

**SPRINKLER PERFORMANCE EVALUATION AT MTIBWA SUGAR ESTATES**

**BY**

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## ABSTRACT

A performance evaluation study aimed at evaluating Mtibwa sprinkler irrigation system was carried out at Mtibwa sugar estates, Morogoro. The specific objectives were: (1) To investigate whether the application rate, duration of application and operating pressure of the current system meet the sugar cane water requirement with respect to the prevailing soil moisture deficit. (2) To investigate sprinkler irrigation performance parameters whether the system is operating as designed and give recommendations in relation to low yield difference between irrigated and rainfed cane. The results showed that about 20 % of all sprinkler irrigated blocks had coefficient of uniformity below 80 %. The pressure recorded ranged from 1.8 to 3.2 bar and 73 % of all blocks had sprinklers operating below the designed pressure of 3.2 bar. From the performance parameters the study showed that about 38 % of all blocks required longer duration of irrigation than the current practiced one. The longer required duration per set is identified to be due to low application rate which is also caused by low operating pressure at the pump stations and consequently to the sprinklers. Therefore, the low yield and insignificant yield differences between irrigated and rainfed sugar cane is caused by poor performance of the sprinkler system. This led to inadequate application of water.

DECLARATION

I, MAREALLE EMMANUEL, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my original work and that it has never been submitted for a degree in any other university.

Signature:  .....

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## 1. INTRODUCTION

The world population is expected to grow from 5 billion people to 6 billion by the year 2000 and to at least 8 billion by the year 2025 (Bos, 1991). In the past, increases in agricultural production have come about through expansion of land under cultivation, crop intensification and the yield improvements. These are signs that water will become a limiting factor in all three methods of production. Hence, irrigation and its respective performance together with drainage will play a major role in achieving food sufficiency.

The use of irrigation in Tanzania is thought to date at least from the iron age (Sutton, 1974). Traditional systems have long been of considerable local importance in various parts of the country. The first modern irrigation system was introduced in then Tanganyika in the 1930s. This was a private enterprise, the Tanganyika planting company (TPC) in Moshi. Other modern systems were then introduced as shown in the Table 1. All these were sprinkler irrigated schemes engaged in tea or sugar cane production. Due to poor performance many irrigation schemes contribute less to agricultural growth and production than expected. Average yields of major crops are far below the practical potential that might be expected with the use of modern farm inputs, predominantly because of water control.

Many of irrigation schemes are poorly adapted to the soils and topography. Intake rates and water holding capacities of the soils are

Table 1: Some sprinkler irrigation systems in Tanzania

Name	Region	Area under irrigation (ha)	Crop
TPC	Kilimanjaro	6840	sugar cane
Kilombero	Morogoro	4400	sugar cane
Mtibwa	Morogoro	1750	sugar cane
Mufindi	Iringa	2000	Tea

Source: SUDECO (1988)

sometimes not known before a field is laid out for irrigation (Criddle et al., 1979).

Because of the growing world population and the important role of irrigated agriculture, the performance evaluation of irrigation schemes should receive greater attention.

Assessing the performance of irrigation schemes is an activity that has drawn increased attention in recent years. The perception that many projects have failed to deliver the levels of performance expected, (Lenton, 1991) and the fact that many new projects are in need of rehabilitation, have led the Irrigation community to look at performance monitoring (Pike, 1991).

In Tanzania many irrigation schemes have shown poor performance which is due to mismanagement and inadequate supply of water. Many of these do not meet the required demand of water due to either poor design or water shortage such that the crop water requirement of intended crops are not met. Examples include TPC, Kilombero and Mtibwa estates (NEI, 1988). The yield levels at these estates show strong fluctuations from one year to the next and generally declining trend during the 1980s especially after 1984 as shown in Fig. 1

The yield levels of sugar cane have been influenced unfavourably by two main factors. First, shortcoming in irrigation system which resulted in negligible difference between irrigated and rainfed cane. In general, irrigation is applied to sandy soils and consequently it also functions as a safeguard against crop failures in dry period. Secondly, poor land preparation (ploughing and levelling) led to drainage problems during heavy rains. Drainage canals were poorly maintained and soils in certain parts have become so saline that they are unsuitable for cane cultivation (NEI, 1988). At Mtibwa sugar estates, cane yields under sprinkler irrigation and rainfed fields show an insignificant difference of a few tons per hectare. According to NDC, (1992), the possible main cause was ineffective irrigation system. The ineffectiveness of the system was due to wrong irrigation cycles, wrong spacing of laterals and inadequate number of sprinklers with low operating pressure. It is from these facts that there is a need to conduct a thorough research on sprinkler performance at Mtibwa aimed at evaluating

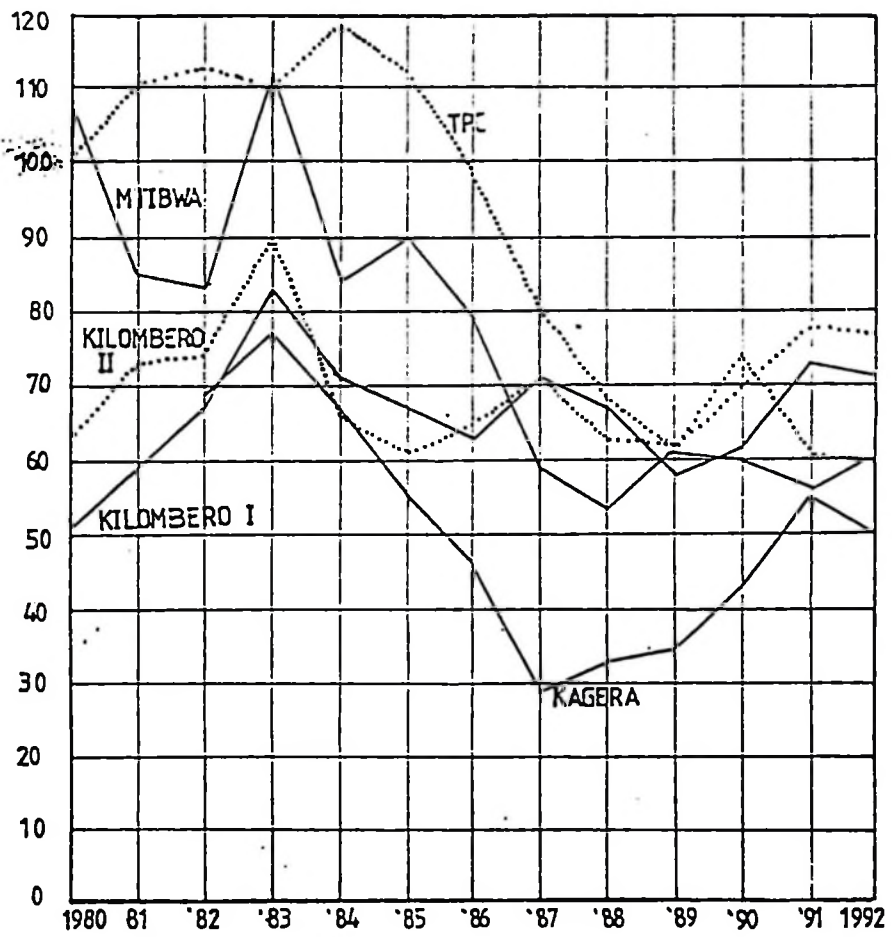


FIGURE 1. YIELDS PER ESTATE 1980-1991 (In tons per ha).

the effectiveness of the system in attaining optimum yields for sprinkler irrigated sugar cane.

In order to achieve this, a study was initiated whose main objective was to evaluate the performance of the sprinkler irrigation system at Mtibwa sugar estates.

The specific objectives were:-

- (a) To investigate whether the application rate, duration of application and operating pressure meet the sugar cane water requirement with respect to prevailing soil moisture deficit.
- (b) To investigate performance parameters i.e uniformity coefficient (UC), distribution uniformity (DU), potential application efficiency (PELQ) and application efficiency of low quarter (AELQ) and whether the system is operating as designed and give recommendations .

## 2. LITERATURE REVIEW

In the past, increases in agricultural production have come about through expansion of land under cultivation, crop intensification and the yield improvements. There are signs, however that water will become a limiting factor in all three methods of expansion. Hence irrigation and its respective performance together with proper drainage, will play a major role in achieving food security.

But many irrigation schemes, both new and recently rehabilitated, contributed less to agricultural growth and production than expected due to poor performance (FAO, 1986). Average yields of major crops are far below the practical potentials that might be expected with the use of modern farm inputs, predominantly because of water control (Bos, 1991). Irrigation efficiency is generally low due to poor design and mismanagement (Anukularmphai, 1976). It is recognised that in practice, with proper design and good management the irrigation efficiency of surface methods can be as high as with sprinkler or drip irrigations. There is a general awareness that irrigation management has been weak in many African countries especially in farmer managed and agency managed schemes (Speelman, 1990).

Because of the growing world population and the important future role of irrigated agriculture for food security, the performance evaluation of irrigations systems have received attention from various disciplines. These disciplines need performance indicators that can be quantified, simple to

measure and widely applicable.

In determining the performance of irrigation schemes, researchers have come up with different views of what seem to be desirable features of a good successful irrigation system (Abernethy, 1986). In order to choose appropriate parameters to define good water management, due consideration has to be given to the definition of the purpose of water management namely delivery of water where and when it can be utilized for crop production, reliably and in appropriate amounts.

The purpose of evaluating irrigation system is fourfold:

- a) To determine the efficiency of the system
- b) To determine how effectively the system can be operated and whether it can be improved
- c) To obtain information that will assist engineers in designing other systems and
- d) To obtain information to enable comparing various methods, systems and operating procedure as a basis for economic decisions.

Measures of the performance evaluation of a given system relating to a single point in time have little meaning. This is because nothing is available with which to compare them, neither measures of performance for that system taken at an earlier time, nor standard against which the measured values can be compared.

Inter-temporal comparison of performance for a single system can be made, showing trends over time. However, in the absence of standards, it

will be impossible to ascertain whether the observed changes are in favourable or unfavourable direction. Comparison among systems will likewise not be meaningful since no evaluative judgement can be made without knowing the desirable state of affairs.

As a result, objective measures of performance evaluation are useful only when they have been normative through the establishment of standards against which they can be compared.

Oad and Marcornick (1989) described the methodology used in studies to assess the performances of irrigated agriculture in several developing countries. The two main methodologies were diagnostic analysis and rapid appraisal.

Diagnostic analysis studies were characterised by long term collection of quantitative field data mainly at the farm level. Rapid appraisal studies looked into short term collection of data.

Attention had initially focused at the on farm level because the diagnostic studies were concerned with the performance of irrigated agriculture and it seemed logical that the causes of poor performances must lie with the primary agricultural producers, the farmers. Only after several years did researchers like Chambers (1988) turned the spotlight on the management of irrigation systems to reveal the blind spot.

Rapid appraisals studies involved collection of mainly qualitative data from all levels of the system and sought to provide and analyze information as quickly and cheaply as possible, in order to improve the system

performance.

Many irrigation systems, both surface and sprinkler, are poorly adapted to the soils and topography. Intake rates and water holding capacities of the soils are sometimes not known before a field is laid out for irrigation. Often, sprinkler irrigation systems fail to apply water in accordance with the soil characteristics and crop needs (Criddle et al, 1979). In the sprinkler method of irrigation, water is sprayed into the air and allowed to fall on the ground somewhat resembling natural rainfall. Sprinkler irrigation has an advantage over the other methods of irrigation in the sense that it can be used for almost all types of crops (except jute and rice) and on most soils. It is however, not usually used in very fine textured soils (heavy clay soils). Other advantages include application of fertilizers and herbicides using the irrigation water with little extra equipment. However, one of the limitations of sprinkler irrigation which affects its performance is wind which distorts sprinkler patterns and causes uneven distribution of water. This is due to the fact that water is applied in the form of a spray which can easily evaporate and get drifted by wind.

