UNIVERSITY OF ZIMBABWE

FACULTY OF ENGINEERING

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TECHNICAL EFFICIENCY OF SPRINKLER IRRIGATION IN SWAZILAND: A CASE STUDY OF THE LUSIP PHASE 1 IN LUBOVANE AREA

by

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In collaboration with

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A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Integrated Water Resources Management of the University of Zimbabwe

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DECLARATION

I, **Celinhlanhla Magagula**, declare that this research report is my own work. It is submitted for the degree of Master of Science in Integrated Water Resources Management (IWRM) at the University of Zimbabwe. It has not been accepted in whole or in part, in any previous publication or application for a degree here or elsewhere, except where other people's work and observations have been duly acknowledged in the text by means of referencing.

Date: ___________________________

Signature: ______________________

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DEDICATION

This work is

specially dedicated to my only parent Mrs Margaret Ntfombiyetive Magagula,

Ms Mateke Mahlalela (my one and only sweetheart), my kids, my brothers and to my sisters.

Without your full support and encouragement I would have not realised my dreams of

attaining this tremendous work.

May the Lord Bless you.

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ABSTRACT

The purpose of this study was to assess the technical efficiency of sprinkler irrigation of smallholder sugarcane scheme in the Lubovane area of Swaziland in terms of design parameters, frequency of water application, adequacy of irrigation and irrigation uniformity. The study was done in Imbali Yamadlenya, Nxutsamlo and Ziyanhle irrigation schemes. Data were collected from each scheme using both primary and secondary data sources between June and September 2013. Primary data included informal interviews and field measurements about operations of the schemes while secondary data included literature review and design documents. Data were analyzed using Microsoft Word and Microsoft Excel. All the schemes were under-performing in terms of the frequency of irrigation, adequacy and irrigation uniformity. Both Imbali Yamadlenya Farmers Association (FA) and Nxutsamlo FA had their emitters discharging more water than the designed specifications while at Ziyanhle FA the discharge was below the design specification. The flow variations for Imbali Yamadlenya, Nxutsamlo FA and Ziyanhle FA were 9.3%, 18.6% and -38.4% respectively. The operating pressure variations were found to be 10%, 8.6% and -40% for Imbali Yamadlenya FA, Nxutsamlo FA and Ziyanhle FA respectively. The first two schemes were over-irrigated while Ziyanhle FA was under-irrigated. The farmers in all the schemes had no systematic irrigation scheduling. They used the "feel" method to determine soil moisture content with one irrigation pattern adopted for the entire season. The calculated CWRs were 4.1mm/day, 11.1mm/day and 1.7mm/day for Imbali Yamadlenya FA, Nxutsamlo FA and Ziyanhle FA respectively. The observed basic infiltration rates for Nxutsamlo, Ziyanhle and Imbali Yamadlenya irrigation schemes were 19.8mm/h, 31.8mm/hr and 10.2mm/hr respectively which meant the soil could absorb water from the sprinklers without experiencing surface runoff. The calculated CUs for Nxutsamlo FA, Ziyanhle FA and Imbali Yamadlenya FA were 55%, 45% and 70% respectively while the DUs calculated were 33.3%, 50% and 60% for all the schemes respectively. The project management need to develop technical interventions for capacity building of the smallholder farmers to better manage their irrigation schemes in order to achieve the project's goal of reducing poverty and improving their livelihoods and that of their communities.

Key words: Crop water requirements, irrigation, LUSIP, timing, technical efficiency, uniformity, Swaziland.

