprinkler block had the lowest plant population compared to the drip treatments. The lower plant population in the sprinkler block could, as much as stalk heights, also be attributed to plant nutrient deficiencies caused by the leaching of soil nutrients during the heavy rains that occurred in the early months in the two seasons.

In the second ratoon (Figure 3.9c) the results show that there were generally no significant differences in plant population among the drip treatments, except only in the second and the fifth months (Figure 3.9c, Appendix 6.2c.). The sprinkler block had the lowest population in the first three months and thereafter it was comparable to the drip treatments. The lower plant density in the sprinkler block in the first four months of growth could be attributed to the lower initial plant population from the previous crops. Thereafter the plant population was comparable to that in the drip block.

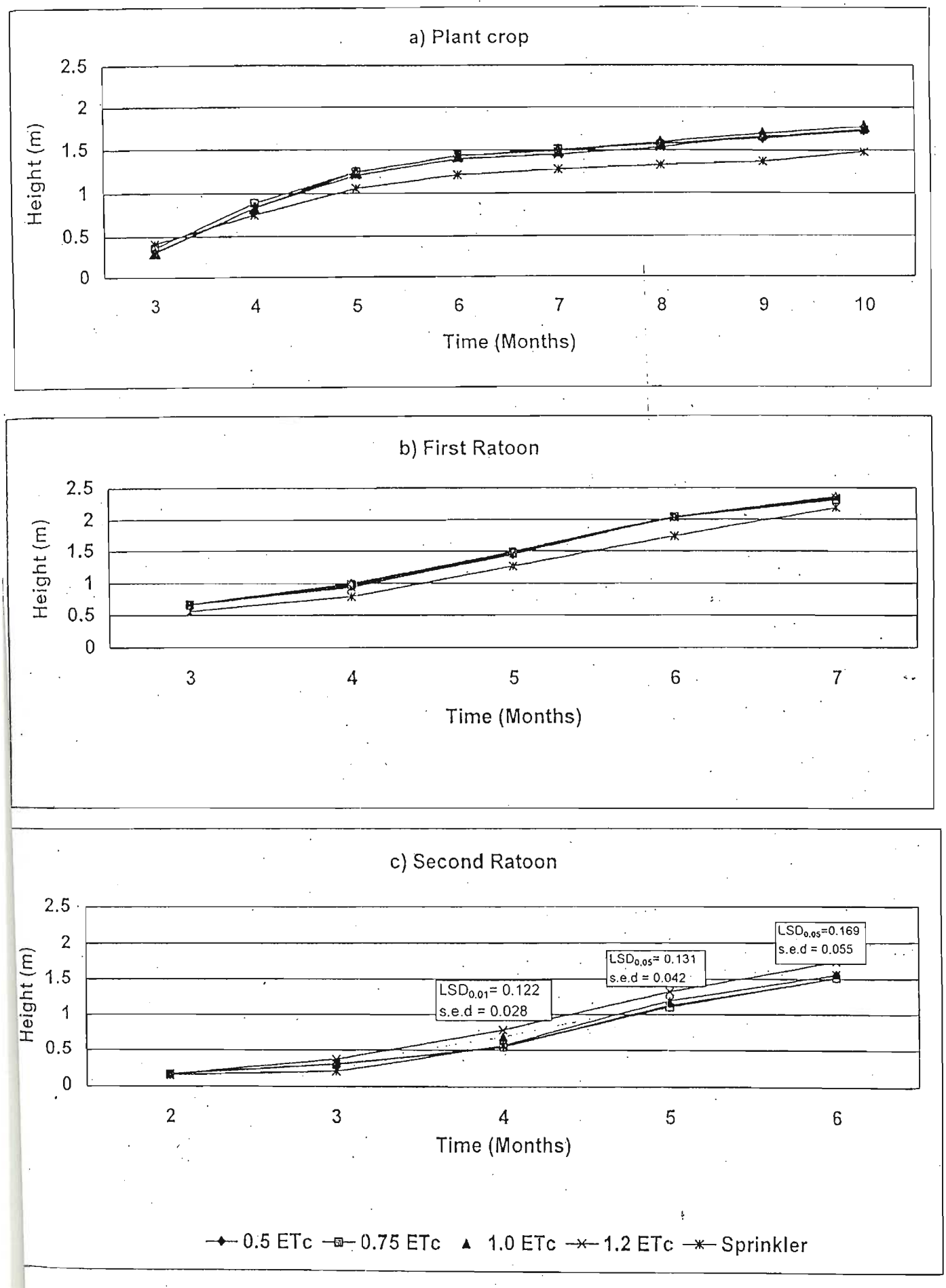


Figure 3.8 Effect of irrigation regimes on stalk elongation.

Note: LSD levels are indicated only where there was a statistical difference. LSD levels excludes the sprinkler treatment.

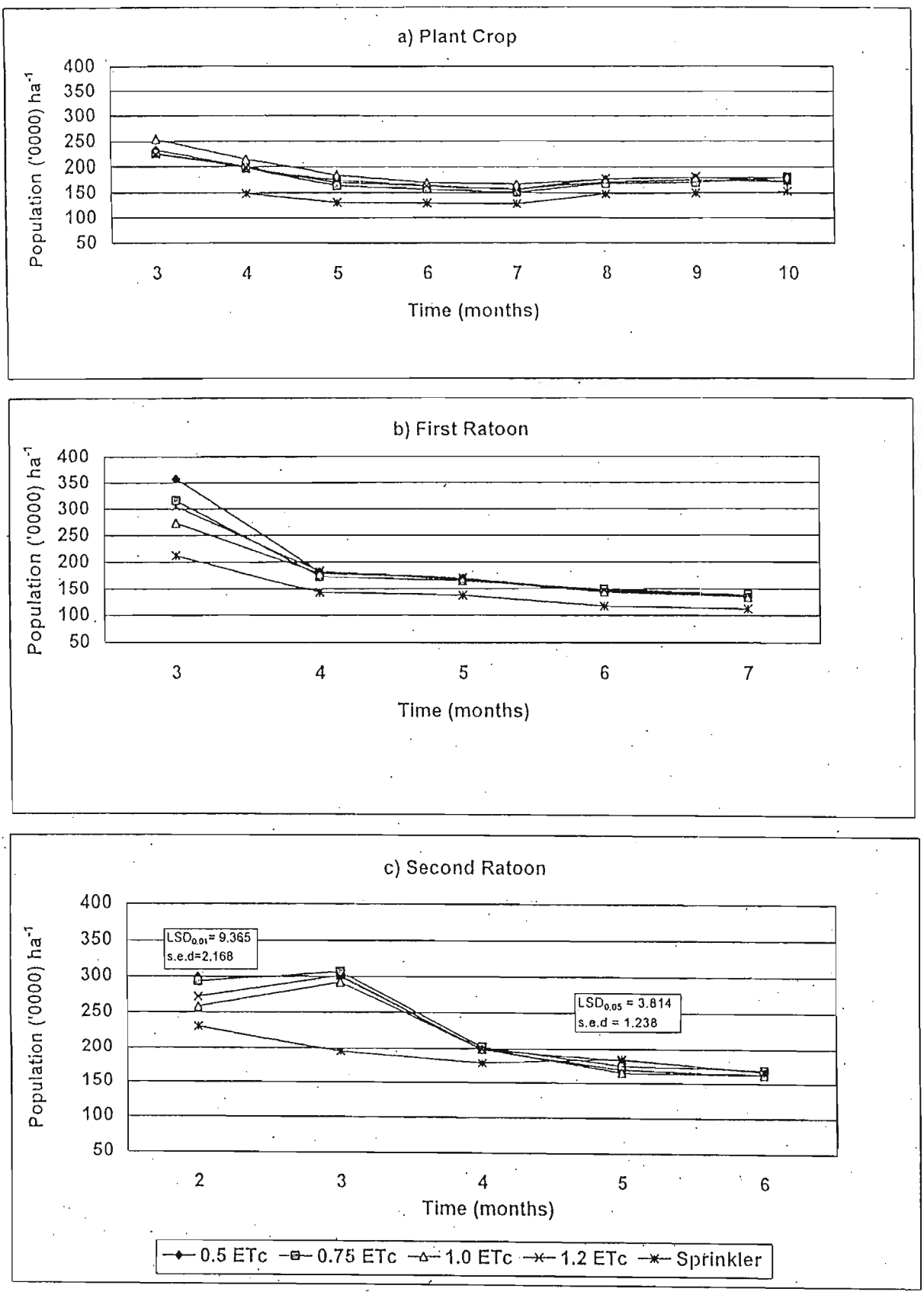


Figure 3.9 Effect of irrigation regimes on plant density

Note: LSD levels are indicated only where there was a statistical difference. LSD levels excludes the sprinkler treatment.

3.4.3 Plant canopy assessment

In the plant cane, there were no statistical differences (p=0.05) in the average number of green leaves per stalk among the drip treatments, except at the 8th and 9th months of age (Figure 3.10a and Appendix 6.2). The 0.5 ETc treatment had the lowest number of green leaves per stalk after the 8th month. The number of green leaves per stalk on the sugarcane growing in the sprinkler was comparable to the drip block. In the first ratoon, there were no statistical differences in the number of green leaves per stalk among the drip treatments (Figure 3.10b and Appendix 6.2). Again the 0.5 ETc treatment had the lowest number of green leaves among the drip treatments. The number of green leaves per stalk in the sprinkler block was the lowest in the first four months and thereafter improved to be above the drip block.

The lack of consistent positive response among the drip treatments in the plant and first ratoon crops could be attributed to the wet weather conditions that were experienced in the two growing seasons, which leveled out the soil water differences among the treatments. It is also possible that the rains might have leached out the N nutrients even in the drip treatments, however it was moderated through fertigation.

In the second ratoon crop, sugarcane growing in the sprinkler block had the lowest number of green leaves in the first 3 months of crop establishment (Figure 3.10c). By the 3rd month the number of green leaves was higher than those in the drip block, and dropped to below the drip irrigated cane in the 6th month. Although there were statistical differences in the number of green leaves per stalk among the drip treatments in the 5th and 7th months (Figure 3.10c, Appendix 6.2 c), there was no consistency to attribute the differences to drip treatment effects.

On leaf length in the plant crop and first ratoon, there were no consistent statistical differences in leaf lengths among the drip treatments (Figure 3.11a, Appendix 6.4). Sugarcane in the sprinkler block had the shortest leaves, of which the lengths were comparable to those in the drip block. The lack of consistent positive response among the drip treatments in the two seasons again could be attributed to the wet weather conditions experienced in the two seasons.

In the second ratoon crop (Figure 3.11c), except in the 6th month, sugarcane in the sprinkler block had the shortest leaves throughout the growing season. There were statistical differences ($p=0.01$) in leaf length among the drip treatments in the 5th month. With the relatively dry season in the second ratoon, the general increase in canopy size in the sprinkler block, indicates that the amount of water and nutrients were comparable to the drip block.

