EVALUATION OF SPRINKLER IRRIGATION PERFORMANCE AT SIMUNYE SUGAR ESTATE IN SWAZILAND

BY

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ABSTRACT

The study evaluated the performance of the sprinkler irrigation system at Simunye, in Swaziland. The specific objectives were: (1) To identify the original design parameters, (2) To investigate performance parameters, whether the system is operating as designed, and (3) To recommend suitable changes in the operation and system configurations that could be implemented to improve the irrigation efficiency.

The results showed that there were no available design parameters on which the system of Simunye Sugar Estate was designed. The system showed a uniformity coefficient (Cu) of 76%, which is within the recommended Cu range for design market acceptance. The Distribution uniformity obtained was 61% and the potential application efficiency for the low-quarter (PELQ) was found to be 54%. Both of these parameters were lower than the recommended ones, and they were significantly different when compared with the recommended ones of at least 67% and 75-85%, respectively. The actual application efficiency for the lower-quarter (AELQ) was found to be 45% which is too low when compared to the PELQ. The minimum basic infiltration rate of the soils irrigated by sprinkler system was 5 mm/h.

Factors which contributed to the non-uniformity of the system were wind velocity and wind direction, the operating pressure (which was too high or lower than the recommended one for the system), evaporation losses, and the sprinkler spacing. From the results it was shown that management of the irrigation system had an effect on the poor performance of the system.

DECLARATION

I, Bongani Harmon Magongo, hereby declare to the Senate of Sokoine University Of Agriculture that this dissertation has not been submitted for any degree award in any other university.

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Finally, my sincere thanks to the British Council whose financial assistance made the completion of the study possible.

DEDICATIONS

I dedicate this work to the sweet and loving memory of my sister.

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ABBREVIATIONS AND SYMBOLS

A = application rate

AELH = actual application efficiency of the lower-half

AELQ = actual application efficiency of lower-quarter

$\overline{AELQ}$ = average actual application efficiency of lower-quarter

α = constant which depend on the soil and initial conditions

ASAE = American Society of Agricultural Engineers

Cu = Coefficient of uniformity

$\overline{Cu}$ = average coefficient of uniformity

Du = Distribution uniformity

$\overline{Du}$ = average distribution uniformity

DU = duplex soil series

Drz = Root zone depth

Σ = Summation

ER = efficiency reduction

f = infiltration rate

Fc = Field capacity

ha = hectare

Ho = Homestead soil series

k = constant which depend on the soil and initial conditions

Km = kilometres

kPa = kilopascal

Abbreviations and Symbols cont..

l/s = litres per second

M = mean depth of observation

m = meters

MAD = maximum allowed deficit

m/s = meters per second

mm = millimetres

mm/h = millimetres per hour

n = number of tests

N = number of observations

^{0}C = degrees celsius

PELQ = Potential application efficiency of lower-quarter

$\overline{PELQ}$ = average potential application efficiency of lower-quarter

q = sprinkler discharge

RE = effective portion of applied water

Ro = Rondspring soil series

SD = standard deviation

S_l = sprinkler spacing along the lateral

S_m = lateral shift distance

Sk = Sikutane soil series

SMD = Soil moisture deficit

SUA = Sokoine University of Agriculture

t = time after infiltration starts

Th = Thorburn soil series

Abbreviations and Symbols cont..

Θ = Soil moisture content measured at that particular time

Tm = Tambankulu soil series

Ts = Tshaneni soil series

Trans. = Transaction

UECWA = United economic commission for western Asia

UNISWA = University of Swaziland

Vs = versus

X = Absolute deviation of the individual observation from the mean

1. INTRODUCTION

Performance of irrigated agriculture is causing concern in many areas of the world. Many irrigation systems, both surface and sprinkler, are poorly adopted to the soil and topography. Intake rates and water-holding capacities of the soil often are not known before a field is laid out for irrigation (Criddle et al, 1959). Uniformity coefficients are parameters describing overall system performance (Fischer and Wallender 1988). The correct timing and amount of water application is critical for efficient irrigation (Bowman et al, 1991). For a given level of irrigation uniformity there is a trade-off between the amount of water applied and the area that receives some target amount of water (Clemmen, 1991). In most schemes more water is delivered per unit area than is required, leading to low irrigation efficiencies (Samad et al, 1992). It has been well demonstrated that the uniformity of irrigation water application has an effect on crop yield (Hunsaker and Bucks, 1987; Solomon, 1984).

Lack of suitable technical criteria to find out the optimal design of on-farm channel has led to the poor efficiencies of many irrigation schemes (Paudyal et al, 1991). All irrigation methods are inherently nonuniform in their application of water. If an abundant supply of water is available, the usual tendency is to apply more water

than needed on average to assure that parts of the field receive an adequate amount. In some cases, this can lead to waterlogging and salinity problems (Clemmen, 1991). According to the civil drawing officer at Simunye Sugar Estate, the fields in the estate performed very well for the first seven years, there-after yield declined and waterlogging was observed. The estate has to install drainage pipes in at least fifteen fields every year.

Measures of irrigation efficiency represent indicators that may be used to assess the performance of irrigation systems. Irrigation efficiencies are arguably the most widely used performance measures among many irrigation specialists (Small, 1992).

At Simunye, sugar cane grown under sprinkler irrigation has produced uneven growth especially in years of low rainfall during the phase of rapid stalk elongation in summer (Simunye sugar estate agronomy department annual report 1993). Water for agriculture is one of the most costly inputs in agriculture and unless scientific water management techniques are adopted, full benefits from costly irrigation projects cannot be reaped (Rydzewski, 1977). At Simunye about 15% of the total production costs is from irrigation.

With each irrigation method, there are many factors that cause irrigation to be nonuniform. With the available methods, it is very difficult to quantify the effects of each of these factors on the irrigation uniformity (Clemmen, 1991). A system evaluation is necessary to measure and show the effectiveness of available irrigation practices (Merriam and Keller, 1978). Thus, in many areas of the world, performance of sprinkler irrigation systems must be improved in order to save water and energy (Jose et al,1992). This generally requires an improvement in the management and application of water (Fischer and Wallender, 1988).

Based on the earlier facts, there is a need to conduct a thorough research on the evaluation of the performance of a sprinkler system. Consequently, the main objective of this research was to evaluate the performance of sprinkler system at Simunye sugar estate in Swaziland. The specific objectives are:

1. To identify design parameters in the original plan
2. To investigate performance of the system.
3. To recommend suitable changes in the operation and system configurations for improving the performance of sprinkler irrigation system.

2. LITERATURE REVIEW

2.1 Introduction

Evaluation is the analysis of any irrigation system based on measurement taken in the field under the conditions and practices normally used (Merriam and Keller,1978). Evaluations are useful in a number of analyses and operations, particularly those that are essential to improve management and control of irrigation system. Evaluation data can be controlled periodically from the system to refine management practices and identify the changes in the field that occur over the irrigation season or from year to year. This type of study is necessary to provide direction to management in deciding whether to improve them. Improved management of water on the farm may conserve water, labour,and soil, and may also increase yields of crops.

Performance is affected by irrigation water management and design of the system. Poor water management and poor design can cause several problems which are environmental and health related. Besides management and design, other indicators of performance and the factors influencing it should be considered in order to evaluate sprinkler irrigation. Consequently, this chapter reviews (1) water management and design as they bring about environmental

and health hazards, (2) indicators of performance, and (3) factors influencing performance.

2.2 Water management and design

Poor water management and poor design of irrigation system can bring about environmental and health hazards.

2.2.1 Environmental hazards

Irrigation creates changes in all the major ecosystem regimes (soil, water and atmosphere) which may have undesirable consequences leading to desertification, unless appropriate counter-measures are incorporated into the system (Obeng,1977). Irrigation also interferes with the prevalent soil regime by introducing moisture in a quantity and sometimes quality which modifies the arid and semi-arid ecosystems.

Losses of irrigation water

Losses of water are basically due to evaporation and seepage and those occurring during the operation of the sprinkler system. According to Holy (1977) losses by evaporation from open water surface are considerable, for in arid zones potential evaporation is significantly higher than rainfall. The value of seepage from canals varies considerably, depending on climatic, soil conditions, the density, and length of the conveyance and

distribution systems. Yet it is evident that losses are large, and to prevent them canals have to be lined. The type of lining is selected within a view to the required effect and with regard to costs.

The United Economic Commission for Western Asia (1980) observed that the irrigation water was not applied scientifically or with adequate efficiency. The actual average water used per cropped hectare in the united nations economic commission for western Asia region averaged 13,400 m^3 against an optimum of 7,500 m^3, assuming rational water use throughout the region. Both the efficiency of conveyance and field application were low. In all countries the conveyance losses were high and the amounts of water applied to the field far exceeded the acceptable limits.

Waterlogging and soil salinity

Waterlogging is a common feature of the majority of the irrigation systems around the world. The speed of rise of the ground water level in irrigated fields may be in some cases rapid, reaching several meters a year, but usually it is measured in several centimetres a year. In any case, the process is inevitable whenever drainage is inadequate.

In most cases, and especially in large plains, the water table is considerably raised by irrigation, and capillarity starting from the higher ground water level causes waterlogging and accumulation of salts both in ground water and in the soil near the surface. In these instances complete control of ground water and soil moisture regimes in the soil has to be achieved with effective drainage systems.

Extensive areas of the presently irrigated land suffer from waterlogging, and yields of crops under such conditions are very low compared to the potential yields. According to El Gabaly (1977) in Pakistan, out of a total of 37 million acres of irrigated land about 27 million acres suffer from salinity, waterlogging or both to varying degrees with a pronounced reduction in the yield of the main crops. In Syria about 50% of the irrigated land in the Euphrates valley is seriously affected by salinity and waterlogging and losses to the main crops amount to 300 million dollars.

Irrigation systems that apply water over the entire area (flooding and sprinkling) typically cause a relatively uniform increase in soil salinity with depth to the bottom of the root zone, providing leaching is not excessive and application is relatively uniform. All water for

irrigation contains some salts. Most irrigation water originates as rainfall which percolates through the soil towards the rivers, collecting salts on its way (Smedema and Rycroft, 1988). If the irrigation frequency is low or if evaporation from the soil surface is high, soil salinity, particularly near the soil surface, increases with time between irrigations. Salt accumulation can also vary widely with a given field if soil hydraulic conductivity, uniformity of water application, or crop water extraction differs (Hoffman et al. 1983).

Salinisation generally refers to the development of a non-salt soil into a salty soil, and especially to the development of a non-saline soil into a saline soil (Smedema and Rycroft, 1988). One mechanism of soil salinisation that has been studied extensively is that related to water movement from an underlying aquifer. The salinisation is caused by discharge of both water and salts to the surface of the affected area from an aquifer receiving recharge from zones at higher elevations (Stolte et al., 1992). Hendry et al. (1990) found that soil salinity was not only related to underlying aquifers nor to seepage from up-slope positions in the basin, but associated with the rise of the water-table whether due to high salts in the ground water or to dissolving solid salts in the soil by rising fresh ground water.

Waterlogging within the irrigated area and salt accumulation under the neighbouring fields are the results of hydrological processes modified by irrigation in the soil-moisture zone and in the ground water space. Kovas (1977) cited the case of New south wales and Kom Ombo areas where irrigation was introduced on higher terrains which resulted in rapid deterioration of the lower lying lands. For the protection of the arable lands against these destructive effects the irrigation schemes have to be supplemented with drainage systems wherever the natural drainage of the area is inadequate.