LIST OF ACRONOMYS AND ABBREVIATIONS

ASAE	American Society of Agricultural Engineers
BoDs	Board of Directors
CWR	Crop Water Requirements
CU	Christiansen's Coefficient of Uniformity
DU	Distribution Uniformity
EIA	Environmental Impact Assessment
ET	Evapotranspiration
FAs	Farmers Associations
FAO	Food and Agriculture Organisation
GDP	Gross Domestic Product
GOS	Government of Swaziland
IFAD	International Food and Agricultural Development
IWRM	Integrated Water Resources Management
KDDP	Komati Downstream Development Project
KOBWA	Komati Basin Water Authority
kPa	kiloPascal
LUSIP	Lower Usuthu Smallholder Irrigation Project
MAR	Mean Application Rate
NDS	National Development Strategy
NIP	National Indicative Program
PDA	Project Development Area
PE	Pattern Efficiency
Psi	pound force per square inch
RDMU	Reconstruction and Diversification Management Unit
SNL	Swazi Nation Land
SWADE	Swaziland Water and Agricultural Development Enterprise
TDL	Title Deed Land
USDA	United States Department of Agriculture
WUGs	Water User Groups
VIS	Vuvulane Irrigation Scheme

CHAPTER ONE

1 INTRODUCTION

1.1 Swaziland's agriculture

Agriculture plays a crucial role in the development of the economy of Swaziland. Firstly it provides inputs for agro-processing industries that form the backbone of the manufacturing sector. In 2008 the agriculture sector contributed 11.9 percent to the gross domestic product (GDP), while the agricultural activities conducted on the Swazi Nation Land contributed about 5 percent of the gross domestic product of the country (Fernández *et al.*,, 2010). The sector also supplies raw materials to the agricultural industry, income support and food security to a large proportion of the rural households, a market for industrial products and an earner of foreign exchange. In addition, it supports the livelihood of 75 percent of the population, for whom 60 percent of the household income is derived from crops and livestock. The remaining 15 percent is derived from wages and remittances, and informal sector activities. The diverse agricultural activities that occur in the country include sugarcane production, citrus fruit, vegetable crops, maize and other cereal crops, cotton, forestry and livestock production (Thompson *et al.*,, 2007).

The agricultural sector of Swaziland is acutely dualistic, with a dynamic commercial sub-sector established on Title Deed Land (TDL) that occupies 26% of the land, holds an estimated 90% of available irrigation infrastructure, and uses modern technologies to produce mainly cash crops (primarily sugar) and a traditional subsistence sector, based on communal tenure in the Swazi Nation Land (SNL) that involves smallholder agriculture with communal grazing.

The total renewable water resources of the country are 4.51km^3/year of which 42% originates from South Africa. Irrigation uses about 90 to 95% of the water resources in the country (Lankford, 2001). Efforts towards improvement of agricultural productivity especially under SNL are constrained by the lack of water. According to Mlilo *et.al.,* (2008) the cultivated area is estimated at 190,000 ha (178,000 ha is under annual crops and 12,000 ha is under permanent crops). Maize is the major crop in SNL because it is the country's staple food. However, there has been a noticed increase in the number of farmers in SNL growing sugar cane, especially those under irrigation. The irrigation potential for the country, based on the physical land capability and water availability, is estimated at 93,220 ha. Mlilo *et al.,* (2008) reported that about 50,000 ha of the irrigated land is used for sugar cane production. Over 84% of the irrigated land is in the Lowveld, with 15% in the Middleveld. He further stated that about 52% of the land is under surface irrigation, while 48% is on other systems (draglines, fixed sprinklers and centre pivots). About 4000 ha of the irrigated land is under smallholder farmers mostly managed schemes, and irrigated mainly by overhead methods.

1.1.1 The sugar industry

The sugar industry in Swaziland dates back when irrigation projects were established at BigBend an area in the Lowveld. This was followed by the establishment of another mill at Mhlume another place in the northern part of Swaziland and later a third mill at Simunye (SSA, 2009). Historically, sugarcane production in Swaziland has been based on estates owned by the millers until 1962 when smallholder farmers under the Vuvulane Irrigation Scheme (VIS) were brought on board through the assistance of Commonwealth Development Corporation. Since 1990, other smallholder sugarcane schemes have been introduced. This was made possible by the Swaziland Sugar Association and the Swaziland Government by setting aside special sucrose quotas and provision of technical assistance (Westlake, 2001).