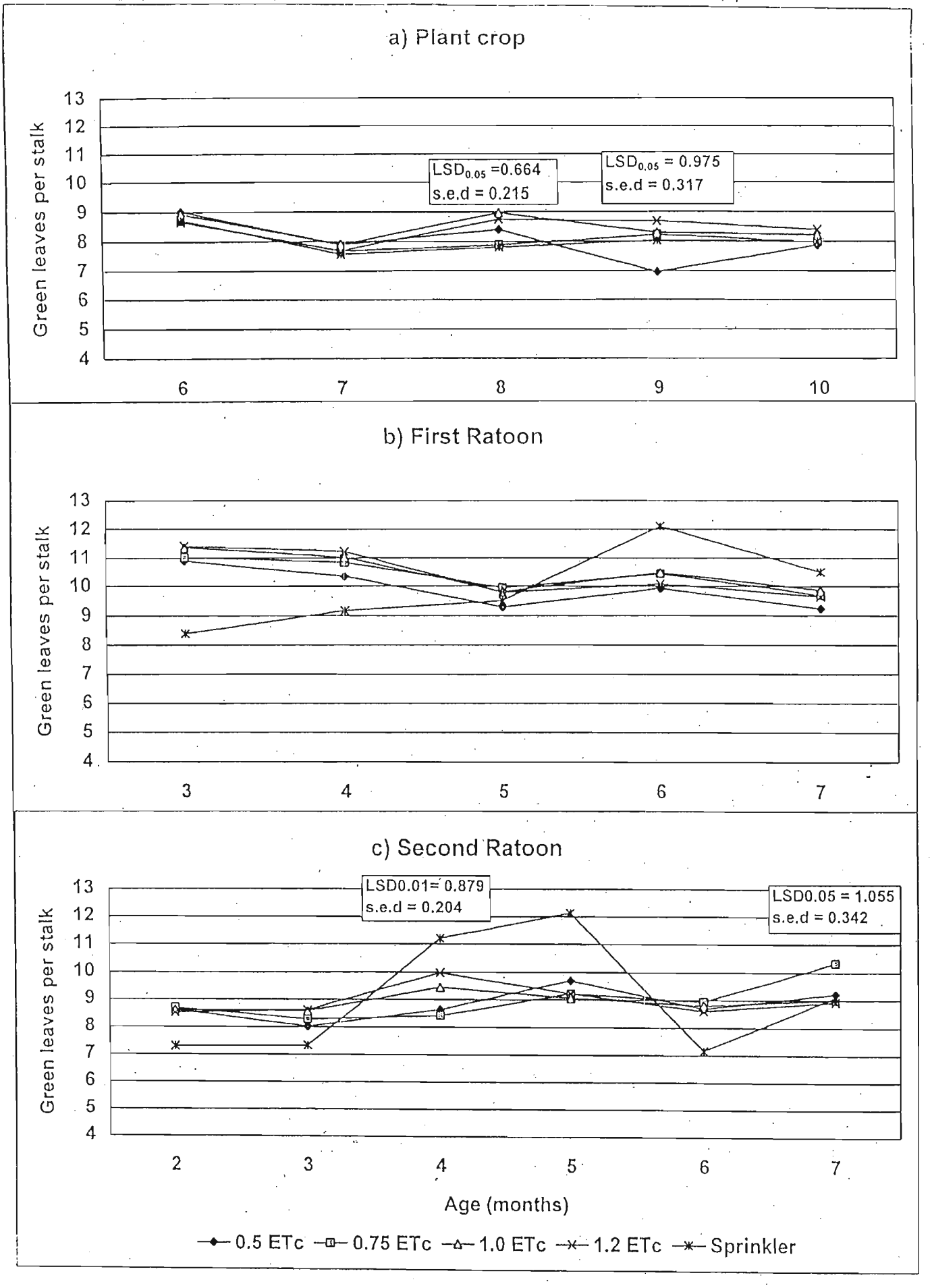


Figure 3.10 Effect of water regimes on the number of green leaves per stalk in the plant, first and second ratoon crops.

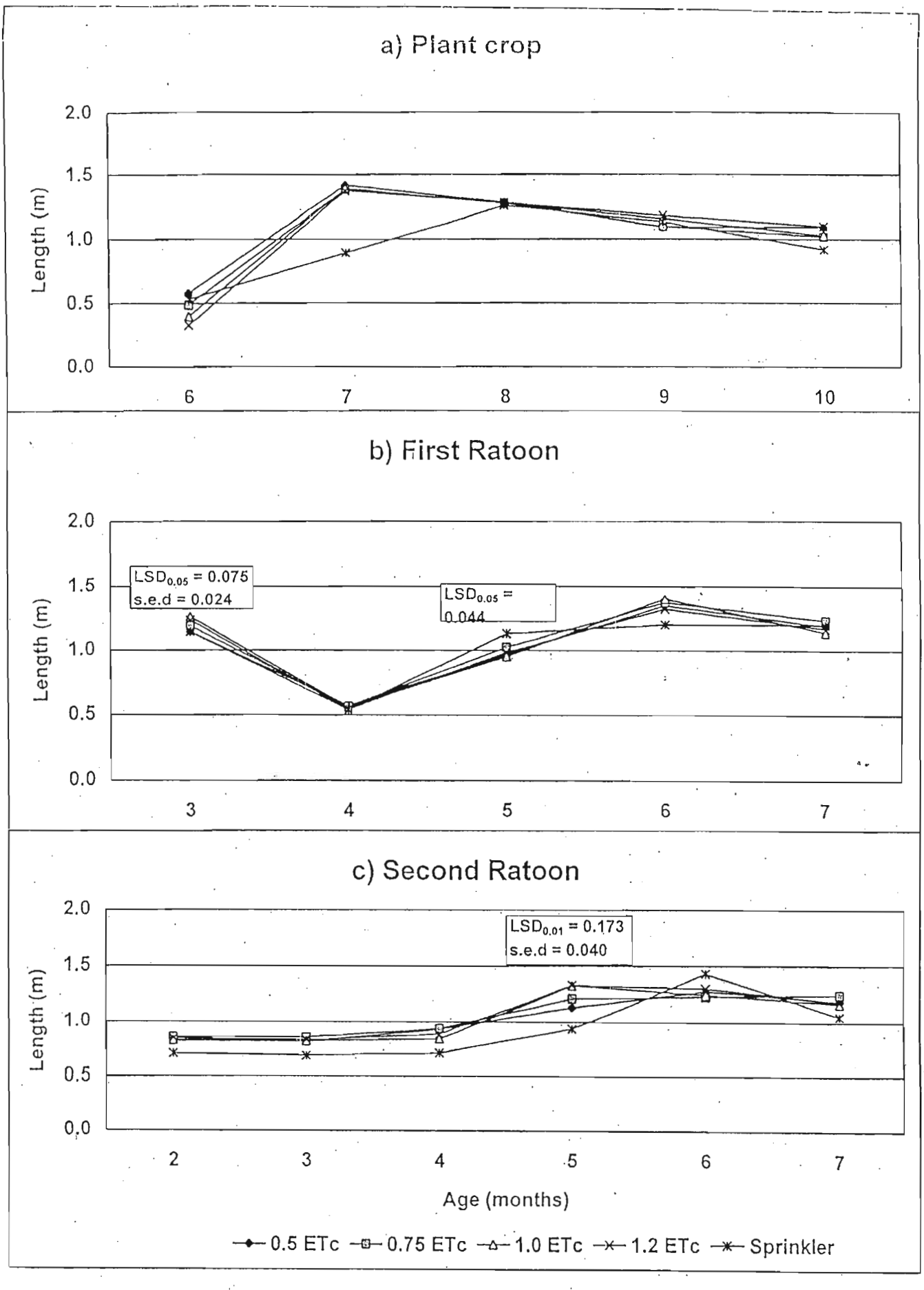


Figure 3.11 Effect of water regimes on leaf length in the plant, first and second ratoon crops.

Note: LSD levels are indicated only where there was a statistical difference, and excludes the sprinkler block.

3.5 Cane quality and yields

In general, there was an increase in cane yield (t ha^{-1}) from the driest treatment (0.5 ETc) to the wettest treatment (1.2 ETc) in the three growing seasons. However, there were statistical differences (P = 0.01) in cane yield among the drip treatments only in the plant and second ratoon crops (Table 3.3, Appendix 7.1). Since crop water stress, particularly for a vegetative crop such as sugarcane, affects crop growth and therefore yield, it follows that yields would be expected to increase from the driest treatment (0.5 ETc) to the wettest treatment (1.2 ETc) (Thompson, 1976), however this was not the case. The lack of a clear and consistent increase in cane yield with increase in water application in the first ratoon, could be attributed to the wet soil conditions caused by the heavy rains that were received in the first five months of crop establishment. The wet conditions resulted in fairly similar soil water and growth conditions especially on the drier treatments. The high yields in the wettest treatment (1.2 ETc) suggests that the soil water content was maintained at a higher level even between and after the periods of heavy rainfall.

The drip treatments had higher sugarcane yields than the sprinkler block in the plant and first ratoon crops (Table 3.3). In the second ratoon cane yield under sprinkler was comparable to the other drip treatments except the 1.2 ETc treatment, which had the highest yield. The gross water application results in the plant crop and first ratoon indicate that the sprinkler block received adequate water. The poor yield response could be attributed to soil nutrient deficiencies caused by the heavy rains that could have leached out the soil nutrients out of the rootzone. Although the nutrient levels were above the respective nutrient thresholds the fact that the leaf nutrient levels were below those in the drip block suggests that there were soil nutrient losses. The split N application in the drip block could have minimised the chances of leaching of nutrients during the heavy rains received within the first five months of crop establishment.

In the second ratoon the cane yields (t ha^{-1}) in the sprinkler block were comparable to the drip block. The leaf nutrient levels were similar to the drip block. Since the weather conditions were relatively drier in this season compared to the previous seasons and the leaf nutrient levels were higher confirms that leaching of soil nutrients was most likely explanation of the poor yields in the plant and first ratoon of the sprinkler block. These results suggest a need to review the N application management.

In both the plant crop and first ratoon, cane quality (% sucrose) was lowest in the wettest treatment (1.2 ETc), Table 3.3). However, there were no statistically significant differences among the drip treatments. In the second ratoon the sucrose content was lowest in the 1.2 ETc. However, there were no statistical differences among the drip treatments (Table 3.3, Appendix 7.2). The results suggest that there was more vegetative growth in the 1.2 ETc treatment and as a result the sucrose content was reduced.

Sucrose yield is the product of cane yield and sucrose content and there were no differences in the latter component between drip treatments. Sucrose yield results mirrored those of the sugarcane yield in the plant crop and first ratoon (Table 3.3). In the second ratoon, there were statistical differences (P = 0.01) in sucrose yield (t ha^{-1}) among the drip treatments.

In the first and second ratoon there was profuse flowering of cane at five months of age (March). The flower survey results showed that the flowering ranged from 64 to 74 % and 48 to 62 % in the first and second ratoon respectively. However, there were no differences statistically (p= 0.05) between treatments in either seasons (Appendix 7.4). The flowering in the sprinkler block was comparable to the drip block.

3.6 Effect on crop water use efficiency (CWUE)

There were statistical differences (P = 0.01) in CWUE among the drip treatments in all three growing seasons (Table 3.4, Appendix 7.5). Except, in the second ratoon there was a general decrease in CWUE from the driest treatment (0.5 ETc) to the wettest treatment (1.2 ETc). The 0.5 ETc treatment had an overall CWUE of 14.25 t ha^{-1} $(100mm)^{-1}$, and the 1.2 ETc had 11.75 t ha^{-1} $(100mm)^{-1}$. Statistical analysis results (Table 3.4, Appendix 7.5), indicate that in all the three growing season there were statistical differences (P = 0.01) in CWUE among the drip treatments. Since CWUE was defined as the ratio of cane yield (t ha-1) over the sum of the effective rainfall and total irrigation water applied. The high CWUE in the 1.2 ETc treatment could be attributed mainly to significantly higher cane yield (t ha^{-1}) obtained in the second ratoon rather than to the water component.

In all the three seasons the sprinkler block had the lowest crop water use efficiency (overall net average of 8.20 t ha^{-1} $(100mm)^{-1}$ compared to an overall net average of 12.43 t ha^{-1} $(100mm)^{-1}$ from the drip block (Table 3.4, Appendix 7.5). The low CWUE in the sprinkler block could be attributed more to the low cane yields (t ha^{-1}) rather than high total net water use. The overall CWUE from the sprinkler block was lower than the normal commercial cane yield target of 9 t ha^{-1} $(100mm)^{-1}$ water that was observed for sugarcane by Thompson and de Robbilard, (1968).

Within the drip treatments the results indicate a general decrease in CWUE from the driest treatment (0.5 ETc) to the wettest treatment (1.2 ETc). The 0.5 ETc treatment had an overall CWUE of 14.25 t ha^{-1} $(100\ mm)^{-1}$ and the 1.2 ETc had 11.75 t ha^{-1}. Statistical analysis results (Table 3.4, Appendix 7.5), indicate that in all the three growing seasons there were statistical differences ($P = 0.01$) in CWUE among the drip treatments.

Table 3.3. Effect of irrigation water regimes on cane yield (t ha^{-1}), cane quality (% sucrose) and sucrose yield (t ha^{-1}) in the plant, first and second ratoon crops.

	Crop	Treatments					$LSD_{0.01}$	s.e.d
		0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc	Sprinkler		
Cane yield (t ha^{-1})	Plant cane	102.43	99.19	109.59	111.05	62.36	8.09	± 1.947
	First Ratoon	114.77	108.56	114.18	121.9	80.63	ns	ns
	Second Ratoon	103.35	104.18	109.09	134.88	106.15	16.66	± 3.856
	Average	106.85	103.98	110.95	122.61	83.05		
Cane quality (% sucrose)	Plant cane	15.7	16.14	15.88	15.25	15.32	ns	ns
	First Ratoon	15.7	15.94	15.68	15.25	15.37	ns	ns
	Second Ratoon	15.64	15.67	15.80	15.39	15.77	ns	ns
	Average	15.68	15.92	15.79	15.30	15.49		
Sucrose yield (t ha^{-1})	Plant cane	16.09	16.01	17.4	16.93	9.55	ns	ns
	First Ratoon	18.02	17.3	17.9	18.59	11.03	ns	ns
	Second Ratoon	16.17	16.32	17.24	20.75	16.74	3.261	± 0.755
	Average	16.76	16.54	17.51	18.76	12.44		

Table 3.4 Effect of irrigation water regimes on crop water use efficiency t ha^{-1}(100 mm)$^{-1}$ in plant, first and second ratoon crops.