2.2.2 Health hazards

The ecological changes create conditions for foreign plants and insect species, including the vectors of malaria and schistosomiasis. According to Obeng (1977) one population infected with schistosomiasis increased from 2 to 75 percent when perennial irrigation was introduced. Serving as a transfer medium and a habitat for vectors and intermediate hosts, water can carry toxic chemicals and many communicable disease. Very often, the negative effects of irrigation are related to wrong irrigation practices and can be alleviated by appropriate management. According to Nahal (1980) case studies of the Greater Massayeb project in Iraq and the Mona Experimental Reclamation project in Pakistan have revealed that the

transmission of water-related diseases such as schistosomiasis, malaria and typhoid fever is accentuated by mismanagement of irrigation water resulting in the formation of stagnant pools. Malaria and schistosomiasis pose serious health problems. Therefore, it is necessary that close collaboration should be established between irrigation and health authorities at an early stage of the project life.

Pollution resulting from the drainage of agricultural lands and urban areas should be of concern. According to Sylvester et al. (1963) as cited by Gloyna (1965) it has been found that irrigation return flows, rather than industrial waste and domestic sewage discharges, were the major factors influencing the over-all water quality of the Yakima river basin.

2.3 Indicators of performance

Irrigation systems and operations need to be measured to estimate the design potential efficiency of the systems and the actual efficiency that is obtained with present management. To avoid confusion with certain similar but more general terms, three important terms used frequently in earlier text have been adopted in this study as they are renamed by Merriam and Keller (1978). Irrigation system efficiency, actual application efficiency, and

distribution efficiency are thus called potential application efficiency of low quarter, actual application efficiency of low quarter and distribution uniformity, respectively. consequently, the indicators of performance include coefficient of uniformity, distribution uniformity, potential application efficiency of low quarter, and application efficiency of low quarter.

2.3.1 Coefficient of uniformity

The coefficient of uniformity (Cu) is an index of application uniformity that has been developed to characterise sprinkler irrigation and is calculated as follows (James et al., 1982):

$$Cu = (1.0 - \frac{\Sigma X}{M \cdot N}) * 100 \quad \text{---------- (2.1)}$$

Where Cu = Christiansen's coefficient of uniformity in percent

X = absolute deviation of the individual observations from the mean

M = mean depth of observations

N = number of observations

The uniformity of application describes how evenly an irrigation system distributes water over a field. Most agricultural sprinkler systems require a Cu value of at

least 80% for market acceptance (Martin-Bernito et al., 1982). James et al. (1982) recommended a Cu of 80% (without air movement), which could vary from 70 to 90% if there is wind for market acceptance. Low Cu values often indicate an incorrect combination of nozzle number and size, operating pressure and spacing (James et al., 1982; Martin-Bernito et al., 1992). A value of Cu equalling 100% means that irrigation is completely uniform (Vories and Von Bernuth, 1986). This value is unattainable in practice, but values of up to 95% have been obtained. In Israel a Cu of 84% is considered acceptable for design purposes. Lower values may be acceptable if the design area has ample rainfall during the irrigation season or if costs are reduced sufficiently to offset any reduction in the returns from crop yields (Benami and Ofen 1983).

2.3.2 Distribution uniformity

Distribution uniformity (Du) is the ratio of the average LQ depth of irrigation water infiltrated (or caught) to the average depth of irrigation water infiltrated (or caught), expressed as a percent. Du indicates the magnitude of distribution problems. A low Du value indicates that losses due to deep percolation are excessive (and that the water table is likely to be high) if adequate irrigation is applied to all areas. Although the concept of a low Du is relative, values less than 67%

are generally considered as unacceptable. However, if deep percolation is limited by reducing the applied depth and the value is low, any area that receives the low quarter depth of irrigation will be seriously under-irrigated (Merriam and Keller 1978). Du can be estimated by using the following equation:

$$Du = \left(\frac{\text{average of low quarter catch}}{\text{average catch}}\right) * 100 \text{ ---------- (2.2)}$$

2.3.3 Potential application efficiency of low-quarter

Potential application efficiency (PELQ) is the efficiency, expressed as a percent, that is obtained when the average LQ depth of irrigation water infiltrated and stored just equals management allowed deficit (MAD). PELQ is a measure of how well the system can apply water if management is optimal. The difference between PELQ and AELQ is a measure of management operations. Low PELQ values indicate design problems. This is the only efficiency term that is used to compare systems or methods. PELQ is also used in design to calculate the gross depth of water to apply per irrigation set. It indicates how effectively a given sprinkler system can apply water under optimum management neglecting prenozzle losses and leaving about 1/8 of the area under-irrigated. The PELQ also indicates how efficiently the tested system can apply water if the system is run at the

correct duration to just satisfy the MAD. PELQ can be estimated using the following equation:

$$PELQ = \left(\frac{\text{average LQ rate of water caught}}{\text{avg. rate applied through sprinklers}}\right) * 100 \text{ ------ (2.3)}$$

2.3.4 Actual application efficiency of low-quarter

Actual application efficiency of low-quarter (AELQ) is the ratio of the average low-quarter (LQ) depth of irrigation water infiltrated and stored in the root zone to the average depth of irrigation water applied (calculated from nozzle discharge for sprinkler systems), expressed as a percent. The average LQ depth infiltrated is the average of the lowest one-fourth of the measured values where each value represents an equal unit of area and cannot exceed the SMD. SMD is expressed numerically as a depth (mm) indicating the dryness of the root zone at the time of measurement. This depth is identical to the depth of water to be replaced by irrigation under normal management. According to Walker and Skogerboe (1987) SMD can be estimated using the following equation:

$$SMD = (Fc-\theta) * Drz \text{ ---------- (2.4)}$$

Where

SMD = soil moisture deficit

Fc = field capacity

Θ = soil moisture content measured at that particular time

Drz = depth of the root zone

The SMD is the depletion of soil moisture below field capacity at the time a particular soil moisture content is measured

Table 2.1 Soil moisture content at field capacity and permanent wilting point, and the total available water.

Soil texture	Field capacity (Fc) (%by vol.)	Permanent wilting (pwp) (% by vol.)	Total available water Percent by volume (v)	Total available water av. (0.10) (Qv) (mm/cm)
Sandy	15 (10-20)	7 (3-10)	8 (6-10)	0.8 (0.7-1.0)
Sandy loam	21 (15-27)	9 (6-12)	12 (9-15)	1.2 (0.9-1.5)
Loam	31 (25-36)	14 (11-17)	17 (14-20)	1.7 (1.4-1.9)
Clay loam	36 (31-42)	18 (15-20)	18 (16-22)	1.9 (1.7-2.2)
Silt clay	40 (35-46)	20 (17-22)	20 (18-23)	2.1 (1.8-2.3)
Clay	44 (39-49)	21 (19-24)	23 (20-25)	2.3 (2.0-2.5)

Source: Hansen and Israelson (1979) *Irrigation principles and practice*. John Wiley & sons, Inc. New york.

Values of AELQ indicate both the uniformity of water distribution and adequacy of irrigation. When the LQ depth value is less than the SMD or the desired MAD, under-irrigation is indicated. The numerical value of the LQ average depth indicates the adequacy of the irrigation (Merriam et al 1983). AELQ can be estimated by using the following equation:

$$AELQ = \left(\frac{\text{avg. LQ depth of water infiltrated } \wedge \text{ stored}}{\text{average depth of wated applied}}\right) * 100 \text{ --- (2.5)}$$

When the average low quarter depth of irrigation water infiltrated exceeds the SMD, which is the storage capacity of the root zone, AELQ can be expressed as follows

$$AELQ = \left(\frac{SMD}{\text{average depth of water applied}}\right) * 100 \text{ ---------- (2.6)}$$

Whenever the irrigation exactly satisfies the SMD in the least watered areas, AELQ equals PELQ (Merriam and Keller (1978). But if excess water is applied, much of it may percolate beyond the root zone and be lost, this would result in an AELQ considerably less than the PELQ.

Application efficiency of the low quarter is given by the Soil conservation service (1972) as:

$$AELQ = Du * RE \quad \text{---------- (2.7)}$$

where

Du = distribution uniformity

RE = effective portion of applied water

This equation relates irrigation efficiency and some measure of uniformity. When the SMD is divided by AELQ to estimate the gross depth of irrigation only about 10% of the area will remain below field capacity. Conversely, about 90% of the area will be adequately irrigated and receive varying amounts of over-irrigation. This is practical for medium to high value field and forage crops. For such crops an application efficiency based on the average low-half depth is more appropriate. Application efficiency of the low half (AELH) can be estimated by using the following equation (Soil conservation service,1972).

$$AELH = Cu * RE \quad \text{---------- (2.8)}$$

The soil conservation service (1972) developed a guide for estimating the effective portion of the applied water which reaches the soil plant surface (Figure 2.1). The effectiveness values given for different potential evapotranspiration rates are based on the assumption of a full plant canopy and 24 hour periods of application

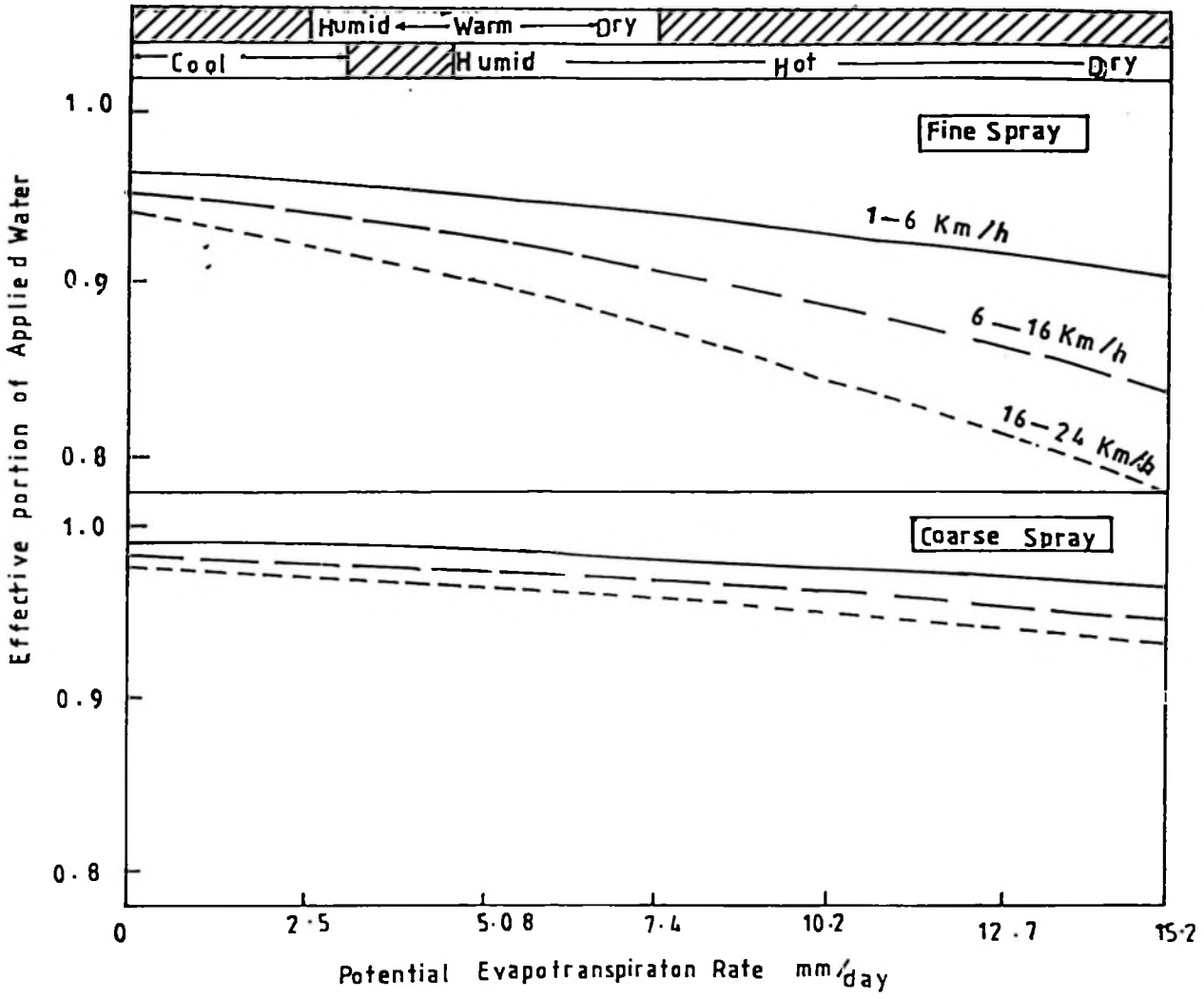

Figure 2.1 The effective Portion of applied water which reaches the Soil Plant Surface (Soil Conservation Service, 1972).