The sugar industry now consists of the miller-cum planters, large cane growers, medium size growers, and smallholder cane growers, who account for 77%, 17%, 5%, and 1% respectively of the industry's total cane production (Masuku and Dlamini, 2012). About 400 cane growers fall under the medium and smallholder farmers, while millers and large cane growers combine are only 10. However, the medium and smallholder cane growers account for a small volume in terms of total cane production. The sugar industry is regulated by the Swaziland Sugar Association through the Sugar Act of 1967 of Swaziland. Any differences among the industry players are attended to by the Swaziland Sugar Association. Currently the sugar industry is going through a process of expansion as a result of the Swaziland Komati Downstream Development Project (KDDP) and the Lower Usuthu Smallholder Irrigation Project (LUSIP). There are five irrigation systems commonly used in Swaziland (Knox *et al.*,, 2010) which are; furrow, dragline sprinkler, floppy sprinkler, centre pivot and the drip system.

The sugar industry is the cornerstone of the Swazi economy. Its contributions amounted to 59% of the agricultural output and up to 18% to the Gross Domestic Product (GDP). In addition, the industry's contribution reached the US$ 300 million mark recently. It contributed more than 70, 000 direct and indirect jobs to the economy (SSA, 2009).

1.2 Problem statement

The irrigation systems in the Lower Usuthu Smallholder Irrigation Project, for almost three years, have lacked evaluation for systems design efficiency. Ideally irrigation equipment should be field calibrated regularly to ensure that application rates and uniformity are consistent with values used during the system design and those given in manufacturers' specifications (Ascough and Kiker, 2002).

In addition, the water application at these irrigation schemes is not known. Since these schemes were established to alleviate poverty and improve the livelihoods of the communities therefore for the selected existing irrigation schemes, knowledge of changes in the magnitude of water applied over time is important to determine the causes of deficiencies in application rates and uniformities.

Smallholder farmers in these irrigation schemes do not have the know-how on irrigation scheduling so it is wise that the timing of water application in the field is assessed. The findings from the study are expected to help the project management and extension officers to develop technical interventions for capacity building of smallholder farmers to better manage their irrigation schemes in order to achieve the project's goal of reducing poverty and improving their livelihoods and that of their communities. Farmers from the different schemes should receive trainings on operations and maintenance of their farms.

1.3 Research objectives

1.3.1 Main objective

The main aim of this research was to assess the technical efficiency of sprinkler irrigation in Swaziland.

1.3.2 Specific objectives

The specific objectives of the research were to:

1. Assess the difference between the actual and design parameters of the system.
2. Assess the frequency of water application.
3. Determine the adequacy of water application.
4. Determine the water application uniformity.

1.4 Justification

The research covered the assessment of technical efficiency of three semi-solid sprinkler systems. The three semi-solid sprinkler systems were found at the following schemes; Imbali Yamadlenya, Nxutsamlo and Ziyanhle. The first scheme is located at Madlenya chiefdom while the rest of the schemes are found at Ngcamphalala chiefdom. These entire irrigation schemes are at the Project Development Area which is Lubovane block at Siphofaneni.

It focused on the frequency of water application, irrigation adequacy and irrigation uniformity. Assessment of the efficiency of sprinkler irrigation was based on comparing the actual water application rates and frequency of the water application on the field if they were consistent with those values given in manufacturers' specifications.

1.5 Research limitations

Limitations of the study included the following;

a) Time was insufficient for data collection as there were delays in starting the process.
b) Funds were also released late for the study which greatly affected the data collection exercise.
c) In the month of August when data was collected was windy which made the field measurements being carried out under trying conditions.
d) There were challenges in acquiring some equipment for use in data collection.
e) Water quality testing was not carried out during the infiltration test.

1.6 Thesis structure

Chapter 1 contains the background, problem statement and justification, research objectives, scope of the research and the research limitations.

Chapter 2 reviews available literature of relevant in-field performance parameters. It gives an overview of the concept of technical performance of irrigation systems and the issues in technical performance of overhead systems.