Evaporation rates are highest when a sprinkler that produces large quantities of small droplets are operated during hot, dry, windy conditions (Hermismeir and Longely, 1988). The evaporation effect is also very high when irrigation water is warm and sprinkler mounting height is high (Pair and Seginer, 1988).

Kohl and Wright (1988) observed that the occurrence of spray

evaporation increase vapour densities and reduces water application efficiency and reduces the targeted soil water deficit and hence low performance. Even with a properly designed water application rates, the yields of crops can greatly be reduced if such factors of wind and evaporation are not taken into account (Longeley, 1988).

However, recent trends in sprinkler irrigation design have led to higher water application rates which results in increased run off and highlight the need of undertaking performance evaluation on such systems (Lyle and Bordovsky, 1991).

Under-designing of a sprinkler system ends up applying water at very low application rates which may require more time to replenish soil water deficit. Low rate of application increases costs in terms of material for covering the intended area under a given irrigation interval. Johns and Pair (1987), conducted a research on sprinkler systems in New Zealand and concluded that soil characteristics, crop water needs and climatic factors should be intertwined in designing for better performance of the system.

## **2.1 Sprinkler performance**

Operating pressure and nozzle geometry (i.e nozzle size, shape and angle) are the primary factors that control the operation of sprinklers. The performance of a sprinkler is described by its discharge, distance of throw, distribution pattern, application rate and droplet size. The spacing between adjacent sprinklers depends, in part, on the distance a sprinkler throws

water. Distance of throw increases as pressure is increased within the range of recommended operating pressure. Distance of throw also increases as nozzle sizes increase (other factors remaining constant).

Droplet size is an important factor affecting the formation of seals on bare soil surfaces that restrict water movement into the soil. Because small droplets possess less energy when they impact the soil surface, seals that limit infiltration form more slowly than with larger droplets. Droplet size is especially important when a sprinkler must operate in winds. Distribution patterns from sprinklers that emit smaller droplets are more subject to wind distribution and lower application uniformity.

Water droplet size is an important consideration in the design of sprinkler irrigation systems. Research has shown that small droplets lead to distortion of spray patterns by wind as well as water loss due to drift and evaporation (Thompson et al, 1986). Nozzle configuration and water pressure are both important factors in determining droplet size as well as distribution pattern. Large droplets may lead to a reduced soil infiltration rate through soil surface disruption caused by droplet impact (Mohammed and Kohl, 1986).

Sprinkler systems operating at lower pressures have received attention in recent years because of rising energy costs. However, for an established system (with circular bore nozzles) a lower pressure usually means larger droplets and a non-uniform distribution pattern. Hills (1987) has shown that poor application efficiency can be improved through operation of the

system with an oscillating pressure centre around a relatively low mean value. The on-farm irrigation systems and operations need to be measured to determine the potential efficiency that is obtained with present management. Sprinkler systems are usually evaluated in the field by determining the uniformity coefficient (UC), distribution uniformity (DU), potential application efficiency (PELQ) and actual application efficiency (AELQ). In addition, measurements are made to determine if the variation between sprinklers along laterals and between laterals are greater than the maximum recommended ones. The test evaluations at the tested area do not include line filling and emptying losses, gasket leakage or non-uniformity of discharge along the lateral and other locations in the field. One of the methods used in evaluation is the catch can method. In this method catch cans are used routinely to evaluate the performance of sprinklers especially in uniformity and efficiency evaluation. The results of a can test may not accurately represent the performance of the system being evaluated. This is mostly due to the following three factors.

a) The area of the catch device is often small compared to the area over which lateral redistribution of water occurs in or over the soils.

b) Significant evaporation losses can occur from the catch cans.

c) Wind causes drift of spray beyond the area which is covered by cans.

A good review of the three factors listed which affect the usefulness of can test is presented by Heermann and Kohl (1987). They indicated that the magnitude of sprinkler loss due to evaporation is higher than from other

sources, such as from catch cans and wind effects.

Previous studies on the effect of wind on catch-can performance have been prompted largely by the need for quantifying wind effects on rain gauges. Kurtyka et al,(1972), found that rain gauges exposed to wind caught less rain than those exposed to wind. Vories, (1988) applied a system for modelling the performance of sprinkler irrigation to show the predicted response of the system. The modelling system was to show the response of the system to varying wind speed, sprinkler spacing and water operating pressures.

One of the most important factors in the operation of a sprinkler irrigation system is the uniformity of distribution of water over the field. Uniformity tests usually require placing several identical collectors in an equally spaced grid in the field around a sprinkler.Griffin (1978) reported that most agricultural sprinkler application requires a coefficient of uniformity of at least 80 per cent for market acceptance. The appropriate design of coefficient of uniformity is a function of available water, crop water response, and crop price (Von Bernuth, 1985). Low coefficient of uniformity, indicates an incorrect combination of sprinkler size, operating pressure and spacing.

Performance measures of sprinkler irrigation systems may focus on a system's impacts, on its output or its internal process. Measures of impact attempt to evaluate the external consequences of the sprinkler irrigation system. These include the effects on agricultural production, and

on the rate of economic development. Measures of output evaluate the amount, time of application, uniformity and quantity of water delivered.

Hence, a system performance evaluation of a sprinkler irrigation system as any other irrigation method, is emphasized so as to undertake corrective measures whenever a shortfall in objective is observed.

### 3. MATERIALS AND METHODS

#### 3.1 Location

Mtibwa Sugar Estates is situated between longitude  $37^{\circ} 38'E$  and latitude  $6^{\circ} 10's$  near the village of Turian in Morogoro Region, Tanzania (Fig 2). The Nguru mountains which rises to about 2135 m border the area to the west. To the south and East are the Wami, Diwale and Njonga rivers. To the North, the area is bordered by the Njonga river which is a tributary of the Wami river.

#### 3.2 Topography and Geomorphology

The area forms a part of the colluvial-alluvial flood plains lying between the Diwale and Wami rivers. The Nguru mountains form an escarpment running to the North East and to the South-West. The Wami river, which is the largest river near the area flows along this escarpment. This river, together with its tributaries (Diwale, Njonga and smaller seasonal streams) form the main sediment transporting and depositing agents.

The altitude of the study area varies from 340m above sea level in the south, to 380m above sea level in the north. The general slope is towards south and south west. The gradient is however, not much pronounced due to cultivation coupled with land levelling. The Nguru mountains lie to the west and rise to a height of 2135 m above sea level.

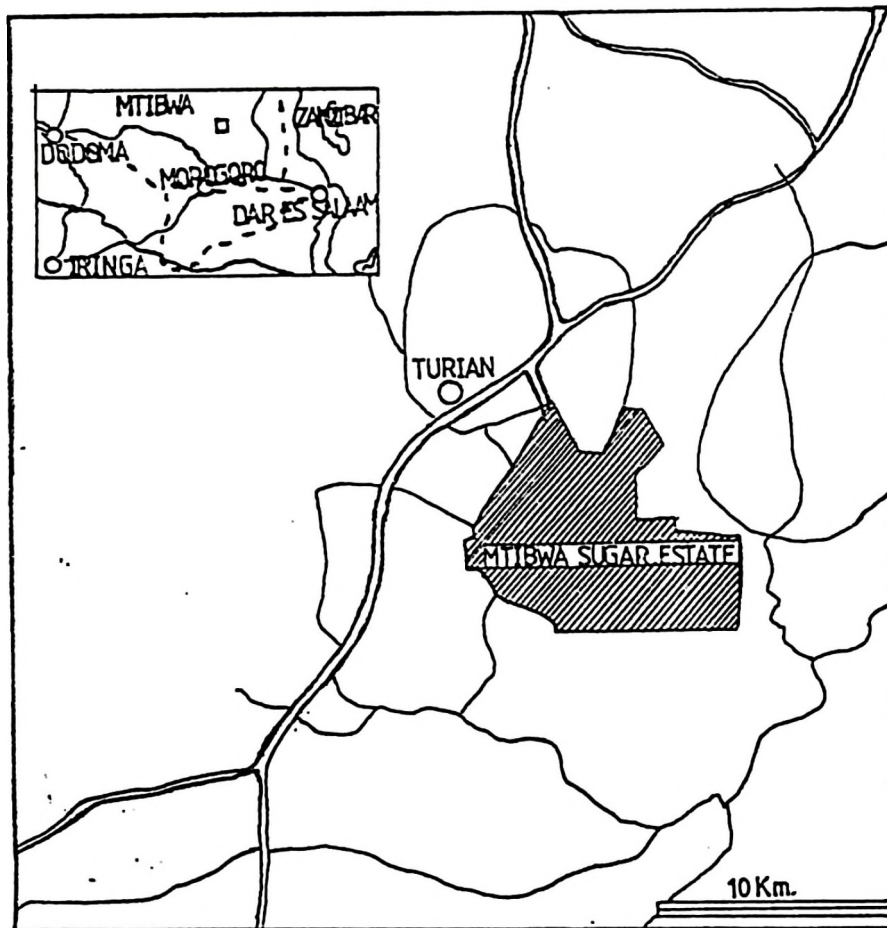


FIGURE 2. LOCATION OF MTIBWA SUGAR ESTATE.

### **3.3 Climate**

#### **3.3.1 Rainfall**

The mean annual rainfall is 1180mm. The long rains begin towards the end of February and end in late April or beginning of May. Short rains come during the months of November and December. The rainfall pattern is bimodal, with one peak (high) during March/April and another (Low) in November/December. The months of June to October are usually dry, receiving the lowest amount of rainfall. The onset of rains and the rainfall distribution pattern over the years has been very much unpredictable and unreliable.

#### **3.3.2 Temperature**

Records of temperature show that maximum air temperature varies from approximately 28°C to 30°C in the coldest months of June/July, with an average of 30°C and between 33-36°C in the hottest months of October/November.

#### **3.3.3 Geology**

A large part of the estate consists mainly of alluvial material deposited by the Wami river and its tributaries, and alluvial material deposited by gravity from the Nguru mountains and the Kidudwe hill. The deposited material is derived from different parent material and therefore vary appreciably in mineralogy. The Nguru mountains are thought to consist

of garnetiferous granulites and some hornblende - biotite gneissose (Bookers Agriculture International, 1979).

#### **3.3.4 Soils**

The soils in this area are generally light to medium textured. They are mainly sandy loam and loamy sand in the top soil and sand loam clay in the subsoil. The soils are heterogeneous in nature and are moderately alkaline, and mild acid. Most soils are weak structured and sandy in nature therefore more frequent irrigation is needed for the good growth and high yield of sugar cane.

### **3.4 Instrumentation for field measurements**

#### **3.4.1 General**

Sprinkler systems are usually evaluated in the field by determining the uniformity coefficient (UC), distribution uniformity (DU), and potential application efficiency (PELQ). These parameters, are found from catch can tests where cans are placed on both sides of the lateral as shown in Figure 3.1.

#### **3.4.2 Can lay-out**

When an individual lateral is being tested, cans were placed on both sides of the lateral as shown in Fig 3. The catches are then mathematically moved so that the effects of overlap can be calculated.