2.4 Factors affecting the performance of sprinkler irrigation

The performance of sprinkler irrigation is affected by a number of variables. The variables include the sprinkler combination of nozzles, operating pressure, spacing, riser height, wind and as well as evaporation.

2.4.1 wind

Wind speed and direction are the two wind characteristics considered in sprinkler design, because they influence the uniformity of irrigation (Martin-Bernito et al. 1992).

Wind velocity

Wind velocity increases with height above a crop or soil surface and can usually be approximated by a straight line when it is plotted against the logarithm of height (Heermann and Kohl 1983). Sprinkler spray ejected high into the air will be subject to greater wind speeds and greater pattern distortion than spray near the surface. The ideal angle for a sprinkler jet under calm conditions is 32 degrees above the horizontal. However, under windy conditions, lower angle should be used to obtain a good range. Most medium size agricultural sprinklers are about 25 to 26 degrees, whereas larger sprinklers are between 23 and 24 degrees (Heermann and Kohl, 1983).

At most continental locations, night wind speeds decrease sufficiently to effect scheduling successive irrigations during alternate day or night periods. A sprinkler system should be irrigating a given location during the night when the preceding irrigation was during the day and vice versa (Heermann and Kohl, 1983).

Wind direction

Wind direction is the other characteristic that affects sprinkler design. Wind direction normally varies, because of the movement of atmospheric pressure centres with their characteristic rotational wind patterns. During the growing season, these pressure centres tend to follow the same routes, resulting in some dominant wind direction quadrants at many locations. Thus, dominant wind directions should be considered in most sprinkler design. Design is based on expected wind speeds and direction during the irrigation season. Vories and von Bernuth (1986) found that where there was no wind all the Cu values were the same. However, the Cu values separated at low wind speeds. wind speeds greater than 2 m/s, higher Cu values resulted as the wind vector approached being parallel to the laterals. For the greatest wind speed tested, 8 m/s, there was a difference of approximately twelve Cu points between the value for a wind blowing parallel to the lateral and the value for a wind blowing

parallel to the main. Vories and von Bernuth (1986) recommended that systems should be oriented so that the wind blows as nearly perpendicular to the long spacing (i.e. parallel to the laterals) as possible.

2.4.2 Operating pressure

Generally, pressure is a measure of the energy required to operate a sprinkler system (Melvyn 1988). Specifically it is defined as a force acting uniformly over an area. Operating pressure and nozzle geometry are the primary factors that control the operation of sprinkler (James 1988). Sprinkler systems operate under a wide range of pressure heads from 3.5 meters to over 70 meters. The desirable pressure head depends upon power cost, area to be covered, type of sprinkler used, sprinkler spacing and crop being irrigated (Hansen and Israelson, 1970). Sprinkler nozzle pressure is a major influence on droplet size. For either circular bore or square bore nozzles, higher pressure creates smaller droplets over the entire precipitation profile (Hills and Gu, 1989). Any conclusion drawn concerning pressure, spacing, and nozzle size are probably combination specific.

Pressure variations throughout the system cause the overall efficiency of the system to be lower than the efficiency in the test area. An estimate of the efficiency

reduction (ER) can be calculated from the maximum, minimum, and average system pressures by the following equation (Merriam and Keller 1978):

$$ER = 0.2 * \left(\frac{\text{maximum pressure - minimum pressure}}{\text{average system pressure}}\right) \text{ ------ (2.9)}$$

The ratio of the average low quarter sprinkler discharges to the average sprinkler discharge in the system is approximately equal to 1.0 - ER. Therefore, the system PELQ can be approximated as follows:

$$\text{System PELQ} = (1.0 - ER) * \text{Test PELQ} \text{ ---------- (2.10)}$$

2.4.3 Nozzle geometry

The nozzle is the hydraulically designed discharge opening or orifice used on a sprinkler to control the volume of discharge, distribution pattern, diameter and drop size (Woodward, 1959). Sprinkler nozzle size can be as small as 1.59 mm to as large as 36 mm (Heermann and Kohl 1983). The size of an area wetted by a single sprinkler and the distribution of water over it depends mainly on the operating pressure and the type of, angle and diameter of the sprinkler nozzle or nozzles (Benami and Ofen 1983). At a given pressure head droplet size increases with nozzle diameter. For a good spray break up, the pressure should

be increased as the nozzle size increases (Heermann and Kohl, 1983).

Hills et al. (1987) evaluated nozzle size, shape and operating pressure under a variety of wind conditions. A sprinkler fitted with a 4 mm circular nozzle and operated with a low pressure oscillation of 69 to 207 kPa, 1 cycle/min, provided an application uniformity superior to that of either a similarly equipped sprinkler or one equipped with a 3.5 mm square nozzle both operated continuously at 138 kPa.

2.4.4 Nozzle erosion

Nozzles get worn-out when they are used for a long time without replacement. This makes the diameter of the nozzle to enlarge and thus affecting the performance of the sprinkler (Merriam and Keller, 1978).

2.4.5 Droplet size

Droplet size is an important factor affecting the formation of "seal" on bare soil surfaces that restrict water movement into the soil (James 1988). Drops greater than 4 mm diameter tend to damage delicate plants and pan the surface of soils with a high clay fraction. Drops of less than 1mm diameter are rapidly retarded in still air and easily deflected by light winds (Withers and Vipond,

1988). Distribution patterns from sprinklers that emit smaller droplets are more subject to wind distortion and lower application uniformity. In addition, the increase of water losses due to wind drift usually occur with small droplet sprinklers (Hills and Gu, 1989). If the pressure is too low the wetted diameter is reduced and an excessive number of large droplets form. If too high, the diameter increases and a high percent of droplets becomes too fine, which result in excessive wind drift (Benami and Ofen 1983). Thus, nozzle configuration and water pressure are both important factors in determining droplet size as well as the field distribution pattern. According to Solomon (1978) as cited by Vories and Von Bernuth (1986) pressure and nozzle size cannot be considered separately.

2.4.6 Riser height

According to Strong (1961) as cited by Heermann and Kohl (1983) the effect of riser height is similar to jet angle. The higher the sprinkler the greater the pattern distortion because of increasing wind velocity with height. Higher sprinklers allow longer travel time during which the wind can act on the spray. Risers should be tall enough for the jet from the sprinkler nozzles to clear the mature plant foliage.

2.4.7 Sprinkler spacing

The spacing between adjacent sprinklers depends partly on the distance sprinklers throw water and expected wind velocity (Schwab et al, 1971). Spacing usually increases as the distance of throw rises.

Table 2.2 Sprinkler spacing and wind velocity

wind velocity (Km/h)	lateral spacing as a percentage of wetted diameter
0	65
8	60
8-16	50
over 16	30

Source: Addink et al. (1983) Design and operation of sprinkler system. In: *Design and operation of farm irrigation systems, (edited by Jensen M.E.)*. American Society of Agricultural Engineers, Michigan.

The operating pressure, and the size, shape, and angle of the nozzle opening determine the distance a sprinkler throws water. Distance of throw increases as pressure increases within the range of recommended operating pressure, holding the other factors constant.

The rate of application decreases from a maximum value near the sprinkler head to zero at the perimeter of the

circle of application. This nonuniform application pattern is overcome in practice by spacing the sprinklers so that there is considerable overlap among individual circle patterns. The closer spacing gives more uniform application of water but also increases the cost of the irrigation system (James et al., 1982).

2.4.8 Sprinkler discharge

Sprinkler discharge is the volume per unit time passing through the sprinkler nozzle (James 1988; Melvyn 1988). It can be calculated as follows (Withers and Vipond 1988):

$$q = \frac{A \cdot S_i \cdot S_m}{3600} \quad \text{---------- (2.11)}$$

Where

q = sprinkler discharge (l/s)

S_i = sprinkler spacing along the lateral,m

S_m = lateral shift distance,m

2.4.9 Application rate

The rate at which sprinklers apply water when a group of them is operating close together is called the application rate (Melvyn 1988). Application rate is an important parameter that is used in the design and evaluation of sprinkler irrigation system to properly match sprinklers to the soil, crop, and terrain on which they operate. When

sprinkler application rates are too high, run-off and erosion can occur. Application rate has dimensions of length per unit time. Withers and Vipond (1988) calculates application rate of an individual sprinkler using the following equation:

$$A = \frac{3600 \cdot q}{S_i \cdot S_m} \qquad (2.12)$$

Where

A = application rate (mm/h)

q, S_i, and S_m as defined earlier

For most sprinklers, variation in operating pressure has little effect, if any, on the average application rate of an individual sprinkler. When operating pressure increases, for example, the increase in q tends to be offset by the increase in wetted area. The average application rate of several identical overlapping sprinklers, however, tends to be directly related to operating pressure, since S_i and S_m remain constant and q increases. Nozzle opening of the shape that creates smaller droplets and wets a smaller area tends to have the highest average application rates. Increasing nozzle diameter usually increases the average application rate, since q normally increases more rapidly than wetted area. Usually, the application rate should not exceed the basic infiltration rate.

2.4.10 Evaporation

Irrigation water that is applied to crops is most effective if that water enters the transpiration stream and contributes directly to dry matter accumulation. Unfortunately, some of the irrigation water may be lost by evaporation without directly contributing to yield. In sprinkler irrigation, droplet evaporation is typically considered to be a major source of water loss. Losses have typically been correlated with wind velocity, vapour pressure deficit, and air temperature. However, because of different techniques used in measuring these losses (i.e., mass balance, electrical conductivity, placement of catch devices, etc.), comparison of results is difficult; often resulting in conflicting conclusions (Thompson et al., 1993). Paz et al. (1991) assessed evaporation losses from a conventional sprinkler irrigation system. They found that wind velocity and vapour pressure deficit had the greatest effect on evaporation and drift losses. Losses increased linearly with wind velocity from 0.5 to 4.6 m/s, relative humidity from 24 to 68% and air temperature from 25-35°C. AT Simunye Sugar Estate, the water budget technique is used to determine when to irrigate. Evapotranspiration is estimated using the following equation:

Moisture lost per day = evaporation x canopy factor (2.13)

2.4.11 Infiltration

Infiltration is the entry of water through the air-soil interface into the soil profile, that is of great practical importance to irrigation design (Skaggs et al 1983). It is the infiltration capacity of the soil that determines the rate that water can be applied to the surface without runoff. Infiltration may involve one-dimensional, vertical soil water movement such as that occurring during sprinkler or flood irrigation; water movement in two dimensions such as the flow in irrigation furrow; or in three dimensions, such as the flow from a drip irrigation emitter. Water supplied in excess of the infiltration capacity will become available for surface storage and/ or runoff.

Cumulative infiltration, F(t) is the total amount of the water infiltrated at any time t and may be expressed as:

$$F(t) = \int_0^t f \cdot dt \quad \text{---------- (2.14)}$$

Where

f = infiltration rate (length/time) that may or may not be equal to infiltration capacity as discussed above.