Chapter 3 outlines the study area and provides a brief overview of the selected study sites. This is in relation to the location, climatic conditions, landscaping, vegetation and the available types of soils of the selected irrigation schemes in the area.

Chapter 4 outlines the materials, methods and analysis used to achieve the stated research objectives. Research design, sampling and data collection techniques employed in the study are discussed.

Chapter 5 presents and discusses the results. It further gives a scientific explanation and a detailed understanding of the findings from the scientific point of view on the irrigation schemes where detailed investigations were carried out.

Chapter 6 concludes the main research findings and makes recommendations based on the conclusions made in relation to stated objectives.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Introduction

Smallholder agriculture provides employment, human welfare, and political stability in Sub-Saharan Africa. In addition, smallholder agriculture can moderate the rural exodus, create growth linkages and enlarge the market for industrial goods. It is also considered to be both a major cause of and potential solution to poverty and economic growth challenges (Machethe, 2004).

This chapter provides information on the concept of technical performance of irrigation systems, issues in technical performance of overhead systems, timing of irrigation and irrigation uniformity.

2.2 The concept of technical performance of irrigation systems

As pressures increase on the finite global water reserves, and as competition for water increases between the different economic and environmental sectors, the irrigation sector, in particular, is being forced to become more accountable for their water use (Ma *et al.*,, 2005).

2.2.1 Irrigation performance of systems

Irrigation performance assessment has been given the highest priority in irrigation research (Nwa and Pradhan, 1993). An ideal irrigation system should apply the correct amount of water, minimize the losses, and apply the water uniformly. Sprinklers apply water more efficiently and uniformly than typical surface irrigation systems, thus they produce more yields for each quantity applied per unit area (Hill and Heaton, 2001).

The performance of an irrigation system is the result of a variety of activities that include planning, design, construction, operation of facilities, maintenance and proper application of irrigation water and agronomic activities. Facilitation and execution of these activities requires proper coordination of functional processes of irrigation (Small and Svendsen, 1990). These activities include personnel management and support, equipment management, financial management and accounting, and resources mobilization. Planning, design and construction of irrigation schemes mainly deal with creation of physical infrastructure to facilitate the capturing of water from its source and transportation up to the farm level. These physical facilities need to be properly operated to ensure the capturing, allocation and delivery of water at the right time and adequate quantity.

According to Malaza and Myeni (2009), the poor performance of existing smallholder farmers requires investigation in field water application. This study sought to determine the irrigation uniformity and timing of water application in the study area.

Performance of irrigated agriculture, which includes irrigation methods or system, must improve in order to have additional food per unit area for a growing population. Irrigation development has contributed immensely to national food security; to economic development and to poverty reduction, yet much more is expected from irrigated agriculture as a result of the increasing population. It is obvious that many irrigation systems are performing below their capacities. This situation may lead to non-uniform and unreliable water distribution. Therefore, a good starting point as identified by (Nwa and Pradhan, 1993) is to assess the performance of available irrigation systems in order to identify areas of lapses in the system design and make amends.

The two major approaches to performance evaluation consider how well service is being delivered and the outcomes of irrigation in terms of efficiency and productivity of resource use. This helps to identify why a scheme is performing in a particular way, which in turn imply means of improvement (Clemmens and Molden, 2007).

The four factors critical to achieving high levels of performance for any irrigation system are: irrigation timing, depth of application, uniformity and water supply characteristics and that is what the study is also trying to address (Phocaides, 2000). This assertion is in line with what Oweis and Hachum (2006) wrote that the principal indices for evaluating the performance of farm irrigation systems are:

- Uniformity of water distribution (the key index in the evaluation)
- Adequacy of irrigation, and
- Efficiency of irrigation

Keller and Bliesner (1990) linked the performance of sprinkler irrigation systems to the sprinkler physical characteristics (i.e. jet angle, number and shape of nozzles and mode of operation), nozzle size and pressure. It was recommended that the CU values used for the final design of a system should be based on actual field or test facility data.