Crop	Treat ment					$LSD_{0.01}$	s.e.d
	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc	Sprinkler		
Plant cane	13.69	12.62	12.23	11.08	6.97	1.002	± 0.232
First ratoon	13.34	10.59	11.74	11.20	7.80	1.832	± 0.424
Second ratoon	15.73	12.80	11.19	12.99	9.84	2.217	± 0.513
Average	14.25	12.00	11.72	11.76	8.20		

CHAPTER 4

4.0 DISCUSSION AND CONCLUSION

The effect of different drip irrigation regimes on water application, sugarcane growth and yields was studied over a three year period covering a plant crop and two ratoon crops. In the plant crop and first ratoon the soil water content was restored to field capacity in all irrigation treatments and irrigations were carried out once the total cumulative daily evapotranspiration (ETc) reached 10 mm in each treatment. The rainfall received within the first five months of establishment and ratooning in the plant and first ratoon crops (1999 and 2000 seasons) was above normal. In order to minimise incidences of waterlogging and to increase the effectiveness of rainfall a deliberate decision was taken to modify the treatments in the second ratoon (2001 season). The only change was to irrigate to restore the soil water content to 50 % total available moisture (TAM) level instead of restoring it to field capacity in all the drip treatments. The control treatment (1.0 ETc) factor was used to lower the soil water content levels to the 50 % TAM soil water content in all treatments.

In the plant crop and first ratoon the differences in total net water use between the 0.5 ETc and the 1.2 ETc treatment were 254.50 and 227.50 mm respectively. In the second ratoon, because of lower rainfall received than the previous seasons, the difference was 381mm. The smaller differences in water use between drip treatments in the plant and first ratoon crops than in the second ratoon crop could be attributed to the above normal summer rains that were received in the two seasons in which the former crops were grown. In some instances, irrigation had to be delayed in 1999 and 2000 seasons because the plots were ponded with water, and as a result the frequency of irrigation in each treatment was reduced. The larger difference in the second ratoon was due to there being less rainfall interference and consequentially, response from the irrigation treatments were more evident. There was also an increase in net rainfall utilisation in the second ratoon because of the relatively drier season.

The soil water distribution results showed that the gravimetric and tensiometer methods used to characterise the soil wetting patterns below an emitter were in agreement for the wetter

treatments. Both methods indicated that there was more vertical than lateral water movement with an increase in irrigation water application.

In the drier treatments (0.5 ETc and 0.75 ETc) the soil wetting pattern was confined to below the emitters and the soil water content decreased with distance away from the emitters. In the 1.0 ETc and 1.2 ETc treatments, higher soil water contents were maintained in the interrows. The soil water potential figures prior to irrigations increased with increase in water application, which indicated that the wetter treatments were maintained at higher soil water content levels than the dry treatments. This was also indicated by the soil water balance estimates.

Wet soil has less resistance to root growth than in the same soil at a lower water content, and root growth tends to be rapid on wet soil (Kramer and Boyer, 1995, Glover, 1968). The differences in the soil wetting patterns caused by the different intervals between irrigations, were expected to influence root development. Roots were predominantly found to a soil depth of 0.3 m, and the density of roots tended to increase towards the emitters, where the soil was wetter. However, under the wet conditions in the plant and first ratoon crops in the 1.2 ETc treatment, root growth decreased towards the emitters compared to the other drier treatments. This rooting behaviour was an indication that probably under the wet weather conditions of the first two seasons there was excessive water application below the emitters and this created waterlogged conditions not favourable to root growth and development. Contrary, in the second ratoon where the weather conditions were drier, the roots were found at shallower soil depths, and root density increased with proximity to the emitters in all treatments. In addition, the 1.2 ETc treatment had roots reaching deeper soil depths than the drier treatments. This suggests that soil in the second ratoon was generally drier, and that the roots proliferated in the wetter parts of the soil profile.

Anything which retards root development is likely to retard plant growth and that which promotes root development is likely to promote aerial growth (Glover, 1968). In terms of cane growth, in the plant and first ratoon there were no differences among the four drip treatments in cane population and stalk height. There were also no consistent differences in the number of green leaves and leaf elongation among the drip treatments. The poor response can be attributed to the above normal rainfall received in the two growing seasons.

In the second ratoon crop because of the relatively drier weather, the wettest treatment (1.2 ETc) had the highest stalk heights. However, there were no consistent differences in plant population, stalk heights, number of green leaves per stalk and leaf length among the other drip treatments.

In the plant and first ratoon crops, the sprinkler block had a low plant population and shorter stalks. However, in the second ratoon stalk heights were comparable to the 0.5, 0.75 and 1.0 ETc treatments and plant population in the early part of the season was lower than in the drip treatments. Since gross water application in the plant crop and first ratoon was adequate, the poor cane growth could probably be attributed to soil nutrient deficiencies caused by the heavy rains that could have leached nutrients particularly N, out of the rootzone. Although leaf nutrient levels were above the respective nutrient thresholds, the observation that leaf nutrient levels in the sprinkler block were lower than those in the drip block suggests that there were soil nutrient losses. The split N application in the drip block could also have minimised the chances of leaching of nutrients during the heavy rains received within the first five months of crop establishment. The taller stalks obtained in the sprinkler block in the second ratoon suggest that the 0.5 ETc, 0.75 ETc and 1.0 ETc introduced similar levels of water stress compared to the other growing seasons. The fact that stalk height in the 0.5 ETc, 0.75 ETc and 1.0 ETc were shorter than the 1.2 ETc treatment suggests that crops irrigated using the 50 % TAM method were under irrigated.

The poor response in yield among the drip treatments in the plant and first ratoon crop reflects the impact of the wet weather during these two growing seasons. This is evident by the small difference in total water use between the driest to the wettest treatment, which minimised the impact of the treatments on crop growth. Given the relatively drier weather during the second ratoon, the wettest treatment produced the highest yield. However, there were no statistically significant differences ($p = 0.05$) between the control (1.0 ETc) and the dry treatments 0.75 and 0.5 ETc. The poor response in the drier treatments suggests that the crop adopted to the water stress conditions and only the 1.2 ETc received adequate water. However, cane quality (sucrose %) was similar in all treatments, which appears to contradict the stress theory. Ellis *et al.*, (1985), also found that yields were not reduced when the total water use was reduced by 20 %.

There were differences in crop water use efficiency among the drip treatments in the three growing seasons. The sprinkler observation block had the lowest crop water use efficiency in the three growing seasons.

The objective of the study was mainly to determine if the estimated crop water requirement under drip irrigation could be reduced without reduction in crop yield. The following important findings show that the objectives of this study were achieved, and the findings are of particular importance for commercial sugarcane production under subsurface drip irrigation:

1. Results from the plant and first ratoon crops suggest that seasons with normal and well distributed rainfall, an application of 0.75 or even 0.5 of ETc may be sufficient to reach potential cane yields. The crop after six months should have fully canopied with roots fully established, and the water stored in the profile should provide the crop with sufficient amounts of water to supplement the reduced irrigation water.

2. Results have also clearly demonstrated that the irrigation water requirement can be reduced by 50 % under drip irrigation while still achieving the commercial average cane yield of 95 t ha^{-1}. The fact that water in this study was applied at a deficit of 10 mm, undoubtedly suggests that a reduction of the estimated crop water requirement by 50 % under daily water application would produce even higher yields.

3. The results from the second ratoon show that maintaining soil water levels at field capacity may not produce better yields than at 50 % TAM level. Maintaining the soil water levels below field capacity may increase the utilisation of rainfall. However, because of the difficulty in accurately estimating 50 % of TAM, the soil water level must be kept between field capacity and the estimated 50 % TAM combined with the use of the 1.2 ETc estimate.

4. The results clearly showed that the sucrose yield (t ha^{-1}) could be increased by 3 t ha^{-1} and at the same time maximising on rainfall efficiency by increasing the current estimate of ETc by 20% at the 50 % TAM level. Increasing the ETc by 20 % will

give a total net water use of approximately 1100 mm, which is still below the current water allocation on Mhlume Estate of about 1300 mm. With the current sucrose price of E1506 ton^{-1}, the net returns from sucrose sale could be increased by E4518 ha^{-1}.

5. Leaching of N fertiliser nutrient was speculated to be prevalent on the sprinkler block as opposed to the drip plots. The split application of N fertiliser under drip irrigation may have helped in minimising N losses compared to where basal fertiliser was applied (in the sprinkler block). There is therefore a need to review the timing of N fertiliser applications, particularly in higher than average rainfall seasons after the leaf samples have been taken where drip irrigation is used.

Further research is required to study the differences in cutting seasons to determine the effect of climatic conditions on estimated crop water requirement. In addition, there is a need to compare similar treatments under daily water applications and to assess N fertiliser requirements under drip irrigation more accurately.

LIST OF APPENDICES

Appendix 1: Summary of evapotranspiration for a reference crop (ETc) with applied factors

a) Factors to convert Class A pan to Penman-Monteith evaporation

				Month of year								
Month of	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
harvest	1	2	3	4	5	6	7	8	9	10	11	12
MAY	0.59	0.53	0.58	0.68	0.77	0.85	0.87	0.86	0.86	0.86	0.85	0.82
JUN	0.77	0.51	0.56	0.65	0.73	0.82	0.85	0.85	0.85	0.86	0.84	0.81
JUL	0.76	0.70	0.53	0.63	0.71	0.80	0.84	0.84	0.85	0.85	0.84	0.80
AUG	0.75	0.70	0.75	0.61	0.70	0.78	0.83	0.84	0.84	0.85	0.83	0.80
SEP	0.75	0.69	0.74	0.85	0.67	0.76	0.81	0.83	0.84	0.85	0.83	0.79
OCT	0.74	0.68	0.73	0.83	0.91	0.73	0.79	0.81	0.82	0.84	0.82	0.79
NOV	0.73	0.67	0.72	0.82	0.89	0.95	0.76	0.78	0.81	0.83	0.81	0.78
DEC	0.72	0.66	0.71	0.80	0.87	0.94	0.94	0.75	0.78	0.81	0.80	0.77
MAR	0.65	0.59	0.65	0.75	0.82	0.89	0.90	0.88	0.88	0.88	0.73	0.70
APR	0.62	0.56	0.61	0.72	0.80	0.87	0.89	0.87	0.87	0.87	0.86	0.68
averag	0.71	0.63	0.66	0.73	0.79	0.84	0.85	0.83	0.84	0.85	0.82	0.77
Max	0.77	0.70	0.75	0.85	0.91	0.95	0.94	0.88	0.88	0.88	0.86	0.81

b) Crop factors

							Current month					
Month cut	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
	1	2	3	4	5	6	7	8	9	10	11	12
MAY	0.25	0.25	0.40	0.40	0.85	1.00	1.00	1.00	1.00	1.00	1.00	D.O.
JUN	0	0.25	0.25	0.40	0.40	0.85	1.00	1.00	1.00	1.00	1.00	1.00
JUL	1.00	0	0.25	0.25	0.40	0.40	0.85	1.00	1.00	1.00	1.00	1.00
AUG	0.70	0.70	0	0.35	0.50	0.70	1.00	1.00	1.00	1.00	1.00	0.85
SEP	0.85	0.70	0.70	0	0.35	0.50	0.70	1.00	1.00	1.00	1.00	1.00
OCT	0.85	0.85	0.70	0.70	0	0.35	0.50	0.70	1.00	1.00	1.00	1.00
NOV	1.00	1.00	0.85	0.70	0.70	0	0.35	0.50	0.70	1.00	1.00	1.00
DEC	1.00	1.00	1.00	0.85	0.70	0.70	0	0.35	0.50	0.70	1.00	1.00
MAR	0.40	0.40	0.50	0.70	0.85	1.00	1.00	1.00	1.00	1.00	0.35	0.35
APR	0.25	0.25	0.40	0.40	0.85	1.00	1.00	1.00	1.00	1.00	0.00	0.25