Attempts to characterise infiltration for field applications have usually involved simplified concepts which permit the infiltration rate or cumulative infiltration volume to be expressed algebraically in terms of time and certain soil parameters. The most obvious characteristic of the infiltration process is that the rate decreases rapidly with time during the early part of an infiltration event.

One of the simplest infiltration equations was proposed by Kostiakov (1932).

$$f = K \cdot t^{-\alpha} \quad \text{---------- (2.15)}$$

where

f = infiltration rate

t = time after infiltration starts

K, α = constants which depend on the soil and initial conditions.

The parameters in this equation have no physical interpretation and must be evaluated from experimental data.

Stationary or solid set sprinkler systems are designed so that the average application rate is less than the basic

intake rate to prevent surface runoff (Pair, 1969). However, moving systems designed to meet water-use requirements often require application rates that exceed soil intake rates (Skaggs et al., 1983). The basic infiltration rate can be used to describe different soil types from an irrigation point of view because infiltration rate depends on soil texture and soil structure (Stern, 1989) (Table 2.3). The larger the soil particles and the longer the pores; thus the higher the infiltration rate.

Table 2.3 Basic infiltration rates for soils

Soil type	Basic infiltration rate (mm/h)
Sand	30-100
Sand loam	20-30
Silt loam	10-20
Clay loam	5-10
Clay	1-5

Source: Stern P.H. (1989) *Small-scale irrigation*. Intermediate technology publications LTD, London.

3 METHODOLOGY

3.1 Introduction

The field work was carried out at Simunye sugar estate, in Swaziland. It was carried out in order to collect data for evaluating the sprinkler system. Tests were conducted on fields of sugar cane, with cane that was less than 80 cm tall. This was done in order to eliminate the error due to interception of droplets by taller cane before it reaches the cans. The data was collected during the months of September to December. A total of 85 tests were conducted at the estate; 53 of the tests were conducted at Ngomane and 32 tests were conducted at Mlaula. Each one of the tests was conducted in different locations. The tests included measurements of soil moisture, operating pressure, catch volume, discharge rate, evaporation and infiltration rate of the different soils. Meteorological data from 1983 to 1993 were also collected from Simunye weather stations (Ngomane and Mlaula weather stations).

3.1.1 Description of the study area

Simunye Sugar Estate is located in the north eastern lowveld of Swaziland (Fig. 3.1). The project has a net planted area of over 9,000 ha. It is divided both geographically and according to the method of water supply into two parts: Mlaula and Ngomane. Mlaula has an area of

2 894.61 ha and the rest is Ngomane. Ngomane is divided administratively into 6 sections, while the Mlaula is divided into 3 sections. The projects grow sugarcane as the main crop and some alternate crops such as cotton, beans, and potatoes. It also has some supportive projects such as a piggery unit, cattle feedlot and an ostrich project.

3.1.2 Climate

The study area has two weather stations located in each of the two administrative areas (Ngomane and Mlaula). The average annual rainfall for Ngomane is 719 mm. Most of the rains occurs during the summer (December-February). It recorded the highest amount in 1983/84 and the lowest in 1991/92. The average annual rainfall for Mlaula is 701 mm. Like at Ngomane most rains occur during the summer. It also recorded the highest rainfall in 1983/84 and the lowest in 1991/92. Although the places are close to each other, there is some difference in the rainfall distribution. At Ngomane the rainfall distribution has less variation than at Mlaula (Fig. 3.2).

Temperatures are usually warm. The average temperature for Ngomane and Mlaula are 21.81°C and 22.1°C, respectively. The highest temperatures occur during the summer and the lowest during the winter. The average maximum temperatures

for Ngomane and Mlaula are similar, being 28.3°C and 28.2°C, respectively. The highest mean temperatures occurred in the season 1991/92 at Mlaula and Ngomane, respectively (Fig. 3.3). While the lowest mean temperature of 20.7°C at Ngomane and 21.6°C at Mlaula in the season 1983/84, respectively. There is more variation of temperature at Mlaula than Ngomane (Fig. 3.3).

The average evaporation for Ngomane and Mlaula are 5.6 mm/day and 5.5 mm/day, respectively. The lowest mean evaporation of 5.3 mm/day for Ngomane occurred in the season 1989/90 while its highest mean evaporation of 6.0 mm/day occurred in the season 1985/86. There are little differences between these values and those for Mlaula. Its lowest value of 5.1 mm/day occurred in the season 1987/88 and the highest of 5.97 mm/day was recorded in the season 1991/92. There is a high variation in the distribution of evaporation for both Ngomane and Mlaula (Fig. 3.4).

3.1.3 Soils

The dark grey or brown lithomorphic vertisols and dark reddish brown or fersiallitic soils predominate the eastern lowveld (Talbot 1976). Texture is usually medium to heavy and the structure varies from being nutty in the brown soils to blocky or prismatic in vertisols along valley bottoms. Generally, they are moderately high in

organic matter and weatherable minerals, and soils appear to be deficient only in phosphates, but imperfected drainage associated with poor consistency and structure is a common characteristic.

Soils in Swaziland were characterised by Murdoch (1970), both descriptive and cartographically. He classified agriculturally significant conditions of 107 soil series into 34 soil sets. The series were apportioned into among broad service pedologique interafricain mapping units. Simunye Sugar Estate is dominated by 6 sets mainly, the T, R, S, K, H, and Z sets.

H set is a two deck with the top of light to occasionally medium texture over mottled sandy clay. It is not highly humic and it has small amounts of free lime permissible in clay pan. It is poorly drained, and mainly acid parent material is frequently pedisediment.

K set is lithomorphic vertisol with black (or nearly so) cracking clay. It is normally 50 to 100 cm deep with blocky or prismatic breaking to blocky. Despite its colour, humus content is medium and it is poorly drained.

R set is brown soil or fersialitic soil. It is dark reddish with heavy texture. It has a compound nutty

structure and moderate permeability. It is mainly found on mid slopes and is from basic parent material.

S set is lithosol derived from basic crystalline rock. Its soil is less acidic than O set. It is very shallow, rarely 40 cm to weathering parent material and approximately the same thickness again to virtually unaltered rock. It has a dark colour. Its texture is medium to heavy usually with appreciable gravel and stone, moderately well supplied with humus. It has a weak horizonation with good drainage and rich in weatherable minerals.

T set is a dark grey or dark brown soils of medium to heavy texture. It is moderately high in organic matter. It has a clear horizonation. It is not calcareous at surface and is from basic parent material on lower slopes.

Z set is a solodized solonetz with two deck profile. It has a thin top of light to medium texture which lies abruptly on compact prismatic dark grey sandy clay, over oliver drab lime-rich zone with silty clay fine earth. It is not high in humus content. It is faintly to appreciably saline and is poorly drained.