According to Dalton *et al.,* (2001), an important component of the evaluation of in-field irrigation system performance is the assessment of irrigation uniformity. Irrigation uniformity is thus an important management factor necessary for achieving high irrigation efficiency.

2.2.2 Sprinkler irrigation system performance

Sprinkler irrigation system performance is often evaluated based on timeliness of irrigation and on uniformity coefficients from water collected from array of measuring devices (catch cans). The Christiansen uniformity coefficient (CU) has been used extensively to characterize irrigation uniformity of sprinkler irrigation systems Elliot *et al.*,(1980).

Despite technical constraints which characterise the smallholder farm sector in developing countries, there have been success stories of technical change. Bingen *et al.*, (2003) assert that a key question which remains is advancements in technology, technology environment and coordination can contribute to broad-based economic growth, toward the creation of an economic cake that is not only increasing in size, but benefits a large part of the population. One of the key areas for improvement is strengthening smallholder organisations (Bingen *et al.*,, 2003).

2.3 Issues in technical performance of overhead systems

The main overhead systems used for sugar cane in Swaziland are semi-permanent sprinklers and centre pivots.

Sprinklers – drag-line: In drag-line irrigation a rotary impact sprinkler is attached to a riser and connected to a quick release valve via a flexible hose They are robust and flexible and can be designed to cope with most soil types, small and odd-shaped fields, obstructions and even different crops (ratoons) within one field. They are simple to operate and highly visible, making faults easy to identify and remedy (Merry, 2003). For these reasons, they have proved popular especially in southern Africa (Zadrazil, 1990). However, the system is susceptible to wind drift as the sprinklers are mounted on 3 m risers to cope with irrigating a full cane canopy.

Nasab *et el.*, (2007) in their evaluation of sprinkler systems in Iran, concluded that the main problems of sprinkler irrigation systems are deficient design and implementation, low distribution uniformity, low water pressure, deficient distribution of pressure, insufficient lengths of lateral pipelines in addition to poor quality equipment and deficient management and maintenance processes.

In sprinkler irrigation, the danger of system failure increases with technological complexity, expertise required for maintenance and availability of spare parts (Keller and Bliesner, 1990). Sprinkler irrigation uniformity varies substantially between irrigation events and single irrigation event evaluations should not be extrapolated to whole season performance. The spatial pattern of low uniformity applications appear reasonably consistent and are likely to be dominated by design and maintenance issues (Hussain and Hanjra, 2004).

A sprinkler distribution pattern depends on the system design parameters such as the sprinkler spacing, operating pressure, nozzle diameter, and environmental variables such as wind speed and direction (Keller and Bliesner, 1990). Thus, both the pattern of irrigation application and the measure of uniformity would be expected to vary within the irrigation event (Dechmi *et al.,*, 2003) and throughout the season (Playán and Mateos, 2006).

Wind is considered to be the main environmental variable affecting the sprinkler performance (Burt *et al.,*, 1997, Dechmi *et al.,*, 2003, Kincaid *et al.,*, 1996).

Centre-pivots: In a number of regions including Africa, Brazil and Australia there has been a steady uptake in the use of centre-pivots in sugar cane. The reasons include low running costs (compared to furrow), lower labour and energy requirements, ease of operation and the potential to achieve high application uniformities even under windy conditions (Teeluck, 1997). Although originally adopted by the large-scale commercial growers, centre-pivots have also proved popular with small-scale farmers in organized associations in Swaziland. The conversion from surface irrigated rectangular fields can create problems dealing with field corners that then require a separate irrigation system, usually dragline sprinklers or drip. Centre-pivots can cope with undulating land and awkward field boundaries (e.g. drainage ditches), but a disadvantage is the relatively high capital cost whilst fields generally need to be at least 40 ha to make investment worthwhile.