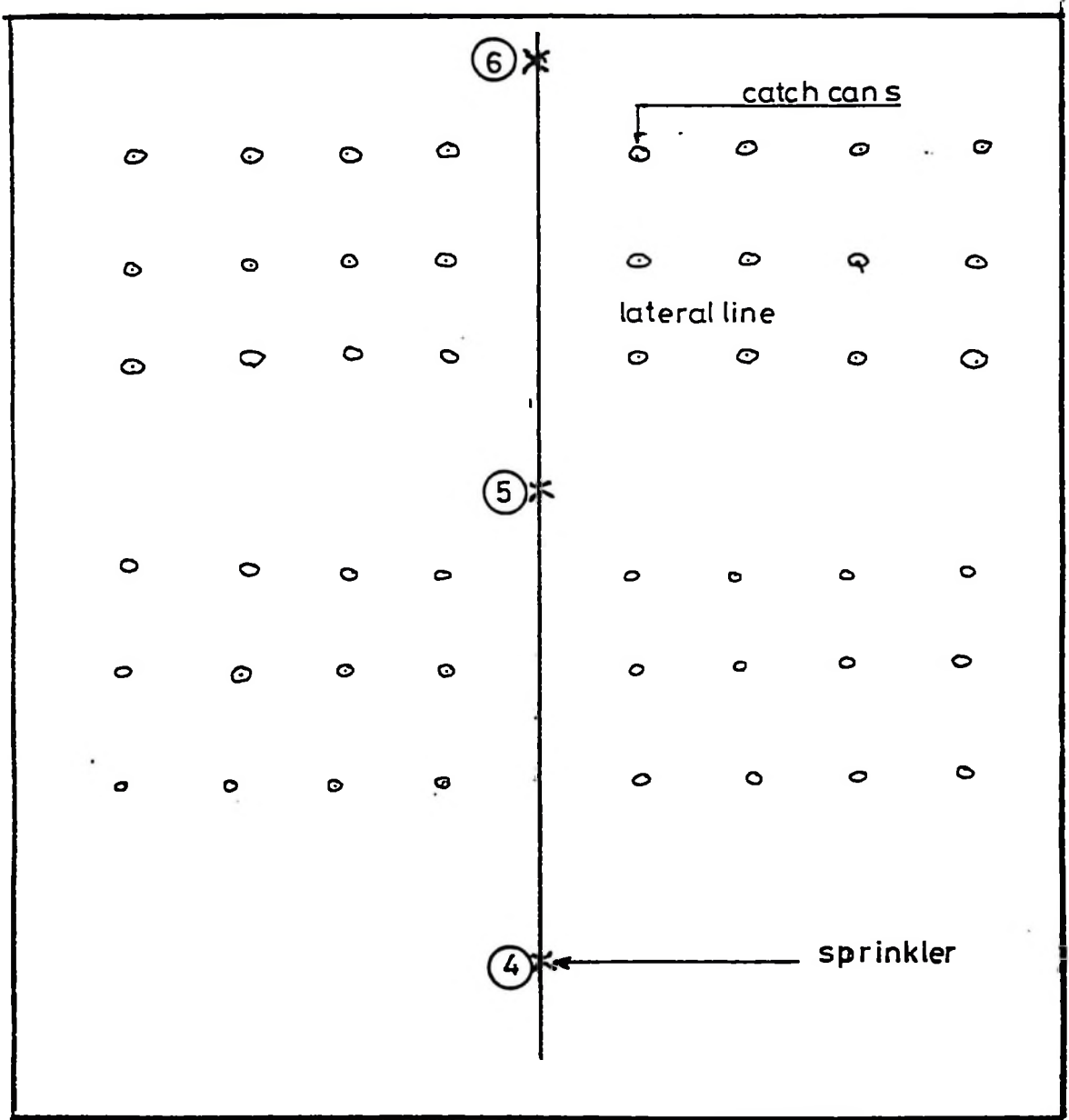


Fig.3 Can layout

Therefore 24 cans of 1 litre each with a spacing of 3m were placed in the overlapped area to give reasonable uniformity test values. Evaporation varies slightly, being greater near the edge than nearer the sprinkler which are more thoroughly wetted and contain water. One test can was set outside the catch area with expected typical catch depth placed in it at the start, and measured at the end to provide an estimate of the loss caused by evaporation.

#### 3.4.3 Water measurement in the catch can

Catchment in the cans were measured directly as depths in centimetres as the sides of the cans were vertical with a rectangular base. The duration of the set was judged when at least an average of 10mm is caught. Hence a test duration of 2 hours per setting was used as per the methods proposed by Merriam and Keller (1978). The recorded values of water caught in depths were converted into rates (cm/hr) by dividing the caught depth by duration of the test and recorded below the line on the data sheet. By assuming that the test is representative and that the next set would give similar/identical results, the right hand side of the catch pattern, as if it were a subsequent set, were overlapped or superimposed on the left hand side to simulate lateral spacing of 24 meters which is practised at Mtibwa sugar Estates.

Whenever a low quarter depth is required, the lowest six depth in each set were summed and averaged to give the average low quarter rate.

This is due to the fact that as they are 24 catch cans, the one quarter of 24 cans is 6.

In each lateral line tested, cans were arranged between sprinkler 4, 5 and 6 such that the data between sprinkler 4 and 5 and 5 and 6 were analyzed separately to give separate results for each parameter measured except for wind speed and sprinkler operating pressure.

#### **3.4.4 Pressure measurement**

Before starting the test, the sprinklers were stopped from rotating to prevent water from entering into the cans. Then, time of starting was recorded when the lateral line control valve was opened and all the sprinklers operating pressure stabilized. One lateral line has 15 sprinklers, hence sprinkler operating pressure was recorded at the 1st, 4th, 5th, 6th, 11th and the last sprinkler during the beginning and end of the test. A 10 bar pressure gauge with a pitot attachment was used to measure pressure in each lateral. Wind speed and direction were also measured during starting, testing and finishing time. After 2 hours, the test was terminated and depth of water in each can was recorded.

#### **3.4.5 Determination of soil moisture deficit (SMD)**

The soil moisture deficit (SMD) for 52 blocks was determined prior to running the test. This helped in knowing the moisture which the system should replenish to satisfy the SMD. The soil moisture deficit was

determined by soil augering at depths 0-30,30-60,and 60-90cm.Soil colour charts with feel method were used in determining the soil moisture.The soils for all 52 blocks of irrigated agriculture and the remaining for rainfed were analyzed by Mushi (1983). Therefore, the information on soil type, texture, and structure for each block was available at the irrigation department which simplified the work in soil measurements.

#### 3.4.6 Actual application efficiency of low quarter(AELQ)

Actual application efficiency of low quarter is the ratio of the average low quarter depth of irrigation water infiltrated and stored in the root zone to the average depth of water applied (Merriam and Keller,1978). Effectiveness of the use of a sprinkler system can be determined from how much of the applied water is stored in the soil and available for consumptive use and how uniformly it is applied.Whenever the irrigation exactly satisfies the soil moisture deficit in the least watered area, AELQ equals the potential application efficiency of low quarter.

##### 3.4.6.1 Determination of AELQ

$$AELQ = \frac{W_{ls}}{W_a} \dots \dots \dots (1)$$

where AELQ = Application efficiency of low quarter

$W_{ls}$  = average low quarter depth of water infiltrated and stored

$W_a$  = average depth of water applied

In this case depths are used instead of rates. As maximum depth of water stored cannot exceed the soil moisture deficit, the numerator in equation (1) equals the SMD.

The average depth of water applied which is the denominator of equation (1) is obtained in equation (3) and the practised duration of the set (Ta)

hence,

$$AELQ = \frac{SMD}{AAR \times TA} \dots \dots \dots (2)$$

where SMD = Soil moisture deficit (mm)

AAR = average application rate

TA = set duration

#### 3.4.7 Potential application efficiency of low quarter(PELQ)

This is the efficiency that is obtained and expressed as a percentage when the average low quarter depth of water infiltrated equals the management allowed deficit(MAD).The PELQ is determined in order to evaluate how effectively the system can utilize the applied water.The PELQ indicates how well the tested sprinklers are able to operate if they are run at the correct length of time to satisfy the soil moisture deficit.

3.4.7.1 Determination of PELQ

$$PELQ = \frac{W_{ra}}{R_s} \dots \dots \dots (3)$$

where  $W_{ra}$  = average low quarter rate of water applied

$R_s$  = average rate applied through sprinklers

The average rate applied through sprinklers ( $r$ ) is given by

$$r = 3600 \times \frac{q}{S_1 \times S_2} \text{ (mm/hr)} \dots \dots \dots (4)$$

where  $q$  = measured sprinkler discharge (liters/second)

$S_1$  = lateral spacing (m)

$S_2$  = sprinkler spacing (m)

The average low quarter rate is obtained as in DU in section 3.4.8.1.

3.4.8 Distribution uniformity (DU)

This is defined as the ratio of the average low quarter depth of irrigation water caught to the average depth of water infiltrated or caught. The distribution uniformity measures how well is the applied water distributed over the irrigated area but does not measure the adequacy of irrigated water. A common way to show how uniformly water is distributed by the uniformity coefficient (UC) which is statistical representation of the catch patterns. The relationship between DU and UC is as shown in Table 3.1.

3.4.8.1 Determination of Distribution Uniformity

$$DU = \frac{W_{qc}}{W_{dc}} \dots \dots \dots (5)$$

where  $W_{qc}$  = average low quarter depth caught

$W_{dc}$  = average depth of water caught

The average depth of water caught in equation (5) is obtained by averaging the sum of values recorded from 24 catch cans.

Table 3.1 Average relationship between distribution uniformity and uniformity coefficient.

Coefficient	Coefficient value in % .							
DU	39	45	52	59	66	74	83	92
UC	60	65	70	75	80	85	90	95

Source: Jensen,(1988).

3.4.9 Determination of UC

$$UC = 1 - \frac{D}{C} \dots \dots \dots (6)$$

where D = average deviation from the average catch

C = average catch

The absolute deviation of each reading in 24 catch cans from the average

catch was obtained, summed and average of the sum gave the numerator of equation (7).

The denominator of equation (7) is obtained as from equation (1).

**3.4.10 Comparison between the practised duration set (Ta) and actual calculated time (ACTIM)**

The irrigation system at Mtibwa has been designed to apply 68mm of water in 10 hours sprinkling in a 12 day cycle for cane with a full closed leaf canopy. In young cane which has not yet a closed leaf canopy, evapotranspiration is less and rooting depths are shallow such that 5 hours of sprinkling in a 8 day cycle can replenish the moisture deficit. Therefore set durations of 5hrs and 10hrs are practised at Mtibwa for young and old cane respectively.

From the catch can data, the duration per set of sprinkling was checked and compared with the practised one for each block.

Hence;

$$ACTIM = \frac{SMD}{LQR} \dots \dots \dots (7)$$

where SMD = Soil moisture deficit

LQR = Lower quarter rate

The soil moisture deficit was obtained from soil measurement taken prior to test run in each block and lower quarter rate was obtained as in other already mentioned parameters.

**3.4.11 Comparison between sprinkler and pump operating pressure versus the designed ones.**

The designed sprinkler operating pressure at Mtibwa sugar is 3.2 bar derived from pumping station 1 (PPS 1) and 2 (PPS 2) which are supposed to operate steadily at a pressure of 7 bar.

Therefore, during running the catch can test, the pump operating pressure was recorded for the entire full day of operating and testing. The results from the recorded pressure were compared with the designed ones.

## 4. RESULTS AND DISCUSSION

### 4.1 INTRODUCTION

This chapter presents the results of sprinkler performance evaluation derived from each block between sprinklers 4 and 5, and 5 and 6 in each lateral under test. The distribution uniformity as well as coefficient of uniformity are presented. The potential application and application efficiencies of low quarter are also calculated in order to evaluate how effectively the system can utilize the applied water. The application rate for sprinklers under test and the required duration of application per one setting is also presented.