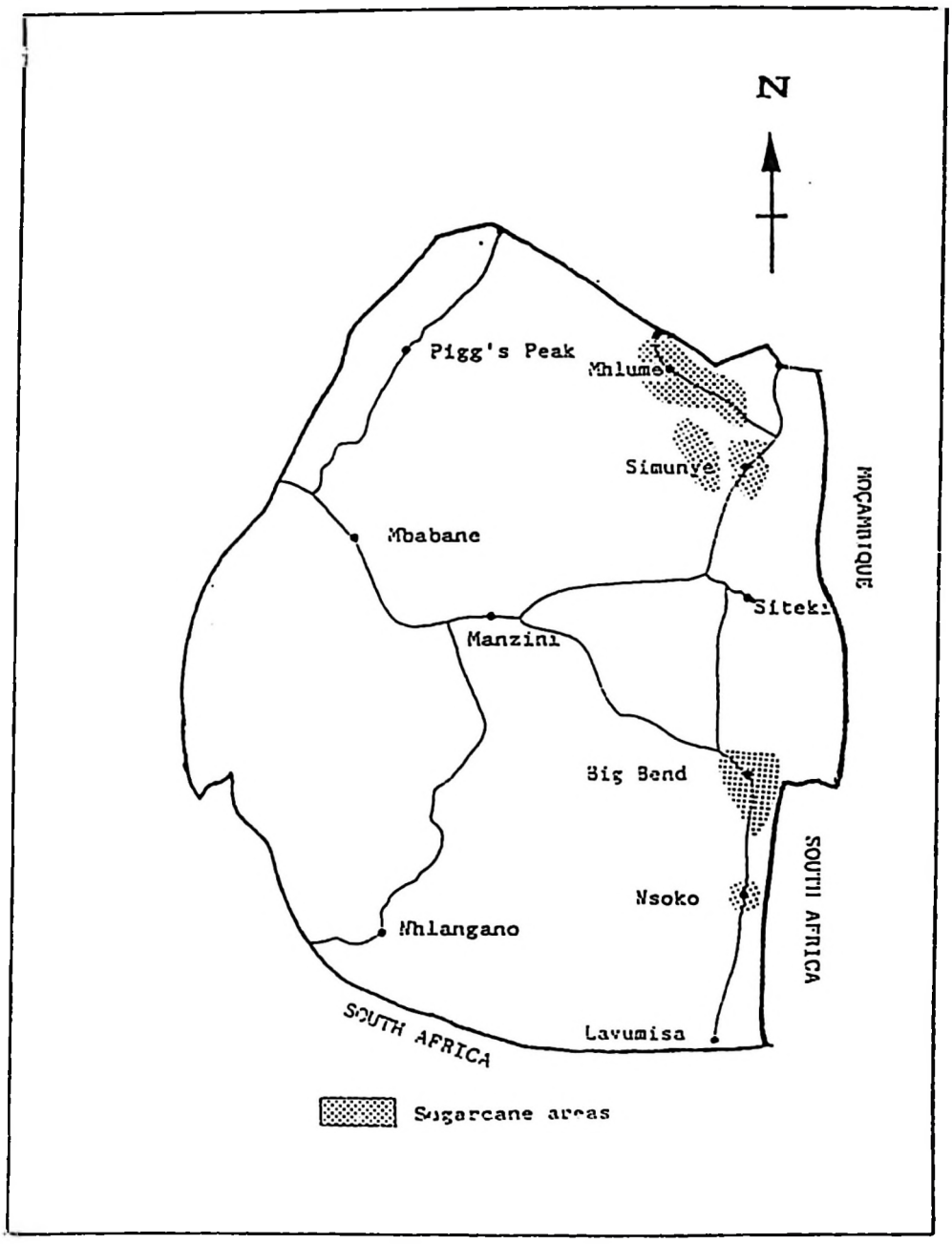

Figure 3.1 Location of Simunye Sugar Estate in Swaziland

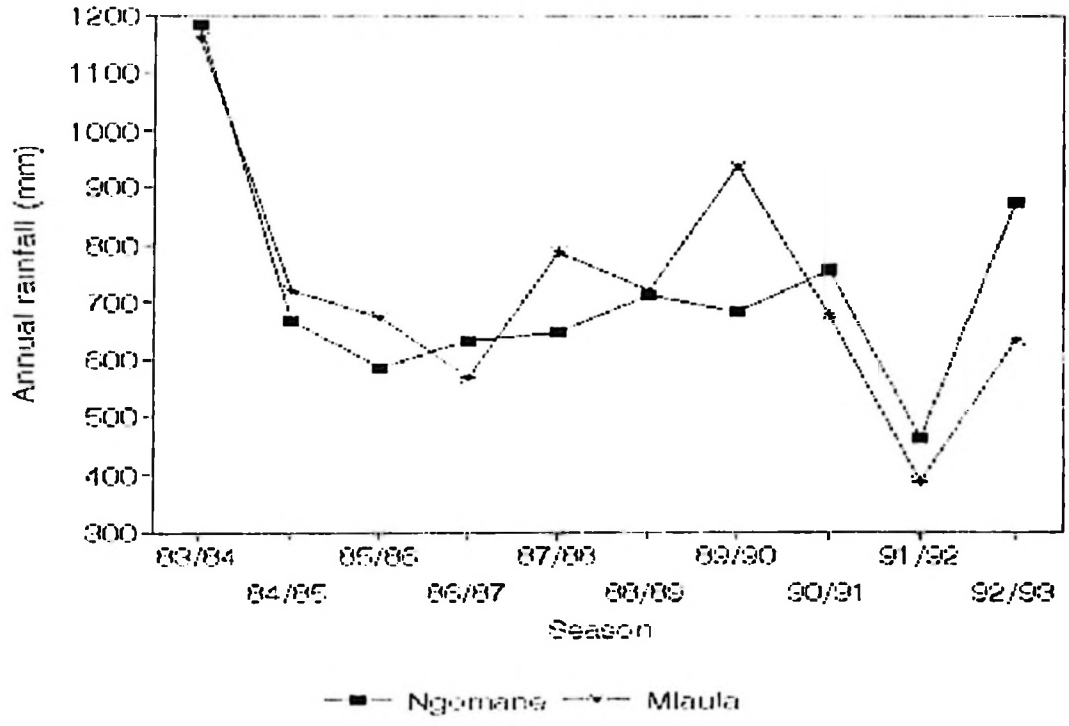

Figure 3.2 Rainfall distribution for Ngomane and Mlaula from 1984-93

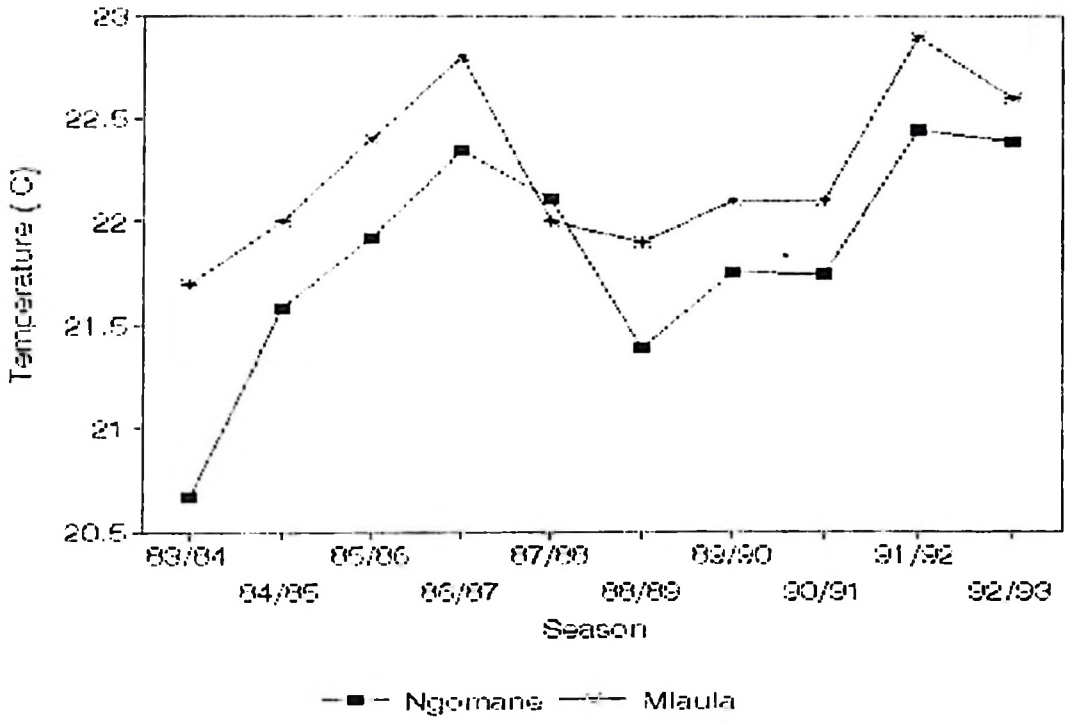

Figure 3.3 Average mean temperature for Ngomane and Mlaula from 1983-93.

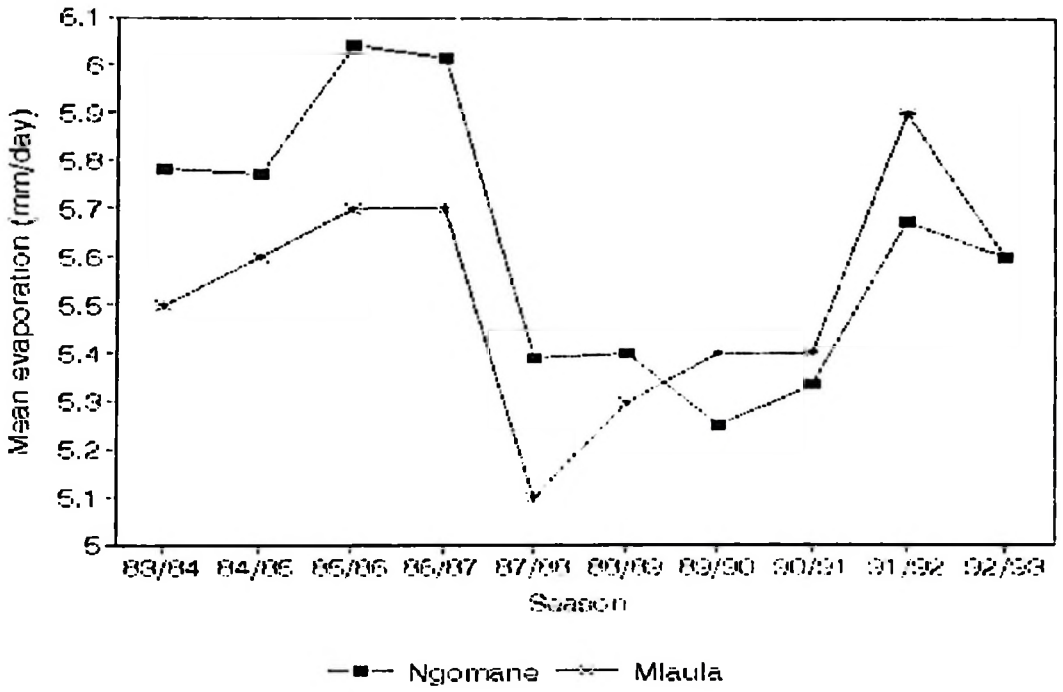

Figure 3.4 Mean evaporation for Ngomane and Mlaula (mm/day) from 1983-93

3.1.4 Land use and vegetation

The lowveld of Swaziland is typically a sweet bushveld, with moderately tall grasses interspersed with fire resistant and drought tolerant bushes and low trees, predominantly leguminosae that are mainly species of deciduous, often thorny, acacias; that is why it is also described as an acacia savanna climate. The land is used mainly for growing sugarcane by the estate. Some alternate crops such as cotton, beans, and potatoes are also grown at a small scale.

3.1.5 Drainage systems

Simunye is drained by two major rivers: White and black Mbuluzi, which both flow towards Mozambique. There are also some natural depressions and small streams which drain water from the fields into the rivers (Fig.3.5).

3.2 Water supply for Simunye Sugar Estate

The Mlaula estate is supplied with water by a pumping station located on the Mbuluzi river, which has two distributaries. These distributaries are the Black and White Mbuluzi (Fig 3.5). The flow of the Black Mbuluzi river is controlled from the Mnjoli dam while that of the white Mbuluzi is not controlled. The Ngomane estate is supplied with water from the Mnjoli dam directly via a feeder canal. Some major canals of both Mlaula and Ngomane

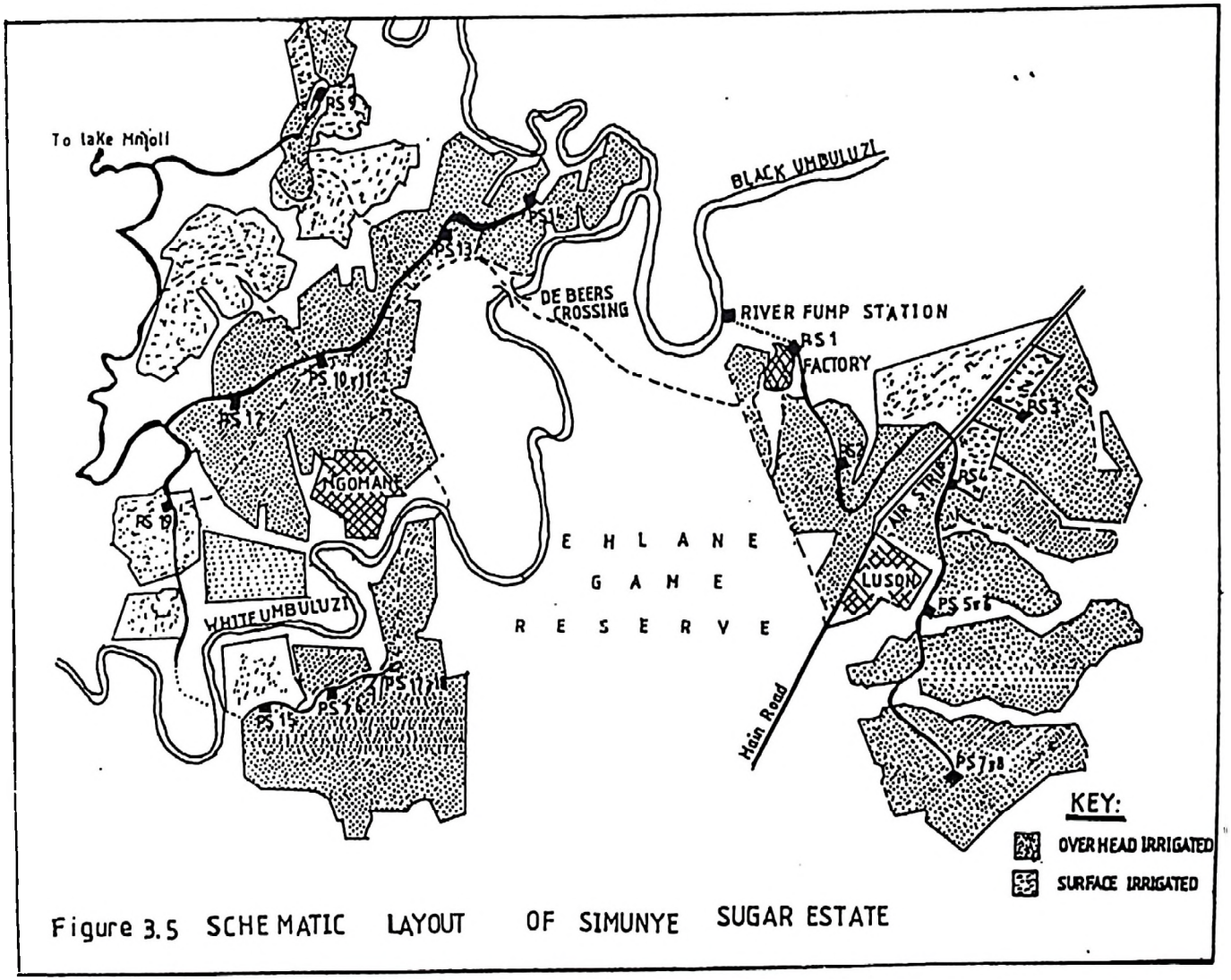

Figure 3.5 SCHEMATIC LAYOUT OF SIMUNYE SUGAR ESTATE

supply water to storage dams for sprinkler irrigation, while others supply water to secondary/tertiary canals for surface irrigation.

3.3 Irrigation system studied

The sprinkler system used for irrigation is a semi-solid "drag-line". Each sprinkler serves 12 positions on an 18m x 20m grid with 6 or 8 hour stand time. Where the soils are shallow restricting the moisture holding capacity, the sprinklers may be moved every 6 hours. On deep soils the sprinklers are moved every 8 hours. The sprinklers are moved parallel to the main. Each sprinkler serves an area of 72 m x 60 m or 0.432 ha. This area is known as the irrigation module. The pressure at the hydrants is set at 4 bars. Where the sprinklers are fitted with 'Dole' valves, the hydrant is fully opened (Fig.3.6).