c) 0.5 ETc treatment

					ETc Factor							
							Current month					
Month cut	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
	1	2	3	4	5	6	7	8	9	10	11	12
MAY	0.07	0.07	0.12	0.14	0.33	0.43	0.44	0.43	0.43	0.43	0.43	0.43
JUN	0.41	0.06	0.07	0.13	0.15	0.35	0.43	0.43	0.43	0.43	0.42	0.41
JUL	0.38	0.38	0.07	0.08	0.14	0.16	0.36	0.42	0.43	0.43	0.42	0.40
AUG	0.26	0.25	0.25	0.11	0.18	0.27	0.42	0.42	0.42	0.43	0.42	0.34
SEP	0.32	0.24	0.26	0.26	0.12	0.19	0.28	0.42	0.42	0.43	0.42	0.40
OCT	0.31	0.29	0.26	0.29	0.29	0.13	0.20	0.28	0.41	0.42	0.41	0.40
NOV	0.37	0.34	0.31	0.29	0.31	0.31	0.13	0.20	0.28	0.42	0.41	0.39
DEC	0.36	0.33	0.36	0.34	0.30	0.33	0.33	0.13	0.20	0.28	0.40	0.39
JAN	0.17	0.27	0.35	0.45	0.45	0.44	0.44	0.44	0.13	0.13	0.13	0.12
MAR	0.13	0.12	0.16	0.26	0.35	0.45	0.45	0.44	0.44	0.44	0.13	0.12
APR	0.08	0.07	0.12	0.14	0.34	0.44	0.45	0.44	0.44	0.44	0.44	0.09

d) 0.75 ETc treatment

					ETc Factor							
							Current month					
Month cut	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
	1	2	3	4	5	6	7	8	9	10	11	12
MAY	0.11	0.10	0.17	0.20	0.49	0.64	0.65	0.65	0.65	0.65	0.64	0.64
JUN	0.61	0.10	0.11	0.20	0.22	0.52	0.64	0.64	0.64	0.65	0.63	0.61
JUL	0.57	0.57	0.10	0.12	0.21	0.24	0.54	0.63	0.64	0.64	0.63	0.60
AUG	0.39	0.37	0.37	0.16	0.26	0.41	0.62	0.63	0.63	0.64	0.62	0.51
SEP	0.48	0.36	0.39	0.39	0.18	0.29	0.43	0.62	0.63	0.64	0.62	0.59
OCT	0.47	0.43	0.38	0.44	0.44	0.19	0.30	0.43	0.62	0.63	0.62	0.59
NOV	0.55	0.50	0.46	0.43	0.47	0.47	0.20	0.29	0.43	0.62	0.61	0.59
DEC	0.54	0.50	0.53	0.51	0.46	0.49	0.50	0.20	0.29	0.43	0.60	0.58
JAN	0.25	0.40	0.53	0.67	0.68	0.66	0.66	0.66	0.20	0.19	0.20	0.18
MAR	0.20	0.18	0.24	0.39	0.52	0.67	0.68	0.66	0.66	0.66	0.19	0.18

ppendix 1 (Continued)

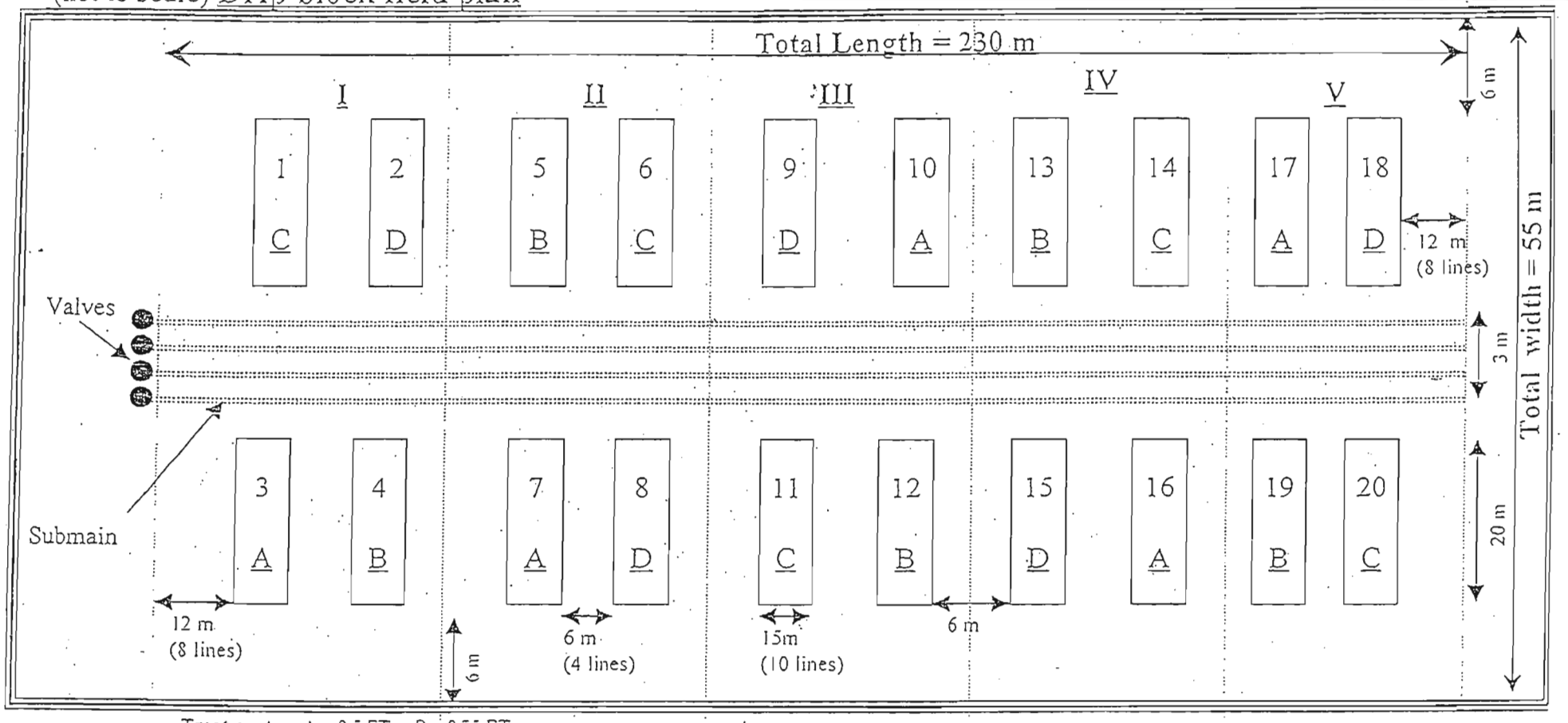
1.0 ETc treatment

					ETc Factor							
							Current month					
onth cut	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
	1	2	3	4	5	6	7	8	9	10	11	12
AY	0.15	0.13	0.23	0.27	0.65	0.85	0.87	0.86	0,86	0.86	0.85	0.85
JN	0.81	0.13	0.14	0.26	0.29	0.70	0.85	0.85	0.85	0.86	0.84	0.81
JL	0.76	0.76	0.13	0.16	0.28	0.32	0.71	0.84	0.85	0.85	0.84	0.80
UG	0.53	0.49	0.49	0.21	0.35	0.55	0.83	0.84	0,84	0.85	0.83	0.68
EP	0.64	0.48	0.52	0.52	0.23	0.38	0.57	0.83	0.84	0.85	0.83	0.79
CT	0.63	0.58	0.51	0.58	0.58	0.26	0.40	0.57	0.82	0.84	0.82	0.79
OV	0.73	0.67	0.61	0.57	0.62	0.62	0.27	0,39	0.57	0.83	0.81	0.78
EC	0.72	0.66	0.71	0.68	0,61	0.66	0.66	0.26	0.39	0.57	0.80	0.77
AN	0.33	0.53	0.70	0.89	0.90	0.88	0.88	0,88	0.26	0.25	0.26	0.24
AR	0.26	0.24	0.33	0.53	0.70	0.89	0.90	0.88	0.88	0.88	0.26	0.25
PR	0.16	0.14	0.24	0.29	0.68	0.87	0.89	0.87	0.87	0.87	0.87	0.17

1.2 ETc treatment

					ETc.Factor							
							Current month					
Month cut	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
	1	2	3	4	5	6	7	8	9	10	11	12
AY	0.18	0.16	0.28	0.33	0.79	1.02	1.04	1.03	1.03	1.03	1.02	1.02
UN	0.97	0.15	0.17	0.31	0.35	0.84	1.02	1.02	1.02	1.03	1.01	0.97
UL	0.91	0.91	0.16	0.19	0.34	0.38	0.86	1.01	1.02	1.02	1.01	0.96
UG	0.63	0,59	0.59	0.26	0.42	0.66	1.00	1.01	1.01	1.02	1.00	0.82
EP	0.77	0.58	0.62	0.62	0.28	0.46	0.68	1.00	1.01	1.02	1.00	0.95
CT	0.75	0.69	0.61	0.70	0.70	0.31	0.47	0.68	0.98	1.01	0.98	0.95
OV	0.88	0.80	0.73	0.69	0.75	0.74	0.32	0.47	0.68	1.00	0.97	0.94
EC	0.86	0.79	0.85	0.82	0.73	0.79	0.79	0,32	0.47	0.68	0.96	0.92
AN	0.40	0.64	0.84	1.07	1.08	1.06	1.06	1.06	0.31	0.30	0.31	0.29
AR	0.31	0.28	0.39	0.63	0.84	1.07	1.08	1.06	1.06	1.06	0.31	0.29
PR	0.19	0.17	0.29	0.35	0.82	1.04	1.07	1.04	1.04	1.04	1.04	0.20

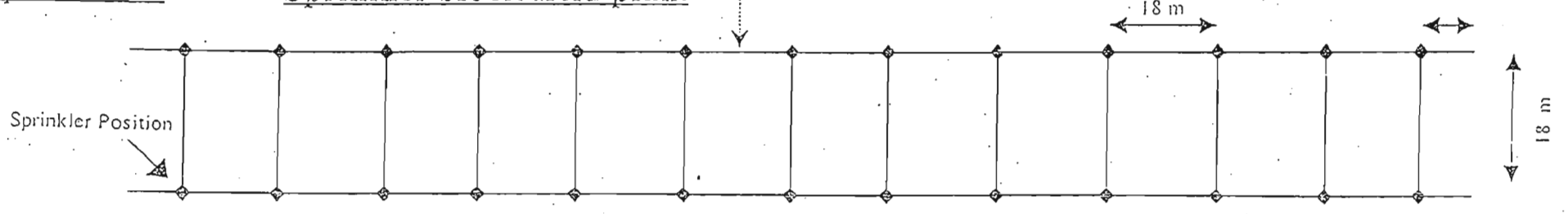
(not to scale) Drip block field plan



Treatment: A = 0.5 ETc. B = 0.75 ETc
C = 1.0 ETc D = 1.2 ETc

Commercial Cane (132 m)

Appendix 2.2: Sprinkler block field plan.



Appendix 3: Monthly total and effective rainfall distribution in each growing season from 1998 to 2001.

				Plant Crop (Year: 1998/99)										
Month	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total	
Longterm mean (mm)	99.2	119.5	146.3	128.5	88.0	53.7	23.6	11.6	10.6	12.0	31.5	69.8	794.3	
Total Rainfall (mm)	68.5	141.0	115.5	148.0	70.8	28.0	9.0	2.0	52.0	19.0	6.0	0.0	660	
Effective rainfall (mm)														% rainfall efficiency
0.5 ETc	68.5	46.8	89.3	49.2	60.2	28.0	9.0	2.0	52.0	19.0	6.0	0.0	430	65
0.75 ETc	36.5	46.8	59.3	39.2	50.0	28.0	9.0	2.0	52.0	19.0	6.0	0.0	348	53
1.0 ETc	68.5	33.1	32.3	15.5	16.2	11.1	9.0	2.0	14.0	0.3	6.0	0.0	208	32
1.2 ETc	68.5	23.1	12.5	11.4	17.9	6.0	7.1	0.0	8.9	3.2	6.0	0.0	164	25
Sprinkler	48.0	40.6	81.7	51.9	60.5	19.8	7.1	0.0	52.0	19.0	6.0	0.0	387	59
				First Ratoon (Year: 1999/00)										
Month	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total	
Total Rainfall (mm)	132.8	85	130	375	243	54	57	3	5	0	35	21	1141	
Effective rainfall (mm)														% rainfall efficiency
0.5 ETc	94.0	66.9	92.3	80.4	56.4	11.5	57.0	3.0	5.0	0.0	35.0	21.0	522	46
0.75 ETc	88.2	43.8	70.7	60.4	77.0	19.8	43.4	3.0	5.0	0.0	35.0	21.0	467	41
1.0 ETc	88.2	39.6	31.8	17.9	20.6	9.5	8.8	1.1	5.0	0.0	11.3	21.0	255	22
1.2 ETc	71.6	11.5	17.3	44.0	37.6	0.0	11.3	1.5	3.6	0.0	0.7	21.0	220	19
Sprinkler	116.9	74.5	99.8	77.6	77.0	19.8	53.3	3.0	5.0	0.0	13.5	21.0	561	49
				Second Ratoon (Year: 2000/01)										
Month	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total	
Total Rainfall (mm)	85.5	31	48.5	147.5	37	57	14	0	3.5	0	24	35	483	
Effective rainfall (mm)														% rainfall efficiency
0.5 ETc	85.5	31.0	48.5	147.5	37.0	57.0	14.0	0.0	3.5	0.0	24.0	35.0	483	100
0.75 ETc	42.4	31.0	48.5	147.5	37.0	57.0	14.0	0.0	3.5	0.0	24.0	35.0	440	91
1.0 ETc	60.7	31.0	48.5	100.0	37.0	57.0	14.0	0.0	3.5	0.0	24.0	35.0	411	85
1.2 ETc	60.7	31.0	34.5	50.0	35.1	37.8	4.5	0.0	1.5	0.0	24.0	35.0	314	65
Sprinkler	34.0	29.0	48.5	66.4	37.0	57.0	14.0	0.0	2.8	0.0	24.0	35.0	348	72

Appendix 4: Net irrigation (monthly) water application in each growing season from 1998 to 2001.