Rain guns: Due to their robustness and versatility, high pressure, high volume sprinklers (rain guns) were widely used from the 1950s to irrigate sugar cane in Mauritius, Zambia, South Africa, Swaziland and Australia. However, the large water droplets can cause damage to young sugar cane and create capping problems on sensitive soils. Since 1990, however, rising energy costs coupled with increasing demands for improved water application and crop uniformity have resulted in these systems being replaced by drag-lines and centre-piv (Teeluck, 1997).

2.3.1 Irrigation management

All sugar cane production is carried out under irrigated farming conditions. An irrigation systems report for one of the smallholder cane growers under the Komati Downstream Development Project revealed that the organisations faced serious constraints in their irrigation management: there were frequent faults in the main river pumps; many equipment was either too old or mismatched; theft and or vandalism of various component was rife; no irrigation scheduling was followed and specific water holding capacities were never considered in designing systems (RMDU, 2008a).

According to Nkambule (2009) at the time of budgeting, organisations make allocations for maintenance and repairs organisations or for servicing irrigation line items. This line item is, unfortunately prone to abuse, reduction or elimination during budgeting so that when the need to carry out repairs or even merely service the machinery there is no money. This makes the issue of irrigation management to achieve better efficiencies is of great concern. What commonly happens is that operators over-irrigate or under-irrigate and this compromises production. These operators most likely cannot read and write and do not understand the concept of irrigation scheduling.

2.4 Timing of irrigation

2.4.1 Irrigation Scheduling

Scheduling water application is also critical, as excessive irrigation reduces yield (Locascio and Delpuglia, 1989), while inadequate irrigation causes water stress and reduces crop production. Application efficiency is affected by irrigation frequency, soil texture, and system design, maintenance, and operation. The use of soil water monitoring devices for scheduling also requires some knowledge of the distribution and relative density of roots, and the uncertainty increases when the wetted area varies in three dimensions, as in drip irrigation and micro sprinklers.

2.4.2 Timeliness

There are two distinct dimensions included in the question of timing of water deliveries to the crop. This can be distinguished by the terms timeliness and reliability. Timeliness means providing of water deliveries to crop need at the right time. It can be considered on the basis of accuracy of fit between two time history curves one of which represents the evapotranspiration needs of the crop throughout its season and the other the actual deliveries of water.

Reliability on the other hand means the degree of which the irrigation system and its water deliveries conform to the prior expectations of its users. It is very important because it affects the efficiency of various field activities. It includes the predictability of flows as indicated by a water schedule or operational plan without which the concept of reliability does not make sense (Abernethy, 1989). Abernethy (1989) further pointed out that performance indicators should provide irrigation managers with the answer to the following three questions;

(1) "Does the quantity of water provided meet the growth needs of the crops planted in a given season?

(2) How fair is the water distribution among multiple users of the delivery system?

(3) Does the water delivery timing match the growth needs of the crop and expectation of the farmers?"

The purpose is to keep as much of the available supply as possible for effective, timely watering work. In rotational irrigation systems, control of water affects the ability to schedule irrigation on time, and in continuously supplied systems, it affects the ability to achieve wetting up within narrower rather than longer time frames.

2.4.3 Infiltration

Infiltration is the process whereby rainfall, or irrigated water, enters the soil profile (Lorenz and Morris, 1995). All the water that enters the soil surface is in transit. Some enters the plant through the root system immediately while another fraction, *viz.* that up to and even exceeding the so-called drained upper limit or field capacity, is temporarily stored as soil water in the root zone. This stored water may also enter the plant, be drawn to the soil surface and evaporate, or eventually move down below the root zone (Burt *et al.*,, 1997).

2.5 Irrigation uniformity

The first requirement for the efficient operation of an irrigation system is the uniform application of water. Crawford *et al.*, (2001) noted that a highly uniform application of water does not ensure high efficiency since water can be uniformly under or over-applied. However, in order to achieve good crop yields, both a highly efficient system and uniform application of water are required.