3.3.1 Sprinkler lateral

The lateral comprises 9 m long aluminum pipe in either 50 mm or 75 mm diameter depending on the total length of the field. The lateral is fixed (positioned) on the main line at the beginning of the growing period, and is not normally removed until the time of harvesting the field. Outlets are provided at 18 m intervals for connecting the sprinkler assembly. These have quick couplers (connections) and incorporate an integral valve. Normally

each sprinkler is used at four outlets. The laterals are spaced at 60 m intervals. The laterals are designed so that the total pressure loss due to friction or elevation losses does not exceed 20% of the sprinkler pressure.

3.3.2 Sprinkler assembly

The sprinkler assembly comprises a 22 m flexible hose of 20 mm in diameter, a tripod, with a 3 m high riser pipe, and a sprinkler. The hose is connected to the base of the tripod and the sprinkler is fitted to the top of the riser pipe. The hose is also equipped with a male connector to fit the lateral outlets. The sprinkler assembly is used in three positions when attached to a single outlet as illustrated in Fig. 3.6. The sprinkler is an impact type, model 14070WH, designed to operate at normal pressure of 3.5 bars discharging water through a 4.76 mm (3/16") diameter nozzle. The normal flow is 0.46 l/sec which gives an application rate of 1.66 m^3/h on a spacing of 18 m x 20 m. The radius of throw is 16.5 m.

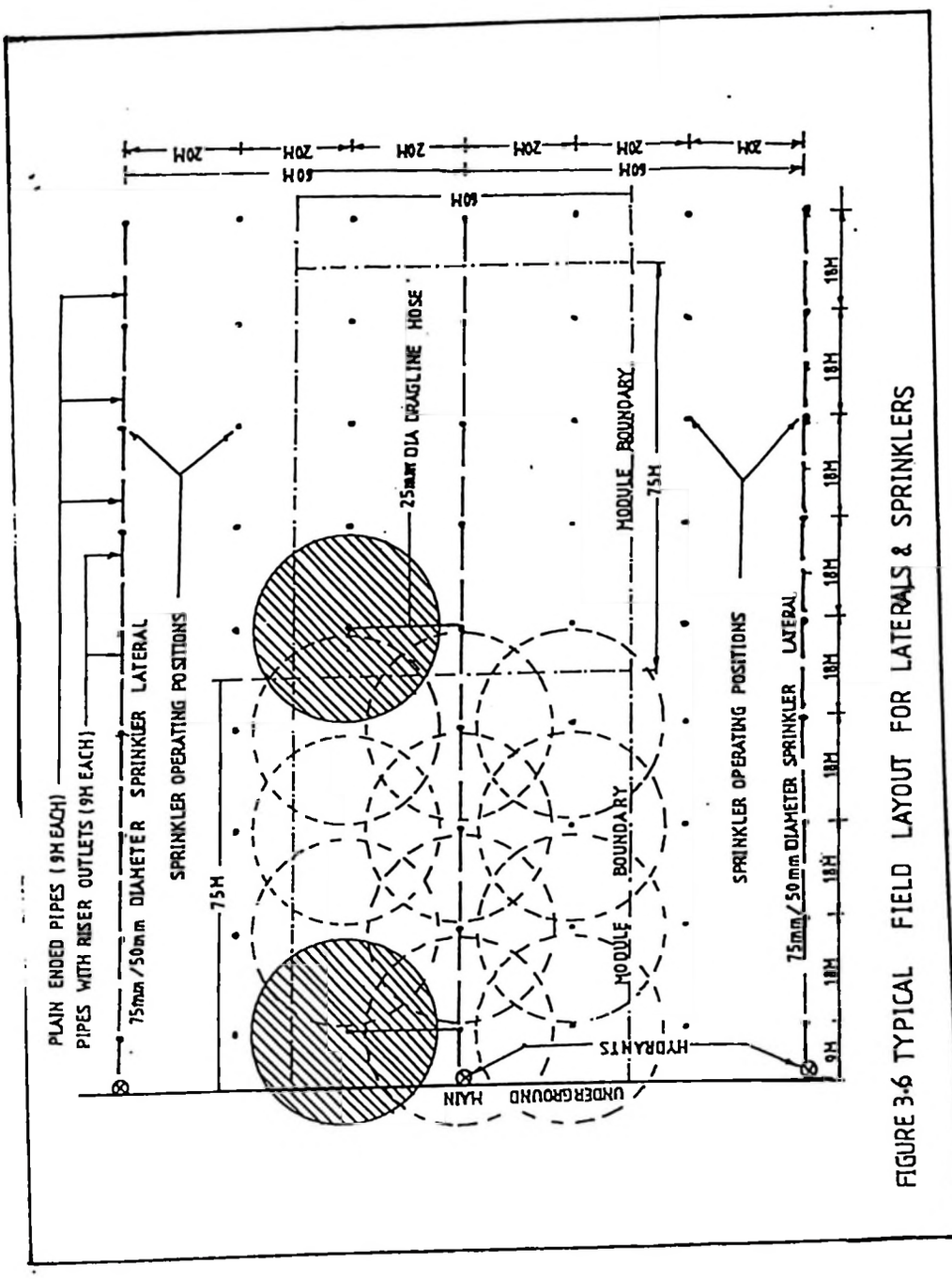

FIGURE 3-6 TYPICAL FIELD LAYOUT FOR LATERALS & SPRINKLERS

3.4 Experimental procedure

3.4.1 Design parameters

A desk research was conducted to identify parameters used when designing the sprinkler system. The design parameters investigated were: distribution efficiency, uniformity of coefficient, actual application efficiency, potential application efficiency, and basic infiltration rate.

3.4.2 Sampling of the fields

A stratified random sampling technique was employed in this study. This was done to eliminate the sampling error. The fields were selected according to the growth stage of the cane in the field, pump stations, and administrative location.

3.4.3 Choosing the location of field test

Usually a single location was chosen along the lateral, at which the pressure was typical (or average) for the entire lateral or two locations near the ends of a lateral to permit the study of the effects of differences in pressure (Merriam and Keller 1978).

3.4.4 Can layout

Since a single sprinkler was used to irrigate an area of 0.432 ha at Simunye, cans were laid around a sprinkler to cover a distance of 18 m x 20 m. A total of 100 cans were

laid at 3 m apart (Fig. 3.7). The amount caught in each can was then superimposed to find an overlap.

3.4.5 Field Performance Measurements

The fixed grid system was employed in this research. Data were collected by using the sprinkler evaluation data sheet (appendix 1). The data was recorded on the sheet prior to the layout of the cans for the can-catch test. The tests were conducted for 3 hours. This was to enable at least an average of more than 10 mm to be caught in the cans (Merriam et al., 1983). The volume of water caught in each can was measured by using a measuring cylinder. It was then converted to depth per millimetre rate for easier comparisons. The data from this system were used to estimate the uniformity coefficient, distribution uniformity, potential application efficiency, and actual application efficiency.

3.4.6 Operating pressure

The sprinkler operating pressure was measured using a pressure gauge (0-1 000 kPa) with a pitot attachment, before and at the end of the test. Nozzle erosion was checked with a feeler gauge (drill bit) that had the diameter specified for the nozzle.

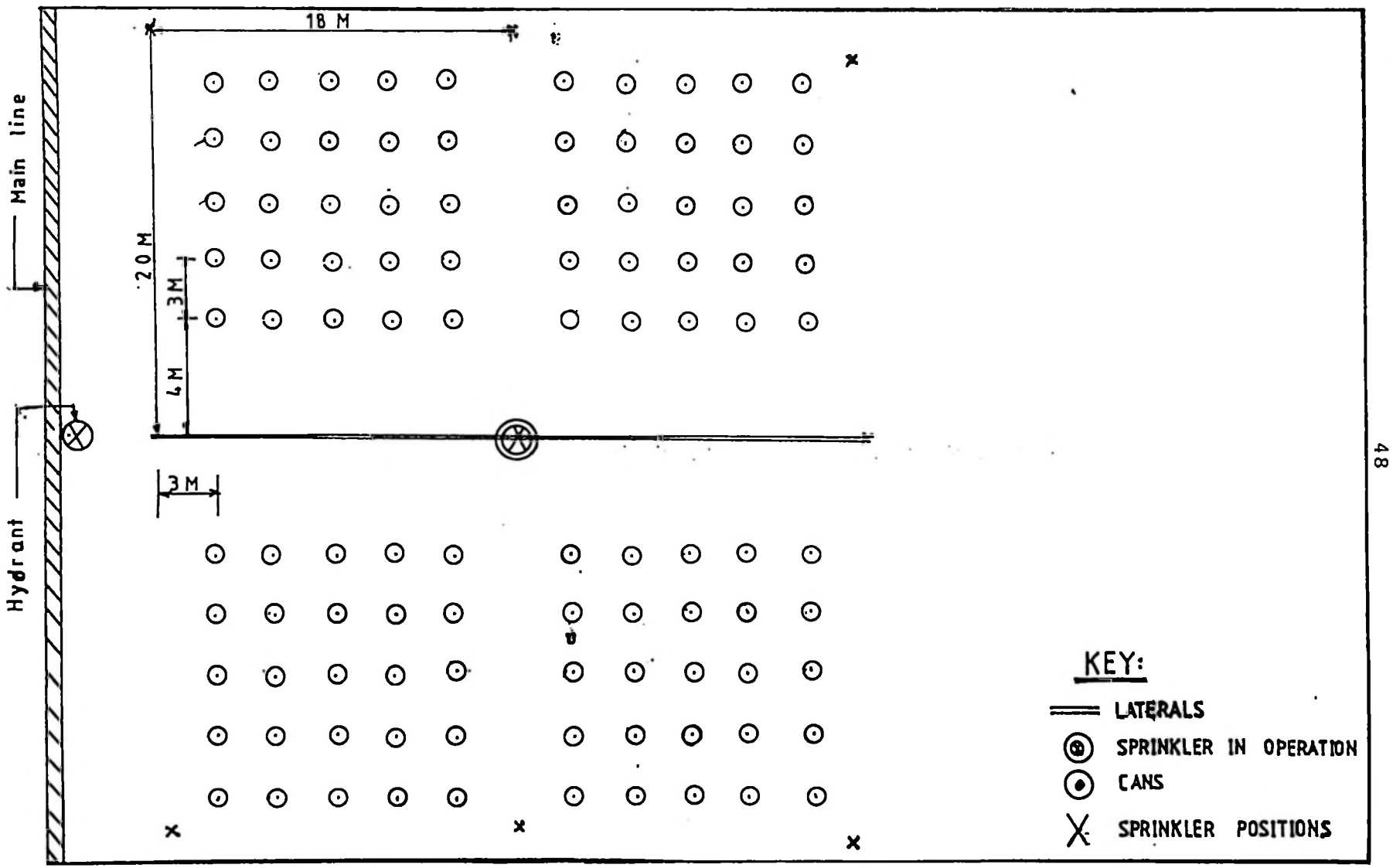

FIGURE 3·7 CAN LAYOUT

3.4.7 Sprinkler discharge

A 3.5 m long flexible hose pipe with a diameter of 12.7 mm (1/2") was used to collect water from sprinkler nozzle to a container. The sprinkler flow rate was then estimated by dividing the volume of water collected by the time taken in collecting the given amount (Merriam and Keller 1978).

3.4.8 Evaporation

Evaporation rate in the can-catch test was measured by providing a container outside the catchment area with 100 ml of water. Then readings were taken at the end of the experiment. The difference was the evaporated water over the test duration.