Plant Crop (Year: 1998/99)

Month	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total Application (mm)	Number of irrigations
0.5 ETc	58	0	30	30	20	40	30	30	10	40	30	0	318	32
0.75 ETc	58	10	50	40	50	60	50	40	30	50	0	0	438	44
1.0 ETc	58	30	60	70	100	70	70	60	40	80	50	0	688	69
1.2 ETc	58	40	90	90	100	90	80	80	50	100	60	0	838	84
Sprinkler	86	0	43	43	43	86	43	86	0	43	43	43	559	13

First Ratoon (Year: 1999/00)

Month	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total Application (mm)	Number of irrigations
0.5 ETc	30	20	20	10	20	20	50	40	20	30	30	48	338	34
0.75 ETc	50	40	40	20	0	40	60	60	40	50	60	98	558	56
1.0 ETc	50	50	70	50	50	60	90	80	50	70	50	48	718	72
1.2 ETc	40	100	90	30	40	80	110	100	60	90	70	58	868	87
Sprinkler	43	0	43	0	0	43	43	86	86	43	86	0	473	11

Second Ratoon (Year: 2000/01)

Month	Nov	Dec.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total Application (mm)	Number of irrigations
0.5 ETc	0	20	40	10	0	0	0	20	20	40	0	24	174	17
0.75 ETc	10	50	70	30	10	20	30	40	30	60	0	24	374	37
1.0 ETc	0	70	120	40	50	40	50	50	40	80	0	24	564	56
1.2 ETc	0	90	160	40	80	60	60	60	60	80	10	24	724	72
Sprinkler	43	86	172	43	86	43	43	43	86	43	43	0	731	17

Appendix 5: Monthly crop water requirement (ETc) and net water application in each growing season from 1998 to 2001.

Plant Crop (Year: 1998/99)

Month	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total	
Total evapotranspiration (mm)	18.6	63.8	110.2	114.6	117.6	86.3	78.5	62.7	58.4	82.3	94.7	61.9	949.8	
Net application (mm)														% of total ETc
0.5 ETc	126.5	46.8	119.3	79.2	80.2	68.0	39.0	32.0	62.0	59.0	36.0	0.0	748	79
0.75 ETc	94.5	56.8	109.3	79.2	100.0	88.0	59.0	42.0	82.0	69.0	6.0	0.0	786	83
1.0 ETc	126.5	63.1	92.3	85.5	116.2	81.1	79.0	62.0	54.0	80.3	56.0	0.0	896	94
1.2 ETc	126.5	63.1	102.5	101.4	117.9	96.0	87.1	80.0	58.9	103.2	66.0	0.0	1002	106
Sprinkler	134.0	40.6	124.7	94.9	103.5	105.8	50.1	86.0	52.0	62.0	49.0	43.0	946	100

First Ratoon (Year: 1999/00)

Month	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total	
Total evapotranspiration (mm)	70.12	103.8	121.1	116.4	97.74	84.451	106.7	81.2	50.59	68.44	85.78	71.664	1058.0	
Net application (mm)														% of total ETc
0.5 ETc	124.0	86.9	112.3	90.4	76.4	31.5	107.0	43.0	25.0	30.0	65.0	69.0	860	81
0.75 ETc	138.2	83.8	110.7	80.4	77.0	59.8	103.4	63.0	45.0	50.0	95.0	119.0	1025	97
1.0 ETc	138.2	89.6	101.8	67.9	70.6	69.5	98.8	81.1	55.0	70.0	61.3	69.0	973	92
1.2 ETc	111.6	111.5	107.3	74.0	77.6	80.0	121.3	101.5	63.6	90.0	70.7	79.0	1088	103
Sprinkler	159.9	74.5	142.8	77.6	77.0	62.8	96.3	89.0	91.0	43.0	99.5	21.0	1034	98

Second Ratoon (Year: 2000/01)

Month	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total	
Total evapotranspiration (mm)	62.2	114.8	169.8	119.8	118	99.224	62.87	45.88	50.9	71.98	71.28	8.489	995.2	
Net application (mm)														% of total ETc
0.5 ETc	85.5	51.0	88.5	157.5	37.0	57.0	14.0	20.0	23.5	40.0	24.0	59.0	657	66
0.75 ETc	52.4	81.0	118.5	177.5	47.0	77.0	44.0	40.0	33.5	60.0	24.0	59.0	814	82
1.0 ETc	60.7	101.0	168.5	140.0	87.0	97.0	64.0	50.0	43.5	80.0	24.0	59.0	975	98
1.2 ETc	60.7	121.0	194.5	90.0	115.1	97.8	64.5	60.0	61.5	80.0	34.0	59.0	1038	104
Sprinkler	77.0	115.0	220.5	109.4	123.0	100.0	57.0	43.0	88.8	43.0	67.0	35.0	1079	108

ppendix 6.1 Analysis of variance table for stalk height in plant, first and second ratoon cane.

A. Plant crop

Age 3 Months

eplication	Treatment 0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
	0.295	0.354	0.317	0.295
	0.303	0.298	0.252	0.244
	0.289	0.450	0.206	0.239
	0.330	0.243	0.350	0.331
	0.359	0.446	0.386	0.391

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.03	0.008	2.52	0.967	
Treatment	3.0	0.01	0.004	1.20	0.388	ns
Error	12.0	0.04	0.003			
Total	19.0	0.08				
% CV	18.14					

Age 4 Months

eplication	Treatment 0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
	0.756	0.862	0.799	0.791
	0.793	0.798	0.749	0.726
	0.831	0.998	0.729	0.736
	0.857	0.797	0.916	0.910
	0.937	0.988	0.978	1.001

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.10	0.026	5.54	0.009	
Treatment	3.0	0.01	0.004	0.79	0.525	ns
Error	12.0	0.06	0.005			
Total	19.0	0.17				
% CV	8.12					

Age 5 Months

eplication	Treatment 0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
	1.165	1.245	1.229	1.136
	1.149	1.094	1.124	1.093
	1.231	1.347	1.122	1.076
	1.317	1.193	1.346	1.311
	1.375	1.370	1.413	1.428

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.190	0.047	8.800	0.002	
Treatment	3.0	0.010	0.002	0.360	0.782	ns
Error	12.0	0.060	0.005			
Total	19.0	0.260				
% CV	5.9					

Age 6 Months

eplication	Treatment 0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
	1.360	1.444	1.412	1.329
	1.349	1.295	1.330	1.286
	1.413	1.561	1.329	1.282
	1.503	1.356	1.534	1.511
	1.557	1.541	1.600	1.608

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.160	0.040	6.490	0.005	
Treatment	3.0	0.000	0.020	0.260	0.850	ns
Error	12.0	0.070	0.060			
Total	19.0	0.240				
% CV	5.48					

Age 7 Months

eplication	Treatment 0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
	1.411	1.484	1.486	1.370
	1.407	1.339	1.376	1.340
	1.462	1.615	1.376	1.332
	1.575	1.516	1.594	1.559
	1.612	1.573	1.658	1.655

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.170	0.043	8.800	0.002	
Treatment	3.0	0.010	0.003	0.600	0.624	ns
Error	12.0	0.060	0.005			
Total	19.0	0.240				
% CV	4.71					

Age 8 Months

Replication	Treatment 0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
	1.480	1.531	1.583	1.483
	1.472	1.383	1.459	1.408
	1.545	1.680	1.457	1.404
	1.666	1.559	1.688	1.636
	1.691	1.652	1.754	1.723

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.190	0.047	8.990	0.000	
Treatment	3.0	0.010	0.003	0.560	0.655	ns
Error	12.0	0.060	0.005			
Total	19.0	0.260				
% CV	4.62					

Age 9 Months

Replication	Treatment 0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
	1.539	1.635	1.684	1.596
	1.505	1.483	1.560	1.550
	1.605	1.771	1.514	1.509
	1.732	1.650	1.803	1.774
	1.760	1.727	1.889	1.825

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.200	0.050	7.590	0.000	
Treatment	3.0	0.010	0.003	0.500	0.690	ns
Error	12.0	0.080	0.007			
Total	19.0	0.290				
% CV	4.91					

Age 10 Months

Replication	Treatment 0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
	1.637	1.707	1.764	1.725
	1.654	1.568	1.662	1.655
	1.676	1.844	1.664	1.597
	1.773	1.750	1.853	1.827
	1.846	1.789	1.930	1.900

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.130	337.000	7.100	0.000	
Treatment	3.0	0.100	29.700	0.630	0.610	ns
Error	12.0	0.060	47.500			
Total	19.0	0.200				
% CV	3.96					

B. First ratoon

Age 3 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	0.703	0.687	0.717	0.778
2	0.724	0.672	0.695	0.607
3	0.520	0.633	0.609	0.675
4	0.670	0.685	0.630	0.596
5	0.695	0.668	0.706	0.654

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.030	0.007	2.710	0.081	
Treatment	3.0	0.000	0.000	0.400	0.987	ns
Error	12.0	0.030	0.000			
Total	19.0	0.060				
% CV	7.66					

Age 4 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	0.984	1.077	1.012	1.008
2	1.033	0.950	0.985	0.907
3	0.743	0.926	1.071	0.958
4	0.992	0.994	0.909	0.890
5	0.989	0.949	1.026	0.922

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.020	0.005	0.860	0.517	
Treatment	3.0	0.010	0.004	0.700	0.567	ns
Error	12.0	0.070	0.006			
Total	19.0	0.100				
% CV	7.99					

Age 5 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	1.407	1.582	1.518	1.643
2	1.464	1.438	1.444	1.387
3	1.342	1.481	1.552	1.424
4	1.463	1.492	1.411	1.373
5	1.540	1.396	1.532	1.476

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.030	0.008	1.290	0.270	
Treatment	3.0	0.010	0.002	0.370	0.779	ns
Error	12.0	0.070	0.006			
Total	19.0	0.110				
% CV	5.29					

Age 6 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	2.018	2.126	2.088	2.184
2	2.084	2.098	2.043	1.913
3	1.963	2.023	2.119	2.063
4	2.057	1.971	1.920	1.992
5	2.040	1.993	2.054	1.969

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.300	0.008	1.520	0.259	
Treatment	3.0	0.000	0.000	0.090	0.966	ns
Error	12.0	0.060	0.005			
Total	19.0	0.090				
% CV	3.53					

Age 7 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	2.370	2.324	2.529	2.533
2	2.316	2.376	2.246	2.193
3	2.397	2.272	2.311	2.367
4	2.160	2.342	2.339	2.239
5	2.296	2.276	2.416	2.380

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.070	0.018	2.400	0.108	
Treatment	3.0	0.010	0.004	0.490	0.696	ns
Error	12.0	0.090	0.007			
Total	19.0	0.170				
% CV	5.8					

C. Second ratoon

Age 2 Months

	Treatment			
plication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 EiTc
	0.162	0.165	0.164	0.167
	0.161	0.146	0.178	0.171
	0.181	0.184	0.150	0.158
	0.145	0.171	0.158	0.163
	0.149	0.160	0.162	0.175

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.000	0.000	0.200	0.936	
Treatment	3.0	0.000	0.000	0.290	0.831	ns
Error	12.0	0.000	0.000			
Total	19.0	0.000				
% CV	7.44					

Age 3 Months

	Treatment			
eplication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
	0.316	0.337	0.316	0.382
	0.300	0.297	0.292	0.413
	0.355	0.283	0.303	0.316
	0.230	0.357	0.298	0.388
	0.312	0.281	0.387	0.378

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.000	0.001	0.280	0.887	
Treatment	3.0	0.020	0.005	2.930	0.077	ns
Error	12.0	0.020	0.002			
Total	19.0	0.040				
% CV	13.16					

Age 4 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	0.509	0.546	0.671	0.766
2	0.480	0.518	0.603	0.796
3	0.630	0.579	0.674	0.766
4	0.455	0.594	0.655	0.794
5	0.623	0.484	0.824	0.781

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.020	0.004	1.060	0.416	
Treatment	3.0	0.210	0.069	17.700	0.000	**
Error	12.0	0.050	0.004			
Total	19.0	0.280				
% CV	9.76					

Age 5 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	1.099	1.130	1.164	1.237
2	1.078	1.062	1.050	1.359
3	1.206	1.114	1.186	1.367
4	0.977	1.221	1.104	1.281
5	1.313	1.005	1.352	1.371

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.050	0.011	1.200	0.360	
Treatment	3.0	0.140	0.046	4.910	0.019	*
Error	12.0	0.110	0.009			
Total	19.0	0.300				
% CV	8.2					

Age 6 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	1.44	1.59	1.52	1.79
2	1.39	1.37	1.52	1.75
3	1.67	1.59	1.46	1.71
4	1.40	1.65	1.52	1.65
5	1.65	1.37	1.80	1.76.9

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.040	0.011	0.720	0.597	
Treatment	3.0	0.170	0.056	3.600	0.046	*
Error	12.0	0.190	0.015			
Total	19.0	0.400				
% CV	7.87					

Appendix 6.2 Analysis of variance table for plant density in plant, first and second ratoon cane.