### 4.2 Coefficient of uniformity

The results of the coefficient of uniformity for all 52 blocks are shown in Table 4.1. The highest coefficient of uniformity of 99 % was obtained in block 10Ca and 10Cb compared with the designed one of between 81 and 87 % respectively. The lowest coefficient of uniformity was 22 % followed by 61 % obtained in blocks 1B and 9Ab respectively. Despite that there were higher values obtained in some blocks, yet many experienced uniformity coefficient below 80 % which is regarded as low for sprinkler irrigation.

Close examination of the results of the uniformity coefficient (UC) show that blocks which experienced low UC values were associated with

Table 4.1 Results for UC,DU,PELG,AEIG,ACTIM, WIND SPEED AND OPERATING PRESSURE

BL0C	UC1	UC2	DU1	DU2	PEL01	PEL02	AEIG1	AEIG2	APPR11	APPR12
1A	88	82	88.88	81.88	81.1	88.8	88.8	88.8	0.9	0.9
1B	72	74	88.97	88.84	80	88	80	80	1	1
1C	88	81	88.48	88.8	87	82	80	80	1	1
2Aa	88	88	78.84	78	78.8	78	88.2	78	0.9	1
2B	76	87	71.47	88.99	78.8	77.8	82.2	82.2	0.9	0.9
3Ca	81	87	88.82	81.42	87	88	88.9	88.9	0.9	0.9
3Cb	88	82	88.88	81.88	81.1	88.8	88.8	88.8	0.9	0.9
3De	88	88	82.42	80.44	78.8	87.8	82.2	82.2	0.9	0.9
3Dd	82	88	82	88.47	80	48	70	70	1	1
3Fa	84	87	80.84	81.8	74	72	80	80	1	1
3Fb	88	88	84.82	81.8	78.8	78	88.2	78	0.9	1
3Ea	88	88	82.1	82.87	80	88	80	80	1	1
3Eb	88	87	81.48	74.01	71.2	88	78	78	0.9	0.9
4Aa	88	88	84.08	72.11	80	71.1	88.8	88.8	0.9	0.9
4Ca	80	82	70.88	84.08	74.4	78.7	88.8	88.8	0.9	0.9
4De	87	82	817	80.47	80	88	80	80	1	1
4Dd	81	88	72.87	74.82	88.7	72.2	88.8	88.8	0.9	0.9
4Ea	84	81	88.9	82.78	70	88.7	88.8	88.8	0.9	0.9
4Eb	88	88	88.44	88.4	70	88.8	88.8	88.7	0.9	0.9
4Fa	88	80	82.88	81.48	80	82.8	80	88.9	1	0.9
4Fb	77	78	87.98	88.91	82.8	80	87.8	87.8	0.9	0.9
8Ea	88	78	84.81	78.91	88	48	80	80	1	1
8Eb	71	88	81.8	88.98	88.2	78	78	78	0.9	0.9
8Aa	81	80	71.84	82.14	80	82.2	87.8	71.8	0.9	0.9
8Ab	88	88	80.82	88.88	81.1	88.8	88.8	88.8	0.9	0.9
8Da	87	88	88.08	88.87	88	88	88.8	88.8	1.2	1.2
8Dd	88	82	81.88	81.82	77.8	88.2	88.9	88.9	0.9	0.9
7Ea	88	88	82.78	88.82	78	78	78	88	0.9	0.7
7Eb	80	82	88.48	88.2	81.2	78.7	87.8	87.8	0.9	0.8
7Ea	88	87	887	80.78	80	88	80	80	1	1
7Eb	88	82	77.88	88.87	84	82.2	80	80	1	1
8Aa	81	82	80.88	78.89	82.8	78	78	78	0.9	0.9
8Ab	81	81	88.48	48.89	82.8	48	78	88	0.9	0.7
8Ga	81	82	88.4	87.84	48	88.8	88.8	78	0.9	0.8
8Gb	70	70	88.48	71.08	88.8	88.2	88.8	78	0.9	0.8
9Ba	84	88	87.24	88.88	78	78	88	88	1.2	1.2
9Bb	82	82	82.98	88.89	88.9	88	72	80	0.9	1
9Ca	87	84	74.88	88.19	78.9	78	81	88.8	1.2	1.2
9Cb	88	80	84.41	81.03	77.7	80	88.7	80	0.9	1
9De	88	84	78.47	89.84	88.2	78	88.2	88.2	1.2	1.2
10Ba	88	84	72.88	88.9	82	80	80	80	1	1
10Bb	77	80	88.08	81.18	70	80	80	80	1	1
10Ca	88	80	82.84	88.84	88.2	88.2	88.7	88.7	1.2	1.2
10Cb	88	82	88.8	88.97	88.2	88.2	78	78	1.2	1.2
10Da	80	77	89.33	84.82	80	70	80	80	1	1
10Dd	78	73	88.43	48.08	78	80	80	80	1	1
10Ea	83	84	88.03	80.88	89	78	80	80	1	1.2
10Fa	84	84	88.9	87.8	80	91	80	80.8	1	0.9
11Aa	84	81	87.84	82.42	80	80	80	80	1	1
11De	87	87	78.98	78.83	83.2	78.9	83.2	78.9	1	1.2
11Ea	87	84	74.28	87.71	83.2	80	88.2	70	1.2	1

Table 4.1 continue

BLOCK	ACTIM1	ACTIM2	OPPRESS	WINSPEED
1A	10	11.42	3.2	2
1B	10.6	13.33	2.6	3.5
1C	8.98	8.98	3.2	3.2
2Aa	11.42	10	3.4	3
2D	6.67	6.67	2.8	2.5
3Ca	10	10	3.2	2.6
3Cb	6.7	6.7	2.9	3.0
3Ca	7	7.8	2.6	4.0
3Cb	8.9	8.9	3.0	2.5
3Fa	8.9	10	3.2	3.0
3Fb	8	8.98	3.2	3.5
3Ea	11.42	10	3.2	2.0
3Eb	8	8.98	3.2	2.0
4Ea	10	9.67	3.0	2.0
4Ca	17.4	15.09	2.0	2.0
4Da	6	6.7	2.6	2.0
4Cb	6	5	2.8	2.0
4Ea	15.36	14.28	2.0	2.5
4Eb	10.67	10.67	2.9	3.0
4Fa	9.23	10.17	2.9	3.5
4Fb	10	10.28	2.0	2.0
6Ea	12.5	14.29	2.2	2.0
6Eb	7.84	7.84	2.1	4.0
6Aa	11.42	10.67	3.2	3.0
6Ab	9.41	15.6	3.0	3.0
6Ca	11.3	13.3	3.2	2.0
6Cb	10.9	8.43	3.2	2.0
7Ba	10.93	10.25	3.2	2.0
7Bb	11.94	11.92	3.0	4.5
7Ea	13.3	12.3	2.8	2.5
7Eb	11.9	12.5	2.6	2.5
8Aa	13.3	8	3.2	2.5
8Ab	8	9.41	3.0	3.0
8Ca	8.9	10.67	3.0	3.0
8Cb	12.2	15.38	2.6	2.0
9Ba	25	18.67	2.0	2.0
9Bb	8.04	9.3	2.0	2.0
9Ca	10.95	16	2.8	2.0
9Cb	5.6	6.25	3.0	2.0
9Da	11.4	14.54	2.0	2.0
10Ba	14	14.58	2.0	2.0
10Bb	10.52	8.82	3.0	2.0
10Ca	9.41	9.3	3.0	3.0
10Cb	9.46	9.72	3.0	3.0
10Da	11.4	10.67	2.8	3.0
10Db	10	9.33	3.2	2.5
10Ea	10.89	11.42	3.0	4.0
10Fa	8	8	3.0	2.5
11Aa	9.5	9.5	2.0	2.0
11Da	38	16.7	1.8	2.0
11Ea	10.34	9.78	3.0	3.0

low application rate and operating pressure which were below the designed ones (Fig. 4.1). Michael (1978) observed that the combination of lateral and sprinkler spacing, nozzle size and operating pressure adversely affect the UC for sprinkler irrigation. Though the coefficient of uniformity does not measure the adequacy of irrigation water applied to satisfy the soil moisture deficit, yet it shows that there is a variation of water received at different blocks or point which can contribute to differences in yields.

Seginer (1978) reported that there is a net loss of \$180 per hectare for a 0.1 decrease in the uniformity coefficient in cotton production due to non uniformity of water application. The low UC observed in some blocks could be attributed to low operating pressure. The sprinkler operating pressure for the blocks with low UC ranged from 2 to 2.8 bar against the designed one of 3.2 bar. Operating at low pressure causes formation of large droplets which causes doughnut water distribution, with outer edges of the irrigated field receiving less amount compared with the inner ones. It is observed that the UC values for some blocks didn't meet the recommended values. It is also clearly observed that the coefficient of uniformity for some blocks did not meet the required standard for sprinklers (Fig.4.2 and 4.3) and hence there is a variation of water received at different blocks and points within the blocks. Lastly, the low values and variation of coefficient of uniformity observed can be due to low application rate, low operating pressure and high wind speeds.