3.4.9 Climatic data

Wind speed was measured using a turbo meter (an electronic digital anemometer), before, during and at the end of the test duration. Other climatic components such as the maximum and minimum temperature, humidity, rainfall, wind direction, were collected from the weather station at Simunye.

3.4.10 Soil related parameters

Soil texture was determined using the available information at Simunye. The initial soil moisture was estimated at 400 mm and 600 mm depth, using the gravimetric method. These depths were chosen because they are the effective depths of the root zone of sugarcane. The soil samples were taken using cores of 47 mm diameter and 37 mm in height, so that the moisture content by weight and bulk density could be estimated.

Infiltration rate for the different soil types was measured in the fields using a single ring infiltrometer. The infiltrometer consisted of a metal cylinder that was driven into the soil. The cylinder had a diameter of 150 mm, 310 mm high, and a wall thickness of 30 mm, which falls within the recommendations of Merriam et al (1980) as cited by James (1988). The cylinder was driven 150 mm into the soil. Water was then added to the infiltrometer to a pre-determined depth. The fall in depth of water level and the time of measurement were recorded until a steady state was reached. The depth was taken after every 2 minutes for the first 12 minutes, after every 5 minutes for the next 30 minutes, then after every 10 minutes for the rest of the period.

4. RESULTS AND DISCUSSION

The purpose of this study was to evaluate the performance of the sprinkler system used at Simunye Sugar Estate, Swaziland. The information gathered from the study is discussed in three sections as follows: (I) Design parameters used in the original design: (II) performance parameters: (III) factors affecting performance. The analysis was done according to Merriam and Keller (1978) recommendations for evaluating sprinkler irrigation systems.

4.1 Design parameters in the original plan.

The company (Tate and Lyle Agribusiness) that constructed the irrigation system did not leave behind any document showing the design parameters except an operation and maintenance manual for the irrigation scheme. This manual states that the sprinkler irrigation system should have an in-field efficiency of 80%.

4.2 Investigating performance parameters

The performance parameters investigated in this study were those outlined by Merriam and Keller (1978); that were Cu, Du, PELQ, and AELQ.

Table 4.1 Shows an average Cu of 79% that is slightly less than the recommended Cu of 80% for market acceptance (Martin-Bernito et al., 1982). In this study a Cu range of 70-90% was adopted as recommended by James et al. (1982) for market acceptance under wind conditions. Thus, the Cu obtained was above the Cu of 70% which is recommended by James et al. (1982) for market acceptance of a sprinkler system operating in wind conditions. The highest Cu was obtained from section 1 while the lowest was from section 3.

Table 4.1 also indicates an average Du of 67%, which is at the border line for the accepted Du of 67% proposed by Merriam and Keller (1978). The least Du was obtained from section 2, while the highest was obtained from section 1.

The average PELQ obtained at Mlaula was 60%, which was less than the recommended PELQ range of 75-85% (Merriam and Keller, 1978). While the average AELQ was 51% as indicated by Table 4.1. The AELQ was far less than the PELQ, that meant irrigation did not satisfy the soil moisture deficit in the least watered areas (Merriam and Keller,1978).

Table 4.1 Calculated performance parameters (Cu, Du, AELQ, and PELQ) for Mlaula area

Section	Cu		Du		PELQ		AELQ	
	Cu	SD	Du	SD	PELQ	SD	AELQ	SD
1	81	5.6	70	10.6	63	12.8	53	11.1
2	76	8.4	63	14.8	56	15	47	13.2
3	80	6.6	67	11.2	61	11.6	53	8.4
Average	79	6.9	67	12.2	60	13.1	51	10.9

Table 4.2 shows an average Cu of 72% for Ngomane area, which was within the range Cu of 70-90% recommended for market acceptance (James et al., 1982). The sections which performed poorly were sections 4 and 5. The average Du obtained from Ngomane was 57% with a standard deviation (SD) of 13.5 . The average PELQ obtained was 49% with a SD of 14.3 while the average AELQ was 39% with a SD of 14.6. The Du and PELQ obtained were less than the recommended Du and PELQ of 67% and 75-85%, respectively, by (Merriam and Keller, 1978).

Table 4.2 Calculated performance parameters (Cu, Du, PELQ, and AELQ) for the Ngomane area

Section	Cu		Du		PELQ		AELQ	
	Cu	SD	Du	SD	PELQ	SD	AELQ	SD
4	69	11.9	53	18.7	44	19.4	36	17.1
5	69	6.1	53	7.8	42	6.5	33	8.1
6	79	5.7	67	8.2	67	10.7	49	14.2
7	71	3.0	53	9.7	42	10.6	33	8.8
8	71	17.5	56	23	47	21.1	40	23.4
9	75	9.1	91	13.7	54	17.2	43	16.3
Average	72	8.9	57	13.5	49	14.3	39	14.6

4.3 Comparison of Mlaula results with Ngomane

According to Fig. 4.1 the performance parameters (Cu, Du, PELQ, and AELQ) estimated for Mlaula were better/higher than those for Ngomane. The average Cu, Du, PELQ, and AELQ for Mlaula were 79, 67, 60, and 51, where-as, for Ngomane, they were 72, 57, 49, and 39 percent, respectively. The only parameter which fell along the acceptable range in both places was the Cu. However, the other parameters were less than the recommended ones. This could have been due to the combination of operating pressure, spacing and nozzle size (Hills and Gu, 1989). Wind could have contributed to the discretion between the results of Ngomane and Mlaula, since both wind velocity and wind direction of the two places were different. The average wind velocity for Ngomane was 2.5 m/s while for Mlaula was 1.6 m/s.

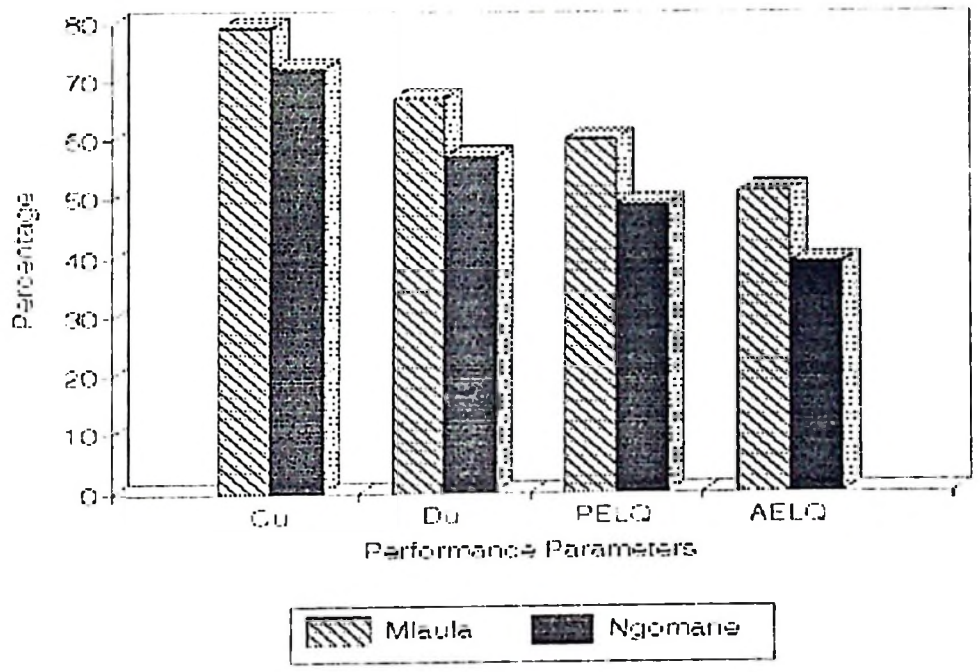

Figure 4.1 Results for Mlaula and Ngomane

The wind direction was in most cases perpendicular to the laterals at Ngomane than at Mlaula. The other factor which might have contributed to the difference was evaporation losses, since the results were from different places. The average evaporation rate for Ngomane and Mlaula which were estimated while the tests were conducted were 0.54 and 0.32 mm/h, respectively.

Table 4.3 shows the performance parameters for Simunye (average for Mlaula and Ngomane). The performance parameters (Cu, Du, PELQ, and AELQ) were 76, 62, 54, and 45 percent respectively. The Cu is the only parameter which fell within the acceptable range of 70-90% (James et al.,1982). The other parameters were less than the recommended values by Merriam and Keller (1978). That might have been caused by the combination of operating pressure, nozzle size, and sprinkler spacing (Hills and Gu 1989), climatic conditions which involves the high evaporation rate (section 4.6), and wind velocity which also proved to be high for the sprinkler spacing used at Simunye Sugar Estate (section 4.3).

Table 4.3 Performance parameters (Cu, Du, PELQ, and AELQ) for Simunye sugar estate (average for Mlaula and Ngomane)

Simunye	Cu	Du	PELQ	AELQ
X	76	62	54	45
SD	9.23	14.0	15.8	14.88

4.4 Factors influencing performance

Pressure variation at Simunye Sugar Estate was very minimum (Appendix 2). The efficiency reduction (ER) was found to be 0.054, thus reducing test PELQ from 54% to the system PELQ of 51% (Equation 2.9). This means that there was less pressure variation due to slope or friction losses. The pressure differences between the first and last sprinkler in a lateral fell within the recommended range of less than 20 % (section 3.3.1).

Wind was one of the major sources of disruption for the distribution patterns of sprinkler irrigation system at Simunye Sugar Estate. The wind velocity was high towards midday until evening. The maximum wind velocity recorded during the running of the tests for Ngomane and Mlaula was 18 and 13.68 Km/h, respectively. The mean wind velocity for Ngomane and Mlaula was 9 and 5.76 Km/h, respectively. This might have contributed in lowering the efficiencies,

since the lateral spacing was too large for the wetted diameter in relation to wind velocity, especially when the maximum wind velocity was considered. At Ngomane the wind velocity could have contributed more to the lowering of the efficiencies, since the mean wind velocity recorded there required a lateral spacing of 16.5 m instead of the 20 m (Table 2.2).

Sprinkler spacing also contributed to the low efficiencies, since the spacing goes hand in hand with wind velocity (Table 2.2). Most of the wind was perpendicular to the lateral spacing (parallel to the mains).

Operating pressure seemed not to be constant in the whole estate. Some sections like in section 4, pump station 21, the operating pressure was high (500-600 kPa). This might have been due to lack of supervision from the administrators' concern in the section, since the hydrants were fully opened, instead of the pressure at 400 kPa. In this fields the efficiencies were very much reduced as compared to the other fields since, high operating pressure produces small droplets which are subject to wind drift and evaporation losses (Hills and Gu, 1989). The uniformity of coefficient was thus very much reduced as compared to the other fields.

Frequency of irrigation, seemed to be very high for most of the fields and thus lowering the application efficiency. The soil moisture deficit was found to be very low and resulted in a low application efficiency for the lower-quarter since the average depth of water applied was constant (equation 2.6). The section managers, when interviewed, stated that they used the water budget technique for scheduling their irrigations. The method used for estimating the evapotranspiration seemed to be over-estimating (Equation 2.13).

Waterlogging was noticed by the researcher in many fields in the estate. In some fields like 1108,1107, 1209, 1212, 1713, 2003, and 2107 waterlogging was a problem, thus runoff occurred. At field number 1108 and 1107 the drainage boxes were clogged. This was a sign of high frequency of water application.

At Mlaula the water used for irrigation was mixed with some effluent water from the factory. This water causes a lot of sprinkler nozzle clogging. In field 313 the researcher noticed a 60% clogging of the sprinkler nozzles, which contributes to the inefficiency of the system in the area.

Nozzle wearing-out was not of a major influence to the lowering of the uniformities. About 1% of the sprinklers checked their nozzles were worn-out. This might be because Sprinklers were serviced after every harvesting sugarcane in the fields.