A. Plant crop

Age 3 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	62.3	73.0	81.5	74.8
2	67.0	73.3	64.3	58.3
3	76.5	65.3	73.5	64.8
4	63.3	60.5	93.0	56.3
5	80.5	67.5	68.8	82.0

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	205.73	51.45	0.53	0.72	
Treatment	3	251.70	83.90	0.86	0.49	ns
Error	12	1175.83	97.99			
Total	19	1633.32				
% CV	14.08					

Age 4 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	62.8	69.3	65.8	62.8
2	62.5	58.8	57.3	60.8
3	65.3	59.3	71.0	62.5
4	53.0	55.5	69.5	50.3
5	62.8	55.0	58.0	60.8

Analysis of variance						
Source of variation	df	ss	Ms	F-value	Prob	Sign
Replication	4	157.67	39.42	1.36	0.30	
Treatment	3	81.66	27.22	0.94	0.45	ns
Error	12	346.81	28.90			
Total	19	586.14				
% CV	8.84					

Age 5 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	48.0	51.3	57.3	53.0
2	48.8	49.3	54.5	53.8
3	54.8	51.3	62.8	54.8
4	49.8	48.8	55.8	45.5
5	54.5	46.0	48.3	57.0

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	78.54	19.64	1.41	0.29	
Treatment	3.0	110.58	36.86	2.65	0.09	ns
Error	12.0	166.81	13.90			
Total	19.0	355.93				
% CV	7.14					

Age 6 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	44.8	50.0	52.5	49.8
2	48.3	47.3	50.3	52.5
3	52.5	48.5	56.0	52.8
4	46.5	46.3	52.8	42.3
5	51.8	44.0	44.5	50.0

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	73.61	18.40	1.61	0.23	
Treatment	3	41.28	13.76	1.21	0.35	ns
Error	12	136.79	11.40			
Total	19	251.68				
% CV	6.87					

Age 7 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	43.3	47.0	50.5	49.5
2	45.3	46.0	48.8	49.8
3	50.0	49.5	55.5	49.3
4	45.3	43.0	50.5	40.3
5	51.0	41.8	45.5	47.5

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	85.51	21.38	2.23	0.13	
Treatment	3	57.90	19.30	2.01	0.17	ns
Error	12	115.29	9.61			
Total	19	258.70				
% CV	6.53					

Age 8 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	50.8	54.0	50.0	53.3
2	50.3	50.8	53.5	55.3
3	56.3	52.5	59.0	58.5
4	48.8	50.3	54.5	45.3
5	52.0	44.8	50.5	55.8

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	110.02	27.51	2.63	0.09	
Treatment	3	35.21	11.74	1.12	0.38	ns
Error	12	125.56	10.46			
Total	19	270.78				
% CV	6.19					

Age 9 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	50.8	54.3	50.3	54.5
2	51.0	52.0	54.0	55.5
3	57.5	52.8	59.3	59.8
4	50.0	51.5	56.5	45.3
5	54.0	45.0	50.8	58.0

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	99.06	24.77	1.70	0.22	
Treatment	3	37.76	12.59	0.86	0.49	ns
Error	12	175.11	14.59			
Total	19	311.94				
% CV	7.19					

Age 10 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	56.0	51.8	60.5	50.5
2	52.8	50.3	53.5	55.0
3	46.5	57.3	51.8	59.0
4	51.3	57.0	61.5	45.3
5	50.5	57.0	46.3	51.5

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	27.39	6.85	0.25	0.91	
Treatment	3	43.46	14.49	0.52	0.68	ns
Error	12	334.13	27.84			
Total	19	404.99				
% CV	9.91					

B. First ratoon

Age 3 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	94.5	118.3	57.0	67.0
2	108.0	66.3	72.5	110.0
3	67.5	113.5	106.0	71.5
4	155.0	63.3	76.8	92.5
5	112.0	112.8	97.3	115.8

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	1538.19	384.55	0.51	0.73	
Treatment	3	1666.54	555.51	0.74	0.55	ns
Error	12	9012.71	751.06			
Total	19	12217.44				
% CV	29.19					

Age 4 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	51.3	53.3	49.8	59.0
2	55.8	51.8	61.3	51.0
3	56.8	54.8	55.3	58.5
4	56.0	46.5	50.8	51.8
5	53.5	55.0	51.8	54.5

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	57.24	14.31	1.12	0.39	
Treatment	3	22.05	7.35	0.57	0.64	ns
Error	12	153.76	12.81			
Total	19	233.05				
% CV	6.64					

Age 5 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	44.3	47.0	52.8	55.8
2	50.8	53.0	56.8	43.8
3	51.8	48.0	48.0	58.0
4	51.0	47.3	52.5	44.8
5	53.8	52.3	46.0	53.5

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	19.64	4.91	0.19	0.94	
Treatment	3	9.73	3.25	0.13	0.94	ns
Error	12	306.53	25.54			
Total	19	335.91				
% CV	10.00					

Age 6 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	37.3	42.8	41.8	46.8
2	45.0	46.0	45.3	39.3
3	46.5	45.5	45.8	47.8
4	41.3	41.8	42.8	41.0
5	44.5	48.5	40.3	44.5

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	57.04	14.26	1.68	0.22	
Treatment	3	12.02	4.01	0.47	0.71	ns
Error	12	101.63	8.47			
Total	19	170.70				
% CV	6.66					

Age 7 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	36.8	41.3	37.8	41.8
2	41.5	39.8	41.8	37.0
3	41.5	43.0	43.5	44.5
4	40.0	37.3	39.3	38.8
5	41.3	46.8	39.0	41.5

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	59.95	14.99	2.72	0.08	
Treatment	3	5.48	1.83	0.33	0.80	ns
Error	12	66.13	5.51			
Total	19	131.56				
% CV	3.69					

C. Second ratoon

Age 2 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1,2 ETc
1	92.3	85.3	82.3	74.0
2	80.0	89.3	75.0	77,3
3	96.0	90.0	80.0	85.0
4	97.0	90.0	76.0	94.0
5	84.0	85.0	74.0	78.0

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	274.68	68.67	2.92	0.07	
Treatment	3	488.75	162.92	6.93	0.006	**
Error	12	282.00	23.50			
Total	19	1045.44				
% CV	5.76					

Age 3 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	93.0	87.3	95.0	85.0
2	85.3	92.3	96.0	83.3
3	94.0	98.0	78.0	94.3
4	93.3	94.3	86.3	90.3
5	84.0	88.3	83.0	99.0

Analysis of variance						
Source of variation	df	ss	Ms	F-value	Prob	Sign
Replication	4	19.6	4.9	0.1	1.0	
Treatment	3	48.9	16.3	0.4	0.8	ns
Error	12	560.6	46.7			
Total	19	629.1				
% CV	7.6					

Age 4 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	63.0	58.0	60.0	61.3
2	59.3	59.0	58.0	55.3
3	57.0	63.0	60.3	62.3
4	59.3	63.0	60.0	54.0
5	60.0	60.3	60.3	65.0

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	31.79	7.95	0.95	0.47	
Treatment	3	3.72	1.24	0.15	0.93	ns
Error	12	100.69	8.39			
Total	19	136.19				
% CV	4.83					

Age 5 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	51.0	52.3	54.0	52.0
2	49.0	52.3	46.3	55.0
3	49.0	57.0	48.0	58.0
4	54.0	49.0	50.0	54.0
5	50.3	51.3	49.0	56.0

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	12.14	3.04	0.40	0.81	
Treatment	3	86.65	28.88	3.77	0.041	*
Error	12	91.95	7.66			
Total	19	190.74				
% CV	5.34					

Age 6 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	50.0	53.3	45.0	44.3
2	51.3	45.0	46.0	53.0
3	50.0	49.0	50.0	56.0
4	49.3	57.3	52.0	45.3
5	44.0	49.0	50.0	52.0

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	32.15	8.04	0.42	0.79	
Treatment	3	14.93	4.98	0.26	0.85	ns
Error	12	227.49	18.96			
Total	19	274.70				
% CV	8.78					

Appendix 6.3 Analysis of variance table for number of green leaves per stalk in plant, first and second ratoon crops.

A. Plant crop

Age 6 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	9.60	8.60	9.50	8.10
2	8.70	8.60	8.70	8.70
3	9.10	8.30	8.30	9.30
4	8.60	9.10	9.10	8.70
5	9.10	8.90	9.00	8.50

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.20	0.049	0.25	0.906	
Treatment	3.0	0.45	0.150	0.76	0.539	ns
Error	12.0	2.37	0.198			
Total	19.0	3.02				
% CV	5.04					

Age 7 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	7.90	7.70	8.40	8.90
2	7.70	7.80	7.20	8.30
3	8.10	7.40	7.50	7.80
4	8.20	7.90	8.10	7.80
5	7.60	7.60	8.30	7.70

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.23	0.058	0.30	0.870	
Treatment	3.0	0.22	0.074	0.39	0.765	ns
Error	12.0	2.30	0.191			
Total	19.0	2.75				
% CV	5.61					

Age 8 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	7.90	7.50	8.80	7.50
2	8.00	6.90	8.60	8.90
3	8.90	7.60	8.70	9.40
4	9.00	8.90	9.50	9.30
5	8.20	8.50	9.20	8.60

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	3.590	0.898	3.880	0.030	
Treatment	3.0	3.260	1.087	4.690	0.022	*
Error	12.0	2.780	0.232			
Total	19.0	9.630				
% CV	5.7					

Age 9 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	7.30	8.20	7.80	7.40
2	6.60	8.10	8.10	9.60
3	7.10	7.60	7.20	8.70
4	6.50	9.30	8.90	9.00
5	7.30	7.90	9.50	8.70

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	2.130	0.533	1.060	0.416	
Treatment	3.0	8.380	2.793	5.570	0.013	*
Error	12.0	6.020	0.501			
Total	19.0	16.530				
% CV	8.81					

Age 10 Months

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	8.10	8.10	8.30	7.60
2	8.00	8.20	8.00	9.50
3	8.00	7.70	8.00	8.90
4	7.90	8.50	8.40	7.90
5	7.40	7.40	8.40	8.10

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.770	0.193	0.800	0.548	
Treatment	3.0	0.830	0.276	1.150	0.371	ns
Error	12.0	2.890	0.241			
Total	19.0	4.490				
% CV	6.05					

rst ratoon

Age 3 Months

lication	Treatment 0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
	11.10	10.60	11.40	11.70
	11.20	11.50	11.20	11.30
	9.90	10.70	11.30	11.50
	11.10	11.00	11.10	10.70
	11.20	11.30	11.80	11.90

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	1.210	0.302	2.040	0.152	
Treatment	3.0	0.970	0.323	2.180	0.143	ns
Error	12.0	1.780	0.148			
Total	19.0	3.960				
% CV	3.44					

Age 4 Months

plication	Treatment 0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
	10.00	10.90	10.50	12.00
	9.90	10.60	10.30	10.60
	9.80	10.70	12.50	11.00
	10.80	11.20	11.80	10.70
	11.20	10.80	10.00	11.80

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	1.430	0.358	0.650	0.638	
Treatment	3.0	2.130	0.710	1.290	0.323	ns
Error	12.0	6.610	0.551			
Total	19.0	10.170				
% CV	6.8					