Keller and Bleisner (2000) noted that the uniformity of sprinkler irrigation is a central design goal. Uniformity relates to how evenly water is applied over a given area. Since no irrigation system can apply water precisely to all areas of the field, it becomes necessary to estimate the uniformity of water application in order to assess the performance of the system

The two most common methods of expressing uniformity are the coefficient of uniformity (CU) and distribution uniformity (DU). CU calculates the average deviation of the catch compared to the depth of the catch, while DU compares the driest quarter of the field to the rest. For a typical overhead system with a statistically normal distribution and CU >70%; CU and DU are approximately related (Keller and Bliesner, 1990). Sadler *et al.*, (2000) also stated that to maximise production efficiency, two irrigation management issues required attention, that is, irrigation scheduling and uniformity. The evaluation of sprinkler systems typically involves an assessment of the volumetric discharge rate and the uniformity of the discharge (Dalton *et al.*,, 2001).

Hieffer and Huck (2008) highlighted that for existing irrigation systems the catch-can test is a good method for evaluating sprinkler system efficiency. Heermann *et al.*, (1990) also noted that irrigation uniformities for overhead sprinkler irrigation systems can be evaluated by measuring the spatial distribution of application depths with catch cans. Therefore, irrigation uniformity is a concept that all areas within an irrigated field received the same amount of water (Kelly and Mason, 1987).
It has been found that raising the irrigation uniformity from 70% to 90% allows half as much area to be irrigated adequately with a given volume of water. Irrigation uniformity is thus affected by the sprinkler characteristics and layout, operating pressure, environmental conditions and management practices. Assessing irrigation system uniformity is therefore pivotal to the design of an effective irrigation system.

Euroconsult (1989) highlights that the important aspects one should take into account when designing a sprinkler system are application rate, uniformity of distribution, pressure, drop size, application efficiency, flexibility and leaching requirements. The basic infiltration rate of the soil should be higher than the maximum application rate of irrigation water.

The unevenness of water distribution should be taken into consideration. Pressure losses in pipes and differences in elevation cause pressure variations and consequently flow variations, since sprinklers operate optimal within a certain pressure range. The drop size is determined by nozzle size and pressure. High pressure and small nozzles give smaller drops, which are easily blown away by wind. Large drops may damage sensitive crops and may lead to deterioration of soil texture.

Different crops and different growing stages require different application depths, irrigation intervals, application rates and elevations of the sprinklers above the land surface. The primary losses associated with sprinkler irrigation (other than those due to over watering) are evaporation from droplets and wet soil surfaces, transpiration from unwanted vegetation, wind drift, field border losses, leaks and system drainage (Li, 1998)). The allowable evaporation losses are 15 %-20% acceptable limit value (Solomon, 1988).

Raine *et al.,* (2002) observed that the ability of the in-field irrigation system to apply water uniformly and efficiently to the irrigated area is a major factor influencing the agronomic and economic viability of the farmers' production system. In addition, Solomon (1988) noted that due to the fact that irrigation uniformity relates to crop yield and the efficient use of resources, engineers regard it as an important factor to be considered in the selection, design and management of irrigation systems.

Irrigation systems should apply water in the most efficient way possible to prevent unnecessary losses and water wastage (Burt *et al.,*, 1997). In order to achieve this, the uniformity coefficient with which the irrigation system applies water will have to be high. The uniformity coefficient of a sprinkler irrigation system has a direct effect on the system's application efficiency and on the crop yield (Li and Rao, 2000) and (Dechmi *et al.,*, 2003). Nutrients can be leached out of the soil due to excess water being applied to overcome poor irrigation uniformity (Clemmens and Solomon, 1997)**.**

Solomon (1990) stated that specific quantitative study of sprinkler irrigation uniformity started with the work of J. E. Christiansen in 1942. High irrigation uniformity connotes water being applied adequately with little excess and low uniformity indicates that some portions of the field would be deprived of water while other locations will become over-irrigated.