4.5 Soil related parameters

4.5.1 Soil texture and moisture

Soils at Simunye are dominated by the six soil sets mentioned earlier. In most fields more than one soil texture occurred. The most dominating soil texture is assumed to be occupying the whole field for design purposes. Due to the lack of pressure plates for determining moisture characteristic curves and field capacity, Table 2.1, was used to estimate field capacity. The field capacity was then used in the estimation of soil moisture deficit (equation 2.4), which was used in the estimation of AELQ (equation 2.6). It was noted that the soil moisture deficit was very low in most of the fields, thus equation 2.6 was used to estimate AELQ because water infiltrated exceeded the SMD (section 2.3.4). The average bulk density for the soils was 1.51 g/cm^3

4.5.2 Infiltration

According to table 4.4 the lowest basic infiltration rate of the soils obtained at Simunye Sugar Estate was 5 mm/h.

The results concurred with the basic infiltration rate for some soils Stern (1989) (Table 2.3). The sprinkler system discharge rate was 4.6 mm/h. Thus, the discharge rate was less than the basic infiltration rate of the soils in the estate despite the compaction by heavy machinery especially during the harvesting period. Runoff was thus prevented, except where there was some leakage on the laterals. A sample of the infiltration curves and the basic infiltration rates are shown in appendix 3a and 3b.

Table 4.4 Basic infiltration rates for some soil series found at Simunye Sugar Estate

Field	Soil series	Soil type	Basic infiltration rate (mm/h)
922	DU	Loam	8
916	Sk	Clay loam	8
1206	Ro	Loam	6
2106	Ro	Loam	6
313	Tm	Clay	5
1209	Ts	Clay	5
1806	Ts	Clay	5
1716	Ho	Loam	6
1713	Ho	Loam	6
1108	Th	Sand-loam	9
621	Ro	Loam	6
1401	Ho	Loam	9
617	Sk	Clay-loam	5
620	Ro	Loam	6

4.6 Evaporation

Evaporation loses obtained from the cans while the tests were run for Mlaula and Ngomane were 0.32 and 0.54 mm/h respectively. Their standard deviations were 0.21 and 0.46, respectively. The maximum evaporation obtained from Ngomane and Mlaula were 1.92 and 0.77 mm/h, respectively. The results showed a high evaporation rate especially at Ngomane. The sprinklers applied water at the rate of 4mm/h, then if 1.92 mm/h did not reach the soil surface, it was a great loss because only 2.08 mm/h was being applied. Despite the fact that a lot of water was lost from the sprinklers before it reached the soil surface more water evaporated while it was already on the ground.

4.7 Comparing recommended parameters with measured parameters

The statistical Z-distribution (Hoel, 1976) was used to compare the recommended parameters (Du and PELQ) to the measured ones. It was found that at 0.01 level of significance both Du and PELQ had significant differences between the recommended and the test values. Thus, confirming the discussion given earlier.

5 Conclusions and Recommendations

5.1 Conclusions

From the study the following conclusions were made:

(1) The sprinkler system of Simunye sugar estate operates within the recommended range of Cu (James et al., 1982) for wind conditions. The average Cu obtained was 76% which was more than the recommended 70%.

(2) The distribution uniformity was lower than the recommended minimum (Merriam and Keller 1978).

(3) The PELQ of the sprinkler system used at Simunye sugar estate was lower than the recommended (Merriam and Keller 1978).

(4) The AELQ was too low when compared with the PELQ and thus it showed that a lot of water was applied and more losses occurred. More problem of waterlogging will result in the estate, since the water will raise the water table. The estate stands a danger of salinity problems in future.

(5) Wind was a contributory factor to the lowering the efficiencies in the estate. When the tests were run the mean wind velocity was 7 Km/h which was higher for a spacing of 18m x 20m.

(6) The average basic infiltration rate was 6.4 mm/h. The least basic infiltration rate of the soils irrigated by sprinkler irrigation system was 5 mm/h, which was above the sprinkler discharge rate, thus very little runoff occurred.

5.2 Recommendations

From the study, the following recommendations are made:

(1) The sprinkler spacing is too large and thus it reduces the design parameters. A study which will investigate the correct spacing under the present prevailing conditions is recommended.

(2) The sprinkler rotation system should be altered so that an area irrigated during the day in the previous irrigation set should be irrigated during the night in the next set. This is to take advantage of the low wind velocity during the night.

(3) Sprinkler maintenance, should be kept at maximum in all the sections, in order to avoid water leakages which result in the lowering of the operating pressure.

(4) The frequency of irrigation should be reduced, i.e. irrigate at the desired MAD.

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Appendices

Appendix 1: **Sprinkler Evaluation Data Sheet**

Location.....observer..... Date.....
Crop: Kind..... Growth stage..... Root zone depth.....
Soil: Texture..... AMC..... MAD%... MAD..... SMD....
Design: Make ..... Model..... Nozzle size.....X.....
Pressure.... Flow rate.... Sprinkler spacing...X
Riser height.... Lateral pipe diameter.....
Lateral slope .... Irrigation duration .....

Weather: Temperature..... Humidity..... Cloudiness.....
Wind velocity initial.... During... Final.....
Wind direction arrow relative to pipe flow direction
Initial..... During..... Final .....

Actual sprinkler pressure and discharge rates

	Sprinkler location number on test lateral					
Initial pressure (kPa)						
Final pressure (kPa)						
Catch volume (l)						
Discharge (l/min)						
Rate (mm/h)						

Sprinkler spacing..... Lateral spacing (move).....
Gauge spacing .....X.....
Time of test: initial..... final.....
Duration hours.....Min... Dec hr.....
Evaporation on gauge depth: Initial..... Final.....
Loss ..... Rate.....

Comments.....
.....
.....
.....

Catch data in gauge containers

Show sprinkler number and location on lateral				Show depth or volume caught above line. Show calculated rate caught below line			

Appendix 2: Performance parameters

Section 1

Field	Cu	Du	PELQ	AELQ	ER
213	85	75	69	61	0.08
215	79	67	60	48	0.08
212	88	82	78	62	0.04
216	74	58	55	39	0.02
217	88	81	79	70	0.08
204	76	57	48	46	0.01
209	78	67	50	47	0.017
Section 2					
402	80	68	66	59	0.11
314	63	39	36	27	0.04
405	83	73	69	57	0.007
401	79	64	51	50	0.03
313	65	43	36	30	0.007
310	81	74	68	55	0.02
307	82	73	67	53	0.11
Section 3					
609	73	63	58	57	0.02
607	72	52	43	43	0.02
501	80	71	65	51	0.13
502	72	56	50	44	0.08
801	81	71	66	60	0.06
807	71	56	54	49	0.07
608	90	84	75	65	0.15
505	87	76	74	59	0.04
610	87	77	70	57	0.012
612	87	79	77	62	0.03
702	76	67	62	54	0.04
701	80	70	64	50	0.07
615	79	69	56	47	0.03
621	87	80	77	63	0.02
613	76	57	49	48	0.14
620	88	81	76	67	0.06
617	73	54	48	42	0.05
618	73	48	46	40	0.05

Appendix 2 (cont..)

Section 4

Field	Cu	Du	PELQ	AELQ	ER
1512	82	75	67	47	0.007
2103	78	66	64	50	0.03
2105	65	42	39	23	0.02
1501	91	85	80	68	0.02
1511	76	72	63	60	0.01
1510	73	59	48	38	0.03
2106	70	49	39	37	0.05
2107	52	46	35	32	0.004
2101	57	34	26	25	0.03
2104	68	55	28	20	0.036
2102	55	26	24	15	0.04
2102	58	30	27	19	0.04

Section 5

1607	67	44	35	24	0.016
1612	73	58	47	32	0.02
1713	59	42	33	26	0.08
1715	65	48	37	25	0.03
1716	64	50	40	31	0.02
1714	73	59	46	38	0.015
1806	70	56	43	41	0.04
1802	78	64	52	46	0.04

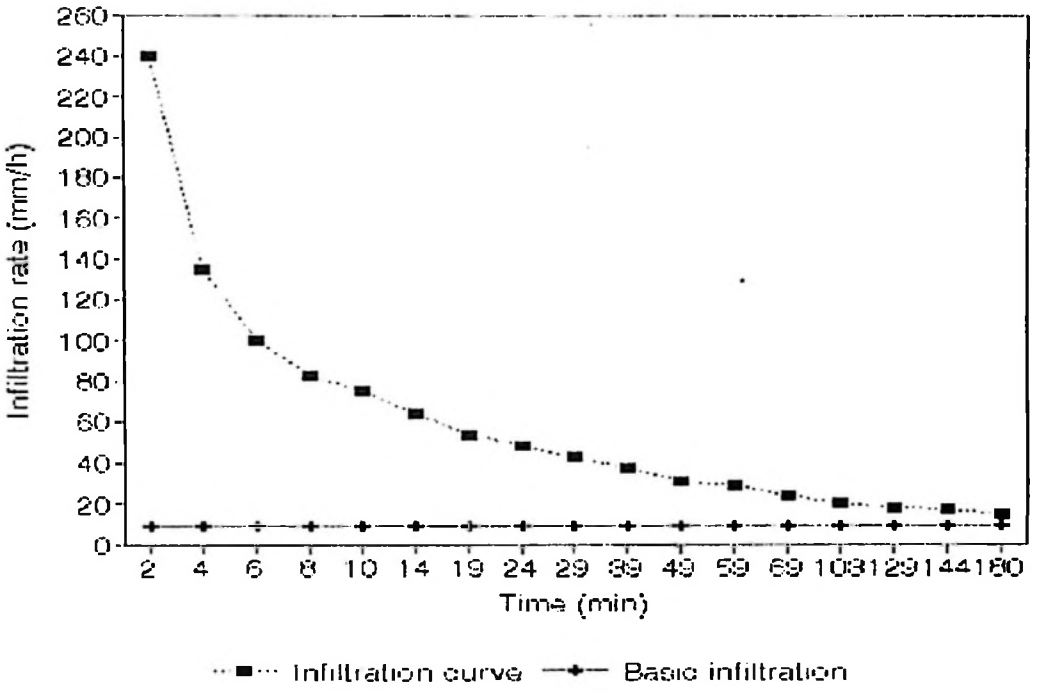
Section 6

1111	83	78	75	66	0.03
1112	75	64	51	50	0.03
1105	87	78	72	63	0.02
1108	83	71	65	64	0.02
1104	79	59	46	41	0.04
1101	74	54	47	32	0.09
1206	69	60	58	49	0.07
1209	83	69	67	61	0.00
1211	80	70	68	25	0.06
1212	68	53	45	28	0.06
1210	77	69	67	53	0.10
1216	80	70	68	61	0.04

Appendix 2 (cont..)

Field	Cu	Du	PELQ	AELQ	ER
Section 7					
2001	74	54	33	28	0.03
2003	67	45	38	32	0.007
1008	72	66	57	45	0.017
1009	70	46	38	25	0.06
1203	83	73	71	44	0.04
Section 8					
1317	46	24	13	8	0.02
1313	73	54	46	38	0.03
1401	84	70	63	58	0.04
1402	82	75	66	57	0.04
Section 9					
917	78	70	67	55	0.05
923	67	59	52	40	0.04
914	77	61	51	47	0.006
915	82	73	65	56	0.05
901	84	77	74	54	0.08
902	65	44	35	25	0.02
921	71	52	41	32	0.024
920	88	76	72	62	0.097
916	60	38	21	18	0.08
919	71	52	48	29	0.03
922	68	53	48	31	0.07
918	86	79	77	68	0.00

Appendix 3a : Infiltration rate vs time for field number 1401 soil type Ho



Appendix 3b: Infiltration rate vs time for field number 1713 soil type Ho