Age 5 Months

Replication	Treatment 0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
	9.60	9.90	10.00	10.50
	8.20	9.90	9.60	9.70
	9.00	9.70	10.50	9.50
	9.80	10.40	9.40	8.70
	9.80	9.80	9.50	10.50

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	1.000	0.269	0.770	0.568	
Treatment	3.0	1.250	0.417	1.190	0.355	ns
Error	12.0	4.210	0.351			
Total	19.0	6.540				
% CV	6.11					

Age 6 Months

Replication	Treatment 0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
	11.80	9.90	11.20	11.20
	9.20	10.50	9.70	10.30
	10.20	10.10	9.80	10.00
	8.70	10.20	10.60	9.80
	9.70	11.40	11.10	9.10

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	3.760	0.940	1.480	0.270	
Treatment	3.0	1.090	0.362	0.570	0.646	ns
Error	12.0	7.630	0.636			
Total	19.0	12.480				
% CV	7.80					

Age 7 Months

Replication	Treatment 0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
	10.20	8.70	11.30	10.10
	9.60	9.50	8.90	9.80
	9.50	9.10	8.40	9.40
	8.00	10.00	10.80	8.70
	8.90	11.20	9.90	10.20

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	3.000	0.751	0.820	0.538	
Treatment	3.0	1.040	0.347	0.380	0.770	ns
Error	12.0	11.010	0.918			
Total	19.0	15.060				
% CV	9.97					

Appendix 6.3 (Continued)

C. Second ratoon

Age 2 Months

	Treatment			
Replication	0.5 ETc	0.75Etc	1.0 ETc	1.2 ETc
1	8.70	8.20	8.60	8.20
2	8.80	8.90	8.60	8.50
3	8.40	8.60	8.70	8.80
4	8.40	9.30	8.70	8.50
5	8.80	8.50	8.50	8.60

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.220	0.056	0.780	0.561	
Treatment	3.0	0.080	0.027	0.380	0.770	ns
Error	12.0	0.660	0.072			
Total	19.0	1.170				
% CV	3.11					

Age 3 Months

	Treatment			
Replication	0.5 ETc	0.75Etc	1.0 ETc	1.2 ETc
1	7.60	7.60	8.60	8.60
2	7.30	8.00	8.20	8.80
3	9.00	8.50	9.10	8.70
4	7.80	9.20	8.80	8.50
5	8.10	8.10	8.20	8.50

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	1.650	0.414	3.120	0.140	
Treatment	3.0	1.190	0.395	2.030	0.164	ns
Error	12.0	2.340	0.195			
Total	19.0	5.180				
% CV	5.27					

Age 4 Months

	Treatment			
Replication	0.5 ETc	0.75Etc	1.0 ETc	1.2 ETc
1	9.50	8.10	8.80	9.10
2	8.20	8.20	9.40	9.80
3	8.90	8.70	10.20	11.00
4	7.90	8.80	8.70	9.80
5	9.70	8.30	10.10	10.20

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	3.760	0.939	4.540	0.018	
Treatment	3.0	7.810	2.604	12.580	0.001	**
Error	12.0	2.480	0.207			
Total	19.0	14.050				
% CV	4.99					

Age 5 Months

	Treatment			
Replication	0.5 ETc	0.75Etc	1.0 ETc	1.2 ETc
1	9.40	9.00	8.80	8.40
2	9.40	8.80	9.20	9.50
3	9.50	9.20	9.50	9.60
4	9.30	9.90	8.90	9.40
5	10.90	9.20	8.90	9.20

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	1.020	0.256	1.120	0.392	
Treatment	3.0	1.150	0.384	1.680	0.224	ns
Error	12.0	2.740	0.229			
Total	19.0	4.920				
% CV	5.14					

Age 6 Months

	Treatment			
Replication	0.5 ETc	0.75Etc	1.0 ETc	1.2 ETc
1	8.60	8.70	8.50	8.30
2	8.30	8.20	9.20	9.30
3	9.30	9.40	8.80	9.50
4	8.70	9.00	8.90	7.70
5	8.50	8.60	8.60	8.20

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	1.510	0.377	1.330	0.314	
Treatment	3.0	0.330	0.110	0.390	0.763	ns
Error	12.0	3.390	0.283			
Total	19.0	5.230				
% CV	6.07					

Age 7 Months

	Treatment			
Replication	0.5 ETc	0.75Etc	1.0 ETc	1.2 ETc
1	8.90	9.80	7.00	8.10
2	8.50	10.20	10.40	9.50
3	9.80	10.20	9.00	9.60
4	9.10	11.60	9.50	8.40
5	9.80	9.90	9.10	9.00

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	4.350	1.088	1.860	0.183	
Treatment	3.0	6.510	2.171	3.700	0.043	*
Error	12.0	7.040	0.586			
Total	19.0	17.900				
% CV	8.17					

ppendix 6.4 Analysis of variance table for leaf elongation in plant, first and second ratoon crops.

Plant crop

Age 6 Months

	Treatment			
eplication	0.5 ETc	0.75 ET	1.0 ETc	1.2 ETc
	0.35	0.48	0.97	0.24
	0.35	0.54	0.22	0.32
	0.61	0.36	0.10	0.45
	0.60	0.31	0.24	0.00
	0.98	0.74	0.47	0.63

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.43	0.108	2.01	0.157	
Treatment	3.0	0.18	0.060	1.08	0.393	ns
Error	12.0	0.65	0.054			
Total	19.0	1.26				
% CV	51.02					

Age 7 Months

	Treatment			
Replication	0.5 ETc	0.75 ET	1.0 ETc	1.2 ETc
1	1.40	1.42	1.41	1.36
2	1.38	1.30	1.40	1.37
3	1.37	1.40	1.37	1.32
4	1.45	1.37	1.40	1.39
5	1.46	1.42	1.35	1.39

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.01	0.002	1.50	0.264	
Treatment	3.0	0.00	0.002	1.24	0.338	ns
Error	12.0	0.02	0.001			
Total	19.0	0.03				
% CV	2.56					

Age 8 Months

	Treatment			
Replication	0.5 ETc	0.75 ET	1.0 ETc	1.2 ETc
1	1.27	1.31	1.26	1.26
2	1.27	1.18	1.32	1.32
3	1.20	1.26	1.27	1.25
4	1.32	1.33	1.25	1.32
5	1.32	1.29	1.25	1.24

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.01	0.002	0.77	0.564	
Treatment	3.0	0.00	0.000	0.06	0.982	ns
Error	12.0	0.03	0.002			
Total	19.0	0.04				
% CV	3.84					

Age 9 Months

	Treatment			
Replication	0.5 ETc	0.75 ET	1.0 ETc	1.2 ETc
1	1.01	1.05	1.02	1.16
2	1.06	0.96	1.24	1.26
3	1.10	1.01	1.20	1.15
4	1.17	1.25	1.12	1.16
5	1.12	1.23	1.20	1.17

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.04	0.010	1.32	0.317	
Treatment	3.0	0.03	0.009	1.29	0.323	ns
Error	12.0	0.09	0.007			
Total	19.0	0.15				
% CV	7.55					

Age 10 Months

	Treatment			
Replication	0.5 ETc	0.75 ET	1.0 ETc	1.2 ETc
1	1.05	0.83	1.30	1.20
2	1.08	1.06	0.95	1.06
3	0.89	1.08	1.11	1.06
4	1.33	1.09	0.88	1.08
5	1.11	1.03	0.90	1.10

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.02	0.004	0.19	0.940	
Treatment	3.0	0.03	0.009	0.40	0.753	ns
Error	12.0	0.27	0.022			
Total	19.0	0.31				
% CV	14.10					

B. First ratoon

Age 3 Months

	Treatment			
Replication	0.5 ETc	0.75 ET	1.0 ETc	1.2 ETc
1	1.13	1.18	1.23	1.22
2	1.14	1.17	1.20	1.15
3	1.21	1.18	1.19	1.15
4	1.11	1.24	1.31	1.35
5	1.13	1.17	1.36	1.29

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.02	0.006	1.71	0.212	
Treatment	3.0	0.04	0.013	3.81	0.040	*
Error	12.0	0.04	0.003			
Total	19.0	0.10				
% CV	4.76					

Age 4 Months

	Treatment			
Replication	0.5 ETc	0.75 ET	1.0 ETc	1.2 ETc
1	0.65	0.54	0.56	0.64
2	0.66	0.58	0.63	0.56
3	0.48	0.58	0.58	0.52
4	0.55	0.50	0.54	0.48
5	0.50	0.62	0.47	0.49

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.03	0.007	2.39	0.109	
Treatment	3.0	0.00	0.001	0.29	0.835	ns
Error	12.0	0.04	0.003			
Total	19.0	0.07				
% CV	10.00					

Age 5 Months

	Treatment			
Replication	0.5 ETc	0.75 ET	1.0 ETc	1.2 ETc
1	0.91	1.18	0.86	1.15
2	1.06	0.95	0.81	0.97
3	0.79	0.98	1.14	0.85
4	1.19	1.08	1.09	1.07
5	0.89	0.92	0.86	0.89

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.40	0.100	3.73	0.034	
Treatment	3.0	0.22	0.075	2.78	0.087	ns
Error	12.0	0.32	0.027			
Total	19.0	0.95				
% CV	17.57					

Age 6 Months

	Treatment			
Replication	0.5 ETc	0.75 ET	1.0 ETc	1.2 ETc
1	1.28	1.38	1.41	1.33
2	1.38	1.37	1.45	1.35
3	1.36	1.34	1.42	1.33
4	1.33	1.33	1.36	1.29
5	1.37	1.43	1.34	1.29

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.01	0.002	1.39	0.295	
Treatment	3.0	0.02	0.006	4.17	0.031	*
Error	12.0	0.02	0.001			
Total	19.0	0.04				
% CV	2.71					

Age 7 Months

	Treatment			
Replication	0.5 ETc	0.75 ET	1.0 ETc	1.2 ETc
1	1.09	1.29	1.08	1.22
2	1.15	1.19	1.21	1.12
3	1.22	1.23	1.07	1.11
4	1.22	1.15	1.10	1.24
5	1.26	1.30	1.22	1.14

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.01	0.003	0.68	0.617	
Treatment	3.0	0.02	0.008	1.71	0.218	ns
Error	12.0	0.06	0.005			
Total	19.0	0.09				
% CV	5.86					

Age 8 Months

	Treatment			
Replication	0.5 ETc	0.75 ET	1.0 ETc	1.2 ETc
1	1.13	1.23	1.15	1.24
2	1.12	1.14	1.22	1.17
3	0.98	1.22	1.10	1.15
4	1.16	1.00	1.23	1.03
5	1.14	1.14	1.14	1.20

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.02	0.005	0.81	0.545	
Treatment	3.0	0.01	0.004	0.61	0.620	ns
Error	12.0	0.07	0.006			
Total	19.0	0.10				
% CV	6.79					

Appendix 6.4 (Continued)

C: Second ratoon

Age 2 Months

	Treatment			
Replication	0.5 ETc	0.75 ET	1.0 ETc	1.2 ETc
1	0.02	0.91	0.05	0.03
2	0.03	0.02	0.06	0.05
3	0.09	0.00	0.75	0.05
4	0.75	0.91	0.00	0.06
5	0.01	0.04	0.05	0.01

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.00	0.001	0.24	0.911	
Treatment	3.0	0.00	0.001	0.60	0.626	ns
Error	12.0	0.03	0.002			
Total	19.0	0.04				
% CV	5.84					

Age 3 Months

	Treatment			
Replication	0.5 ETc	0.75 ET	1.0 ETc	1.2 ETc
1	0.02	0.90	0.04	0.79
2	0.02	0.01	0.05	0.04
3	0.00	0.02	0.75	0.05
4	0.74	0.90	0.00	0.06
5	0.00	0.04	0.05	0.00

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.00	0.000	0.06	0.992	
Treatment	3.0	0.01	0.002	0.73	0.555	ns
Error	12.0	0.03	0.002			
Total	19.0	0.03				
% CV	5.87					

Age 4 Months

	Treatment			
Replication	0.5 ETc	0.75 ET	1.0 ETc	1.2 ETc
1	0.90	0.70	0.00	0.95
2	0.95	1.01	0.75	0.00
3	0.99	0.97	0.72	0.70
4	1.02	0.99	0.04	0.00
5	0.00	0.94	1.01	0.93

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.01	0.003	0.31	0.863	
Treatment	3.0	0.03	0.011	1.04	0.410	ns
Error	12.0	0.12	0.010			
Total	19.0	0.17				
% CV	11.19					

Age 5 Months

	Treatment			
Replication	0.5 ETc	0.75 ET	1.0 ETc	1.2 ETc
1	1.13	1.23	1.42	1.37
2	1.13	1.27	1.19	1.35
3	1.27	1.10	1.35	1.27
4	1.23	1.21	1.34	1.36
5	0.90	1.10	1.34	1.31