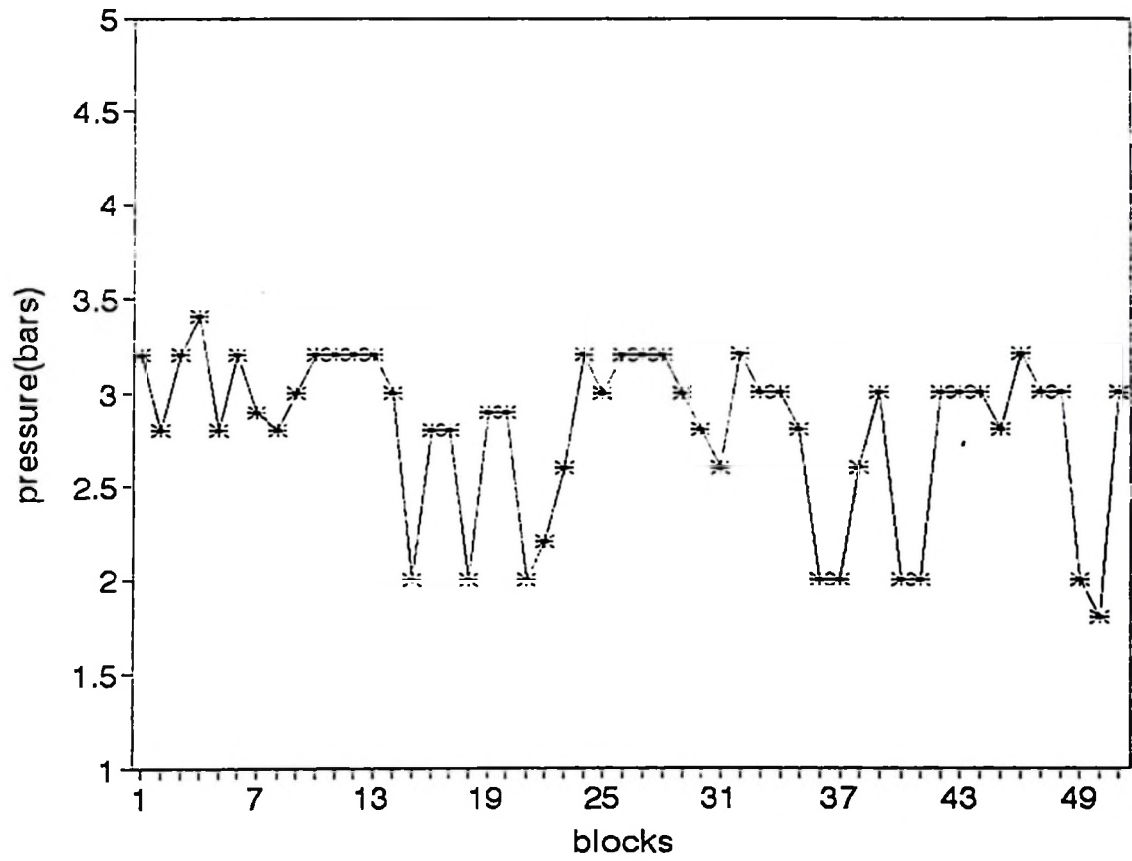


Fig 4.1 Sprinkler operating pressure

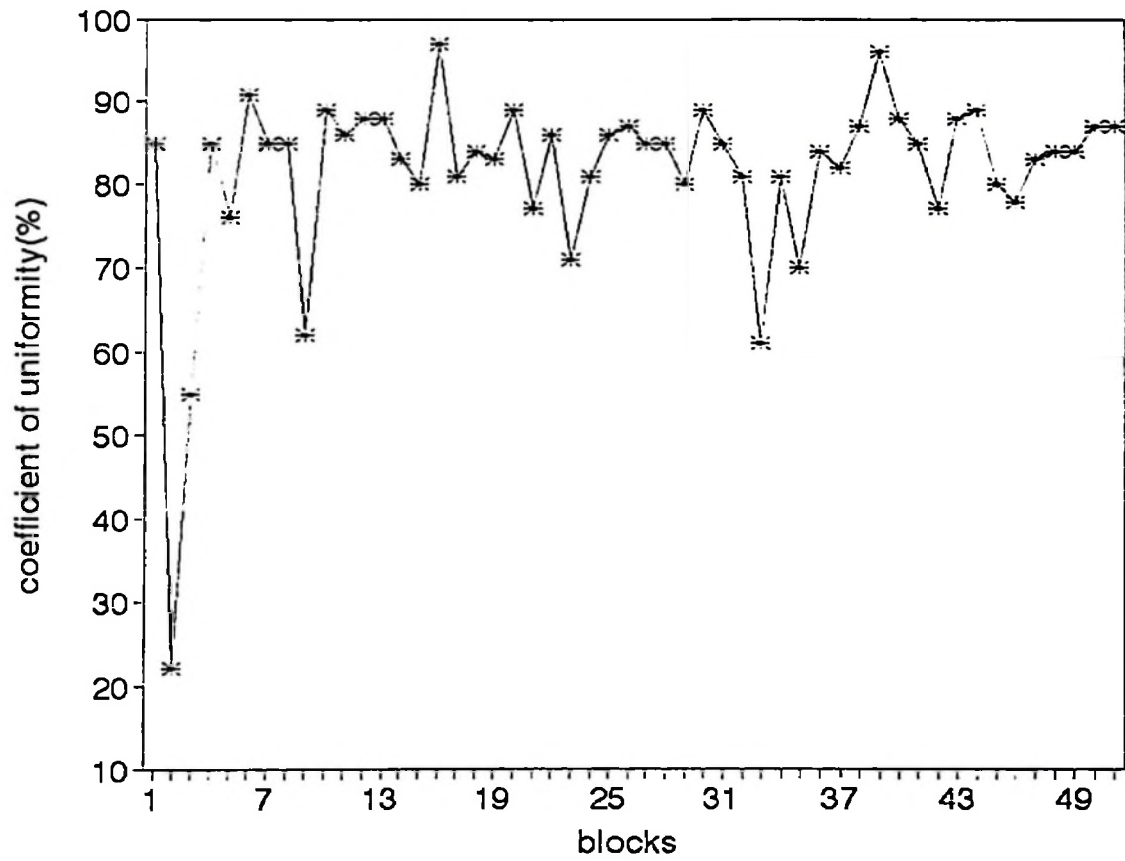


Fig 4.2 Coefficient of uniformity between sprinkler 4 and 5

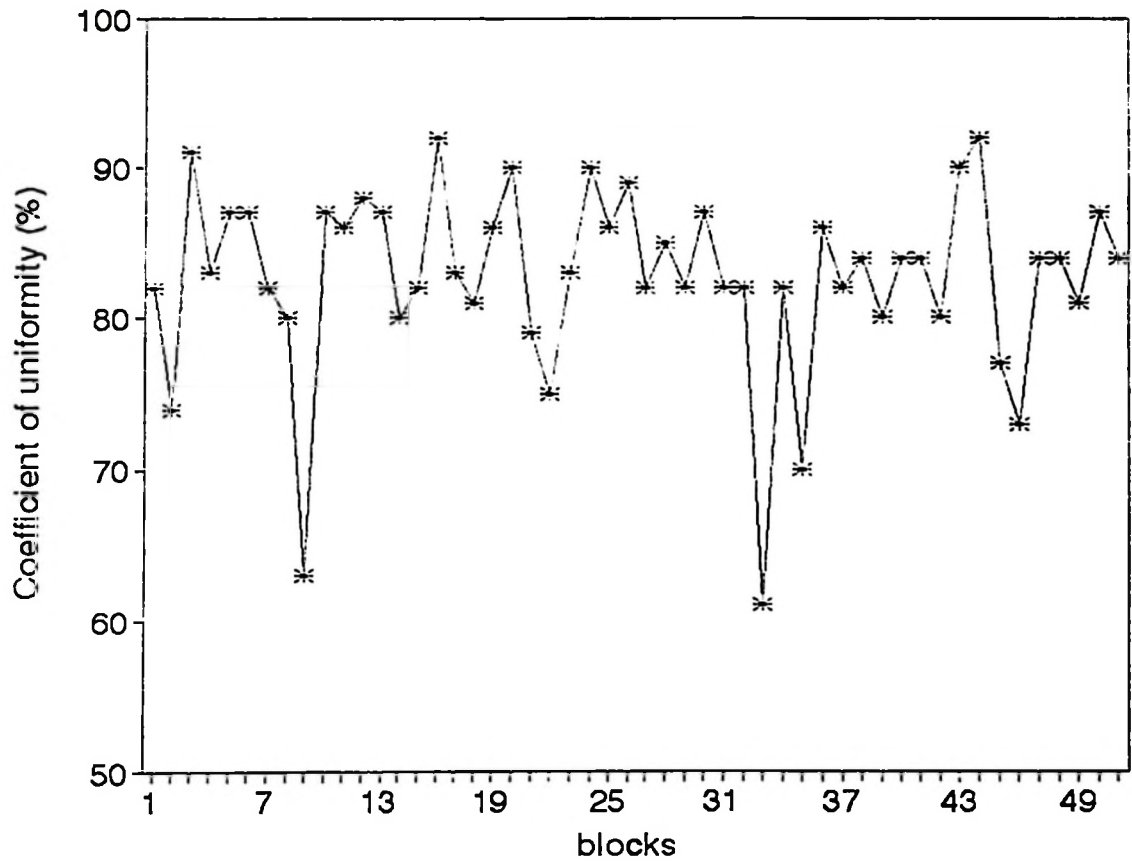


Fig 4.3 Coefficient of uniformity between sprinkler 5 and 6

#### 4.3 Application efficiency of low quarter (AELQ)

The results of actual application efficiency of low quarter are as shown in Table 4.1 (AELQ<sub>1</sub>, and AELQ<sub>2</sub> representing results between sprinkler 4 and 5, and 5 and 6 respectively). The AELQ results between sprinkler 4 and 5 range from 58.3 to 92.2% while the AELQ results between sprinkler 5 and 6 range from 50 to 92.2%. About 50.7% of the blocks tested showed AELQ of less than 80% between sprinklers 4 and 5 and 38.4% of the blocks showed AELQ less than 80% between sprinklers 5 and 6. Merriam and Keller (1978) suggested that for a sprinkler irrigation, high values of AELQ above 80 % should be achieved for minimum losses of water applied. From these results, it shows that the values of AELQ obtained are low and hence indicate management problems of the system.

#### 4.4 Potential application efficiency of low quarter (PELQ)

The results for potential application of low quarter are as presented in Table 4.1. The PELQ, range from 30 to 90% between sprinkler 4 and 5 and from 40 to 92.2% for sprinkler 5 and 6. However 30.7% of the blocks tested showed PELQ of less than 80% between sprinklers 4 and 5 and about 50% of all the blocks recorded PELQ of less than 80% between sprinkler 5 and 6.

The low values of PELQ observed indicate that there is a problem in the system in its design and hence certain variations on operations should be changed for better performance of the system.

Effectiveness of use of a given sprinkler system can be determined from how much of the water applied is stored in the soil and available for consumptive use and how uniformly it is applied. Whenever the irrigation exactly satisfies the soil moisture deficit (SMD) in the least watered area, AELQ equals PELQ. (Merriam & Keller, 1978)

But if excess water is applied much of it may percolate too deep and be lost. This would result in an AELQ considerably less than PELQ. Close examination of results of AELQ and PELQ for both sprinkler's set (i.e sprinkler 4 and 5 and 5 and 6) show that 31 blocks tested between sprinkler 4 and 5, values of AELQ are greater than PELQ which is about 59% of all blocks. Likewise 23 blocks which is about 44% of all blocks show values of AELQ greater than PELQ.

Whenever there is a difference between AELQ and PELQ, it indicates that there is a management problem. Either the irrigation duration is too long or too short. When AELQ is greater than PELQ, it shows that the duration of irrigation per set is short and hence inadequate water applied to meet the prevailing soil moisture deficit. It can be clearly concluded that the amount of water applied at blocks with AELQ greater than PELQ did not meet the prevailing soil moisture deficit and hence the crop experienced water stress which adversely affected crop growth and ultimately sugar cane yields. As it has been observed that there was under-irrigation in about half of the blocks, the insignificant yield difference between the rainfed and sprinkler irrigated is due to this inadequate water supply.

#### 4.5 Actual application duration required

The results for actual application duration (hrs) are as shown in Table 4.1. ACTIM1 refers to actual application duration between sprinklers 4 and 5 while ACTIM2 refers to actual application duration between sprinkler 5 and 6.

From Fig 4.4 and Fig 4.5, it is clear that 36.5% of total blocks between sprinkler 4 and 5 and 40% of the total blocks between sprinkler 5 and 6 required longer duration per set. The variation of duration of application per set was attributed to low application rate recorded which also was due to low operating pressure. The sprinkler operating pressure is the most important component of a sprinkler irrigation system. Its operating characteristic under optimum water pressure and climatic conditions, mainly wind velocity will determine its suitability and efficiency of the system (Michael, 1978).

#### 4.6 Wind speed

Wind speed and direction are the two main wind characteristic considered in sprinkler design and which affect greatly the uniformity application of the applied water (Convey et al, 1958).

The wind speed variation during the testing is as shown in Figure 4.6. Wind speed varied from a minimum of 2m/s to a maximum of 4.5m/s.

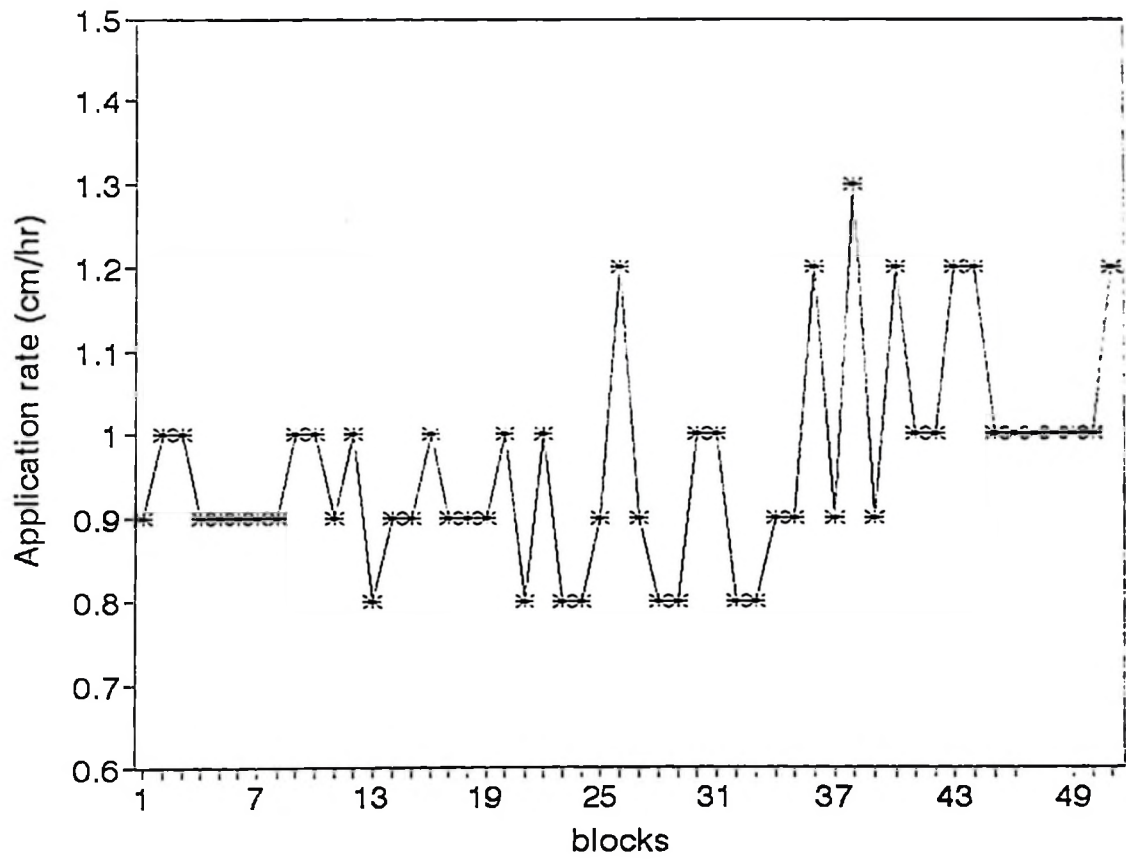


Fig 4.4 Application rate between sprinkler 4 and 5

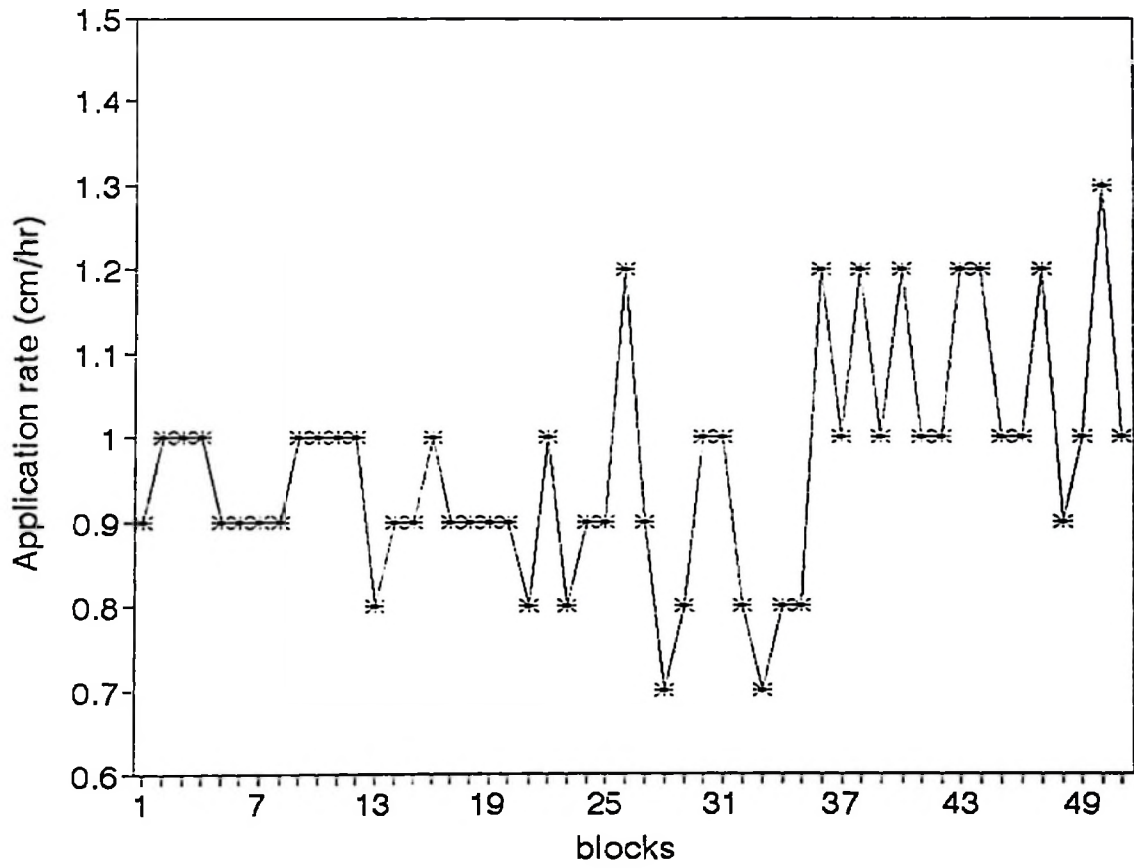


Fig 4.5 Application rate between sprinkler 5 and 6

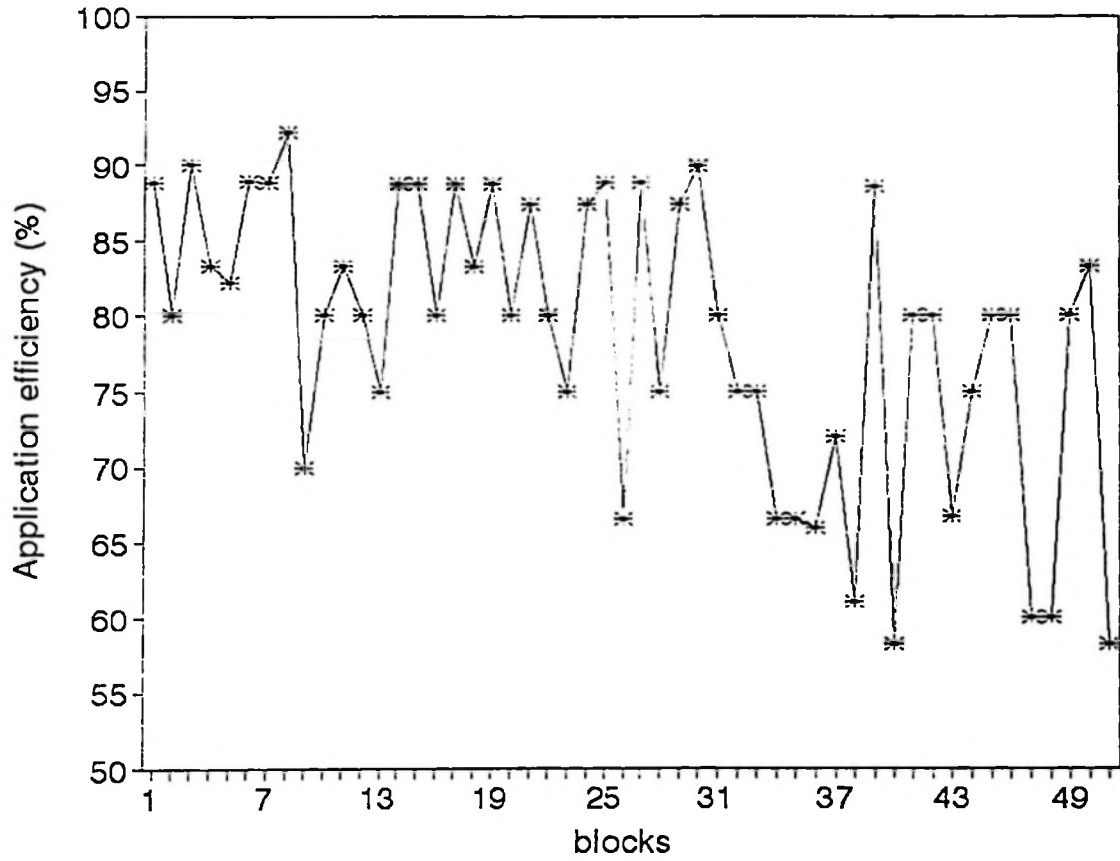


Fig 4.6 Application efficiency law quarter between sprinkler 4 and 5

Sprinklers spray ejected high into the air will be subjected to greater wind speeds and greater pattern distortion than spray near the surface. The ideal angle for a sprinkler jet under calm condition is 32 degrees above the horizontal. However, under windy conditions, a lower angle must be used to obtain a good range. The effect of riser height is similar to jet angle (Strong, 1961). The higher the sprinklers the greater pattern distortion because of increasing wind velocity with height.

The high values of wind speed recorded were mostly in the morning hours (from 8.00 to 11.00 hrs) and lower values during the remaining period. As windspeed increases, spacing must be decreased to maintain the same coefficient of uniformity. The average wind speed at Mtibwa was 3m/s (10.8km/h) which according to Merriam & Keller (1978), a lateral spacing of 50% of wetted diameter should be practised. Fortunately, the overlap practised at Mtibwa is 30% which is even closer than the recommended spacing.

Therefore, it can be concluded that the effect of wind in lateral spacing is within the recommended range and thus the low yield level of sugar cane is not due to high spray distraction due to windspeed. Diurnal reduction in wind speed is one of wind speed characteristics. At most locations, night wind speeds decrease sufficiently to effect scheduling successive irrigation during alternate day/night. It is thus, suggested that the Mtibwa system be irrigating a given location during the night when the preceding irrigation was during the day and vice-versa.

#### 4.7 Operating pressure

The application rate for most of the blocks are below 10mm/h (Fig.4.4 and 4.5) against the designed one of 10.2mm/hr and this can be due to low operating pressure for most sprinklers compared to the designed one of 3.2 bar. The problem of operating at low pressure is also observed in both pumping stations 1 and 2 where maximum recorded pressure is 5 bar against the designed one of 7 bar. Due to this, the throw distance of the sprinkler is reduced such that there is a need to reduce the lateral spacing rather than maintaining the designed one of 24m. The reduction of lateral spacing can also check the effects of wind. Another problem observed is of edge effect where the edge of an irrigated field does not always receive the full overlap application from other sprinklers. This includes both the area parallel to the last lateral set on each side of the block and at the ends of the block.

Hart and Heermann (1985) reported about 10 % loss of water if the laterals are placed right on the field boundary edge and if they extend to the ends. This problem was observed at each end of the block where last sprinklers were irrigating the service roads.

The results of average sprinkler operating pressure recorded for sprinklers 4,5 and 6 in each block are as shown in Table 4.1 and Fig 4.1. The pressure recorded range from 1.8 to 3.2 bar against the designed nozzle operating pressure of 3.2 bar.