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.03	0.008	1.00	0.445	
Treatment	3.0	0.14	0.047	6.06	0.009	**
Error	12.0	0.09	0.008			
Total	19.0	0.26				
% CV	7.02					

Age 6 Months

	Treatment			
Replication	0.5 ETc	0.75 ET	1.0 ETc	1.2 ETc
1	1.21	1.19	1.08	1.21
2	1.24	1.01	1.29	1.30
3	1.26	1.36	1.36	1.43
4	1.21	1.27	1.17	1.34
5	1.47	1.31	1.32	1.23

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.10	0.024	2.59	0.091	
Treatment	3.0	0.02	0.006	0.60	0.629	ns
Error	12.0	0.11	0.009			
Total	19.0	0.22				
% CV	7.64					

Age 7 Months

	Treatment			
Replication	0.5 ETc	0.75 ET	1.0 ETc	1.2 ETc
1	1.20	1.31	1.15	1.15
2	1.10	1.27	1.10	1.11
3	1.29	1.22	0.06	1.24
4	1.03	1.29	1.35	1.20
5	1.33	1.15	1.30	1.19

Analysis of variance

Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4.0	0.02	0.006	0.31	0.866	
Treatment	3.0	0.02	0.006	0.36	0.783	ns
Error	12.0	0.21	0.018			
Total	19.0	0.25				
% CV	11.15					

Appendix 6.5 Effects of irrigation regimes on root density (mg cm^{-3}) distribution.

a) First Ratoon

		Distance from the center of the cane row (m)				
Treatment:	Depth	0.75m	0.375m	0m	0.375m	0.75m
0.50 ETc	0-10	0.25	0.56	1.67	0.25	0.13
	10-20	0.03	0.23	1.24	0.30	0.15
	20-30	0.26	0.24	0.78	0.22	0.10
	30-40	0.12	0.14	0.49	0.15	0.16
	40-50	0.07	0.05	0.43	0.28	0.14
	50-60	0.15	0.08	0.24	0.05	0.08
		0.75m	0.375m	0m	0.375m	0.75m
0.75 ETc	0-10	0.25	0.46	2.27	0.23	0.30
	10-20	0.13	0.40	1.76	0.13	0.16
	20-30	0.12	0.55	1.01	0.26	0.15
	30-40	0.08	0.29	0.75	0.14	0.05
	40-50	0.05	0.12	0.21	0.18	0.02
	50-60	0.00	0.05	0.54	0.05	0.16
		0.75m	0.375m	0m	0.375m	0.75m
1.0 ETc	0-10	0.17	0.20	1.75	0.26	0.21
	10-20	0.15	0.25	0.90	0.21	0.09
	20-30	0.10	0.09	0.41	0.20	0.10
	30-40	0.11	0.07	0.50	0.13	0.02
	40-50	0.06	0.07	0.08	0.12	0.03
	50-60	0.10	0.06	0.09	0.29	0.04
		0.75m	0.375m	0m	0.375m	0.75m
1.2 ETc	0-10	0.22	0.45	1.22	0.19	0.10
	10-20	0.14	0.30	0.85	0.32	0.19
	20-30	0.13	0.11	0.75	0.33	0.10
	30-40	0.07	0.19	0.25	0.18	0.01
	40-50	0.02	0.11	0.07	0.12	0.03
	50-60	0.03	0.18	0.08	0.04	0.04

Appendix 6.5 (Continued)

b) Second Ratoon

		Distance from center of cane row (m)				
Treatments	Depth (m)	0.75m	0.375m	0m	0.375m	0.75m
0.5ETc	0-10	1.25	1.31	4.70	1.13	0.56
	10-20	0.69	0.55	2.99	0.44	0.21
	20-30	0.60	0.68	1.87	0.37	0.32
	30-40	0.46	0.28	0.97	0.38	0.31
	40-50	0.46	0.22	0.96	0.18	0.08
	50-60	0.57	0.07	0.79	0.35	0.02
	60-70	0.25	0.07	0.57	0.23	0.11
	70-80	0.08	0.00	0.23	0.07	0.05
	80-90	0.00	0.00	0.03	0.00	0.02
		0.75m	0.375m	0m	0.375m	0.75m
0.75 ETc	0-10	1.18	0.78	2.51	1.26	0.44
	10-20	0.90	0.35	2.62	1.08	0.32
	20-30	0.48	0.26	0.43	0.61	0.18
	30-40	0.59	0.03	0.68	0.26	0.35
	40-50	0.24	0.01	0.49	0.43	0.13
	50-60	0.18	0.02	0.99	0.14	0.00
	60-70	0.04	0.01	0.07	0.06	0.00
	70-80	0.06	0.02	0.07	0.08	0.00
	80-90	0.01	0.00	0.00	0.00	0.00
		0.75m	0.375m	0m	0.375m	0.75m
1.0 ETc	0-10	0.86	0.31	4.06	1.68	0.28
	10-20	0.47	0.23	2.38	0.80	0.45
	20-30	0.22	0.19	0.63	0.71	0.17
	30-40	0.34	0.20	0.66	0.40	0.19
	40-50	0.13	0.12	0.30	0.54	0.09
	50-60	0.08	0.45	0.45	0.11	0.01
	60-70	0.23	0.11	0.23	0.18	0.00
	70-80	0.15	0.12	0.12	0.02	0.00
	80-90	0.06	0.01	0.08	0.00	0.00
		0.75m	0.375m	0m	0.375m	0.75m
1.2 ETc	0-10	0.98	0.72	4.77	1.35	0.76
	10-20	0.27	0.26	3.06	0.71	0.36
	20-30	0.34	0.18	1.38	0.88	0.33
	30-40	0.45	0.32	1.19	0.40	0.64
	40-50	0.29	0.17	0.52	0.18	0.22
	50-60	0.26	0.24	0.72	0.17	0.11
	60-70	0.21	0.14	1.75	0.23	0.12
	70-80	0.10	0.05	0.39	0.15	0.08

Appendix 7.1 Analysis of variance table for cane yield (t ha^{-1}) in plant, first and second ratoon cane.

a) Plant Crop

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	102.46	100.09	109.96	109.48
2	97.87	83.96	98.17	105.24
3	99.71	96.95	104.94	102.36
4	105.51	101.58	121.21	117.68
5	106.62	113.38	113.66	120.47

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	820.94	205.24	10.83	0.0006	
Treatment	3	483.22	161.07	8.50	0.0027	**
Error	12	227.33	18.95			
Total	19					
% CV	4.12					

b) First Ratoon

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	108.10	115.70	113.00	124.20
2	106.10	108.70	114.20	104.50
3	116.30	100.40	114.30	149.00
4	122.50	100.00	116.40	118.10
5	120.80	108.10	113.00	113.80

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	291.6	72.9	0.8	0.6	
Treatment	3	448.8	149.6	1.5	0.3	ns
Error	12	1172.1	97.7			
Total	19					
% CV	8.61					

c) Second Ratoon

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	85.00	112.80	101.00	130.00
2	109.20	96.50	103.00	127.20
3	97.80	99.50	106.10	142.10
4	104.30	109.20	108.40	129.40
5	120.50	102.90	126.90	145.80

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	694.90	173.73	2.34	0.1145	
Treatment	3	3324.98	1108.33	14.90	0.0002	**
Error	12	4912.20	74.36			
Total	19					
% CV	7.64					

Appendix 7.2 Analysis of variance table for cane quality (sucrose %) in plant, first and second ratoon cane

a) Plant crop

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	15.06	16.65	16.60	13.54
2	15.54	15.60	16.08	15.33
3	15.85	16.23	15.54	15.62
4	16.25	15.79	15.87	15.66
5	15.82	16.41	15.31	16.08

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	0.57	0.14	0.29	0.88	
Treatment	3	2.11	0.70	1.43	0.28	ns
Error	12	5.88	0.49			
Total	19					
% CV	4.45					

b) First Ratoon

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	15.06	15.65	15.60	13.54
2	15.54	15.60	16.08	15.33
3	15.85	16.23	15.54	15.62
4	16.25	15.79	15.87	15.66
5	15.82	16.41	15.31	16.08

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	2.50	0.62	2.41	0.11	
Treatment	3	1.20	0.41	1.60	0.24	ns
Error	12	3.10	0.26			
Total	19					
% CV	3.25					

c) Second Ratoon

	Treatment			
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	15.57	16.24	15.57	14.94
2	15.91	16.24	16.17	15.50
3	15.78	15.78	16.06	16.31
4	15.05	15.29	15.49	15.43
5	15.87	14.80	15.73	14.75

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	1.79	0.45	2.57	0.09	
Treatment	3	0.46	0.15	0.87	0.48	ns
Error	12	2.10	0.18			
Total	19					
% CV	2.68					

ppendix 7.3 Analysis of variance tables for cane sucrose yield (t ha^{-1}) in the plant, first and second ratoon cane.

a) Plant crop

	Treatment			
plication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	15.43	16.67	18.25	14.82
2	15.21	13.10	15.79	16.13
3	15.80	15.73	16.31	15.99
4	17.15	16.04	19.24	18.43
5	16.87	18.60	17.40	19.37

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	25.04	6.26	4.77	0.02	
Treatment	3	6.71	2.24	1.71	0.22	ns
Error	12	15.74	1.31			
Total	19					
% CV	6.89					

b) First Ratoon

	Treatment			
plication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	16.29	18.10	17.63	16.81
2	16.49	16.95	18.37	16.03
3	18.44	16.30	17.76	23.27
4	19.91	17.36	18.48	18.50
5	19.10	17.73	17.30	18.29

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	11.66	2.92	1.05	0.42	
Treatment	3	4.23	1.41	0.51	0.68	ns
Error	12	33.27	2.77			
Total	19					
% CV	9.27					

c) Second Ratoon

	Treatment			
plication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	13.24	18.32	15.73	19.41
2	17.37	15.67	16.65	19.71
3	15.43	15.71	17.04	23.17
4	15.70	16.69	16.79	19.97
5	19.12	15.23	19.96	21.50

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	11.59	2.90	1.02	0.044	
Treatment	3	68.65	22.88	8.03	0.003	**
Error	12	34.18	2.85			
Total	19					
% CV	9.58					

ppendix 7.4 Analysis of variance table for % flowered stalk in first and second ratoon cane

A) First Ratoon

Treatment				
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	90	90	80	100
2	50	70	60	80
3	70	60	50	70
4	50	60	80	50
5	90	90	50	60

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	2350	587.5	2.7	0.1	
Treatment	3	280	93.3	0.4	0.7	ns
Error	12	2570	214.2			
Total	19	2387				
% CV	36.3					

B) Second Ratoon

Treatment				
Replication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	50	60	50	40
2	50	70	60	50
3	60	60	70	40
4	40	30	60	50
5	60	30	70	60

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	470	117.5	0.8	0.5	
Treatment	3	580	193.3	1.3	0.3	ns
Error	12	1770	147.5			
Total	19	2820				
% CV	22.92					

ppendix 7.5 Analysis of variance table for crop water use efficiency, t ha^{-1} $(100\ mm)^{-1}$ in plant, first and second ratoon cane.

a) Plant Crop

	Treatment			
plication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	12.27	11.49	12.65	12.37
2	11.72	9.64	11.29	11.89
3	11.94	11.13	12.07	11.56
4	12.64	11.67	13.94	13.30
5	12.77	13.02	13.07	13.61

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	11.21	2.80	10.44	0.0007	
Treatment	3	17.51	5.84	21.73	0.0000	**
Error	12	3.22	0.27			
Total	19					
% CV	4.18					

b) First Ratoon

	Treatment			
plication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	14.20	15.56	15.84	18.33
2	13.93	14.63	16.01	15.43
3	15.27	13.52	16.02	21.99
4	16.08	14.80	16.32	17.43
5	15.85	14.54	15.84	16.79

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	2.00	0.70	0.78	0.560	
Treatment	3	20.81	6.94	7.72	0.004	**
Error	12	10.79	0.90			
Total	19					
% CV	8.09					

c) Second Ratoon

	Treatment			
plication	0.5 ETc	0.75 ETc	1.0 ETc	1.2 ETc
1	12.94	13.86	10.37	12.52
2	16.61	11.86	10.57	12.25
3	14.89	12.23	10.88	13.69
4	15.88	13.41	11.12	12.47
5	18.33	12.64	13.02	14.04

Analysis of variance						
Source of variation	df	ss	ms	F-value	Prob	Sign
Replication	4	10.28	2.57	1.95	0.1665	
Treatment	3	53.57	17.86	13.56	0.0004	**
Error	12	15.81	1.32			
Total	19					
% CV	8.71					

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