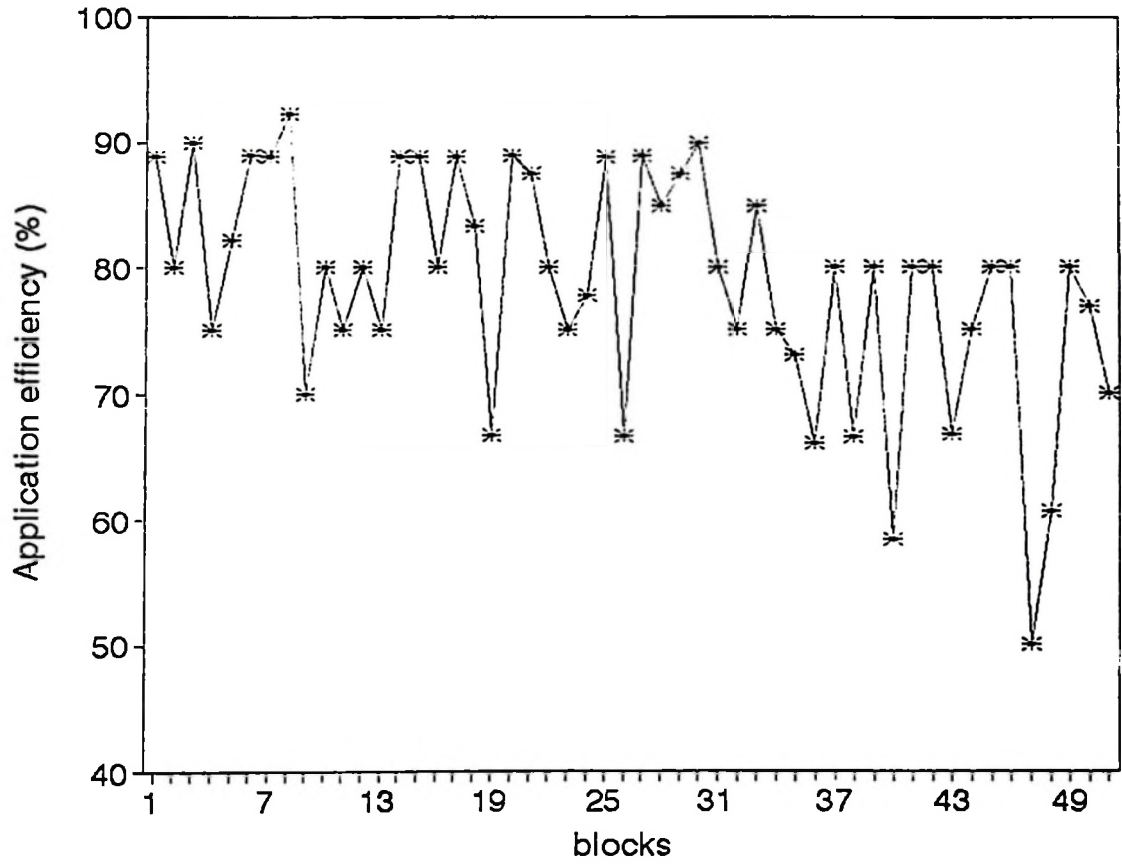


Fig 4.7 Application efficiency low quarter between sprinkler 5 and 6



Fig 4.8 potential application of low quarter between sprinkler 4 and 5

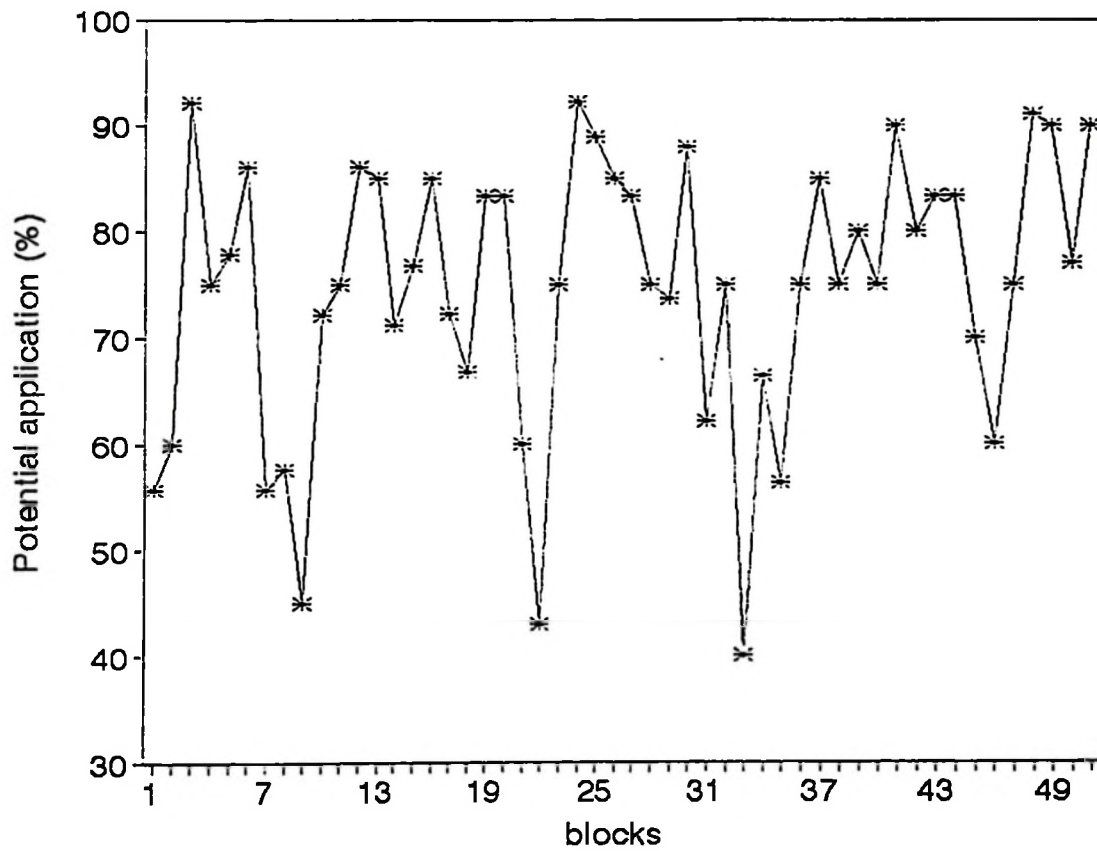


Fig 4.9 Potential application of low quarter between sprinkler 5 and 6

The recorded pressure shows that 75 % of all blocks had sprinkler operating pressure below the designed one. The low sprinkler operating pressure is caused by mainly operating the two pump station at low pressures. A report by National Development Corporation (1992) concerning the Mtibwa sugar estate system pointed out that for well functioning sprinklers, the water pressure should be kept as constant as possible. A constant pressure of 7 bar at the two pump stations should be maintained during operating the system. Conversely, the maximum operating pressure recorded in pumping station 1 and 2, when all sprinkler lines were working was 4 bar with two pumps working. When the 3 pumps were all operated with all lines working, the maximum pressure recorded was 5.4 bar.

This clearly shows that the low sprinkler operating is caused by low pressure from the pumps. The problem of pumps operating at low pressure and consequently the low sprinkler operating pressure is caused by two factors. Firstly, the sprinkler system is fed from two sources of power, the factory generated one using a generator and the National Grid system. When the factory one is stopped for one reason or another a change-over is made to the National Grid. The capacity of this line is insufficient for both the factory and irrigation and the power supply to the pumpstation is reduced to 1200 Amperes only which is insufficient. The fluctuating power supply leads to irregular water deliveries to the field and consequently to low sprinkler operating pressure and low cane yields.

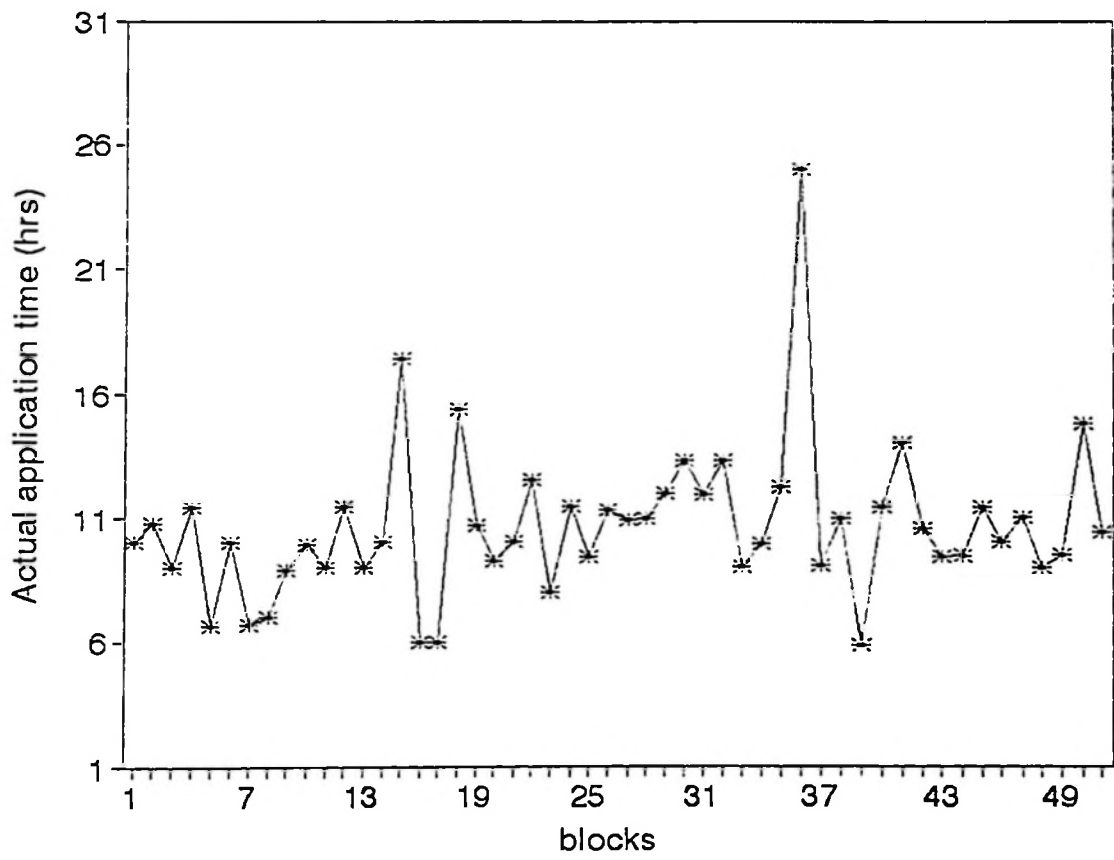


Fig 4.10 Actual application time

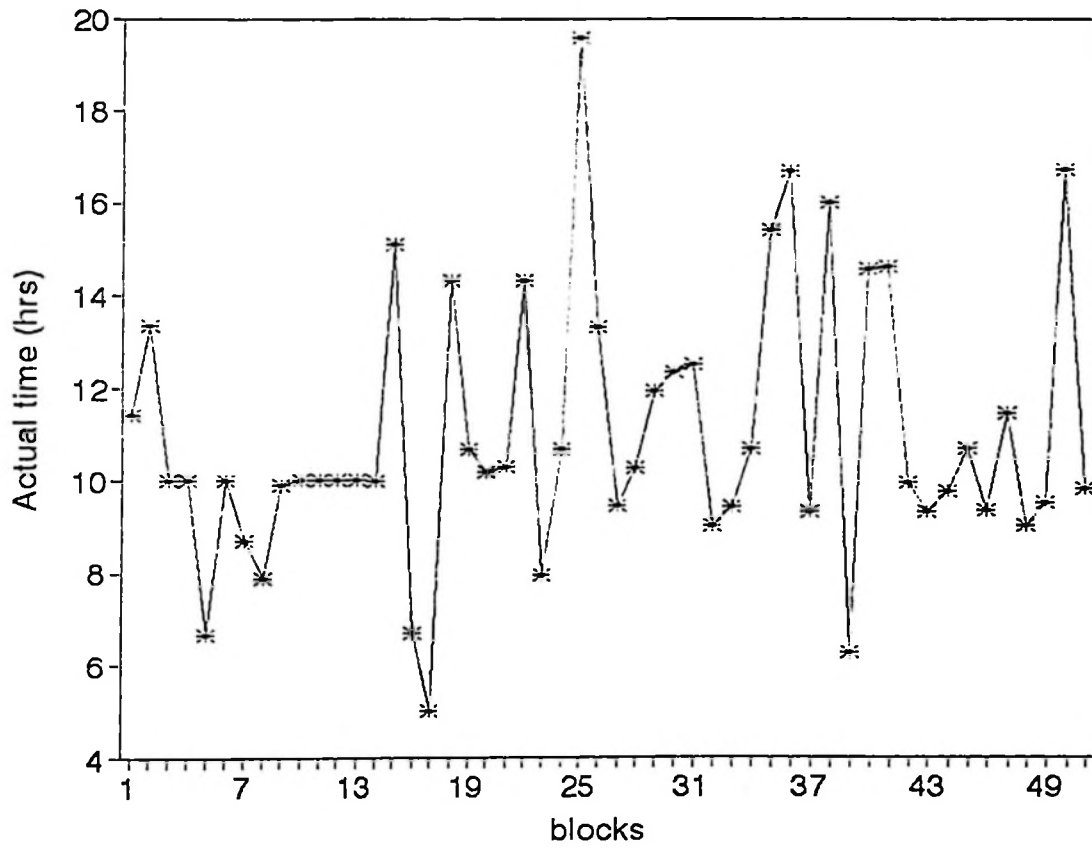


Fig 4.11 Actual application time between sprinkler 5 and 6

Secondly, the reset alarm which was installed to alert the pump operator of how much water is flowing and number of sprinkler lines are in operation, is not working since 1982.

Hence, the pump operators cannot know exactly how many lines are working and instead they rely on trial and error in regulating the pressure. Sometimes, this resulted to bursting of the mains as three pumps were operated while no line was in operation. That is why the H.V.A. International (1978), the company which installed the system suggested in their report that a test should be carried in order to determine the number of laterals, including the number of sprinklers, which can be operated while keeping the pressure at the pumps constant at 7 bar.

In 1992, the Netherlands Development Cooperation which aided the sugar sector in Tanzania from the early 1970's conducted an evaluation on the performance of four of the largest sugar estates in Tanzania, namely Mtibwa, Kilombero, Kagera sugar, and TPC.

In the evaluation report, Netherland Economic Agency (NEI) (1992), reported the main factors which influenced the low level of yield of cane for all four estates. The low yield levels of various estates show strong fluctuations from one year to the next and generally declining trend during the 1980s, especially after 1984.

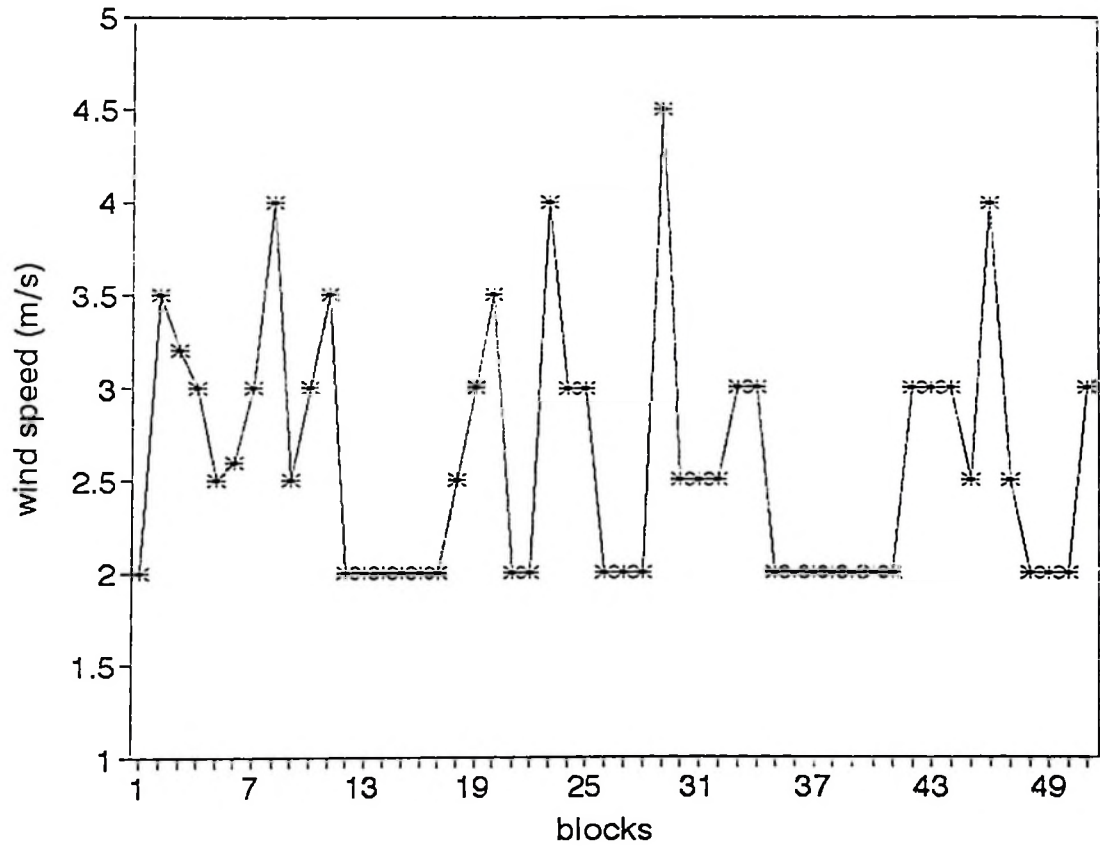


Fig 4.12 Average wind speed

The low yield levels at Mtibwa sugar estates is due to shortcomings in the irrigation system which result in negligible differences between irrigated and rainfed cane (NEI, 1992). The main problems, as pointed by the evaluation report which agrees partly with the results of this study are the wrong irrigation cycles, wrong spacing of laterals, an inadequate number of sprinklers and the large amount of idle equipment. Lastly, the report concluded that in spite of purchased new equipment, poor irrigation remains a problem, which is also related to irrigation being considered by workers as inferior job, and to drainage problem due to shortcomings in management.

## 5. CONCLUSION AND RECOMENDATIONS

### 5.1 Conclusions:

From the study the following conclusion can be made:-

- 1) The coefficient of uniformity varied from as low as 22% to a maximum of 99%. In the study it was found that 20% of all 52 blocks showed coefficient of uniformity of below 80% against the designed one of between the range of 81 to 87%.
- 2) There is a large variation between the sprinkler operating pressure and the designed one. The pressure recorded ranged from 1.8 to 3.2 bar against the designed nozzle operating pressure of 3.2 bar. In the study, it was found that 73% of all blocks had sprinkler's operating pressures of below 3.2 bar. The cause of low sprinkler operating pressure was identified as due to operating the two pump stations (PPS1 and PPS2) at low pressure against the designed of between 6.5 to 7.0 bar with all sprinkler working. The study revealed that the maximum recorded pumping pressure was 5.4 bar with all three pumps working. A steady pressure of 4 bar was recorded when two pumps were operated especially when not all lines were working.
- 3) The causes of low pumps operating pressure and consequently the low sprinkler operating pressure were identified as follows:-

The sprinkler system was designed to be fed by two power sources, namely the factory generated one and the National Grid system. Hence, wherever one of the two sources is

stopped for one reason or another, as the case during the study, the power capacity is insufficient for both factory and irrigation and consequently the power supply to pump stations is reduced to 1200 amperes only. This leads to irregular sprinkler operating pressure and water deliveries to the field. Another cause of low pressure pumping was due to management negligence such that the pump operators could not know how many lines at any time are operating due to a defective reset alarm. This led the pump operators to rely on trial and error in regulating the pressure according to number of lines working. Due to this, they tend to operate at low pressure for fear of bursting the mains.

- 4) About 59% and 44% blocks for sprinkler set between 4 and 5 and 5 and 6 showed application efficiency of low quarter (AELQ) greater than potential application efficiency of low quarter (PELQ). This identified that, there is a management problems of the irrigation duration being short and hence in adequate supply of water required to fill the prevailing soil moisture deficit.

The study shows that an average of 38% of all 52 blocks required longer duration per set greater than the current one. The variation of duration per set is identified to be due to low application rate which is also caused by low operating pressure.

- 5) Therefore, the low yield and the insignificant yield difference

between the irrigated and rainfed sugar cane is caused by poor performance of the sprinkler system which led to inadequate application of water. Hence, if all other factors e.g. soil variation are constant, under-irrigating is the main cause of low yields observed.

## 5.2 Recommendations:-

From the study, the following recommendations are made:-

- 1) As the coefficient of uniformity for some blocks was lower than the designed and recommended one, there is a need of reducing the lateral spacing. This will improve the coefficient of uniformity even if the present sprinkler operating pressure remains the same. Likewise, the distance of throw of the sprinkler will be satisfactory due to reduced lateral spacing such that the effect of operating at low pressure will be compensated by reduced lateral spacing.
- 2) The designed pump and sprinkler operating pressure be kept at 7 and 3.2 bar respectively throughout during the operating time. This will improve and restore the designed application rate of 10.2 mm/hr. A stand by power source eg. diesel generator, be provided to go in hand with any of the two powersources i.e factory and National Grid, in use when one of them is stopped for any reason.
- 3) As many blocks required longer duration of application than the current one, the duration of application be increased accordingly. This can be implemented by measuring soil moisture deficit before

starting irrigating. A simple method of feel test can be used to estimate the SMD instead of fixing the application of duration indefinitely without checking prevailing soil moisture available.

- 4) If recommendation (3) above is not feasible due to some constraints in attendant's working hours, then the interval of irrigation be reduced so as to protect sugar cane from water stress.
- 5) As diurnal reduction in wind speed is one of wind speed characteristic, it is suggested that the blocks be irrigated alternately. That is irrigating a given location during the night when the preceding irrigation was during the day and vice-versa. This is to reduce the effect of high wind speed observed during day time working hours.
- 6) As high water losses were observed at each end of the lateral line, it is suggested to tip the risers or increase the spacing of the last sprinkler on the line from the boundary of the block. This will prevent sprinklers from irrigating untargeted areas e.g service roads as observed during the study.
- 7) The attempts of extending the irrigable area than the designed one, be discourage as this reduces the efficiency of the system due to required increase in capacity of the system which it can not provide. This was observed in block 13 and 14 which eventually led to low operating pressure of neighbouring lines.
- 8) The reset alarm which is out of order be restored. This will enable

the operating to know how many lines are at work at any time and hence know exactly how many pumps should be in operation at what discharge while keeping the pressure constant.

- 9) The pump operators, line attendant, and irrigation staff should be given remedial courses for better performance of their duties. Emphasis on estimating SMD prior to irrigation should not be ignored.
- 10) Finally, as the system was installed in 1978, a thoroughly check on the strength of underground main line be conducted. This will be able to justify the Mtibwa management fear that the system can no longer withstand the designed pressure of 7 bar.

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