2.5.1 Christiansen's Coefficient of Uniformity (CU)

One of the first and most common quantitative measures of uniformity is the Christiansen Uniformity coefficient (CU). This was developed for evaluating sprinkler systems in 1942 by Christiansen, and is still the most widely used and accepted measure for uniformity (Ascough and Kiker, 2002) The CU provides a quantitative measure of the average deviation from the mean application depth (Sadler *et al.,*, 2000)

Coefficient of uniformity is a measure of non-uniformity of water application for a given sprinkler head, nozzle type, operating pressure and sprinkler spacing combination. It is thus an index of irrigation uniformity. The main stream agricultural industry has long used a calculated coefficient of uniformity to measure the non-uniformity of water application (Solomon and Jorgensen, 1992). Application efficiencies greater than 80% can easily be achieved depending on slope of land, scheduling practices, system design and wind conditions (Keller and Bliesner, 1990).

Dalton *et al.,* (2001) found CU as the most commonly used quantitative measure of irrigation uniformity. This coefficient measures the average deviation from the mean application depth. Hence, for a perfectly uniform application the CU is 100%, which is impossible to achieve on a field scale due to equipment deficiencies and limiting environmental factors. CU values of 80-90% is attainable for set-move systems which are properly designed and maintained, operating under moderate wind speeds less than 16km/h. It has been found that CU values as low as 60% can occur with systems on undulating topography, with worn or plugged nozzles, and/or under windy conditions (Sadler *et al.*,, 2000).

Smith (1995) as in Dalton *et al.,* (2001) indicated that the uniformity of application is acceptable for CU values greater than 0.84 or 84%.

Keller and Bliesner (1990) also stated that in general CU of at least 85% is recommended for delicate and shallow-rooted crops such as potatoes and most other vegetables, whilst values between 75% and 83% is acceptable for deep-rooted crops like alfalfa, corn, cotton and sugar beets. In cases where chemicals are applied through the irrigation water, the CU should be at least 80%. Montero *et al.,* (2000) stated that low values of CU are usually indicators of a faulty combination of factors such as nozzle sizes, working pressure and spacing of sprinklers.

Pang *et al., (1997)* reported that decreasing Christiansen uniformity coefficient (CU) from 100 to 75% caused a significant increase in water losses by deep percolation, nitrate leaching and a reduction of yield.
The coefficient of uniformity is, therefore, most often used to describe the uniformity of overhead sprinkler, floppy and centre pivot irrigation systems (Haman *et al.*,, 1996, Magwenzi, 2000).
The CU can be expressed by (ASAE, 1990):

$$CU = 100[1 - \frac{\sum_{i=1}^{n}|Di - D|}{\sum_{i=1}^{n} Di}$$

Where;
D_i is the catch-can depth of application [mm],
D is the mean catch-can depth [mm], and
n is the number of catch cans.

2.5.2 Distribution Uniformity (DU) / Pattern Efficiency (PE)

Distribution uniformity is usually defined as a ratio of the smallest accumulated depths in the distribution to the average depths of the whole distribution (Ascough and Kiker, 2002). This uniformity measure is also called low-quarter distribution uniformity and it is often used to quantify irrigation uniformity of surface systems (Sadler *et al.*,, 2000). The DU coefficient takes into account the variation of can readings from the mean but concentrates on the lowest 25% of readings. A commonly used fraction is the lower quarter, which has been used by the USDA since the 1940s (Ascough and Kiker, 2002).

The distribution uniformity of an irrigation system depends both on the system characteristics and on managerial decisions (Pereira *et al.*,, 2002).

Rogers *et al*., (1997) the distribution uniformity gives an indication of the magnitude of the uneven distribution and can be defined as the percent of average application amount in the lowest quarter of the field. The lowest quarter fraction, Dlq [mm], has been used by the United States Department of Agriculture (USDA) since the 1940s' and has proved to be useful in irrigated agriculture and is defined by the following (Burt *et al.*,, 1997).

$$Dlq = \frac{volume\ accumulation\ in\ 1/4\ total\ area\ of\ elements\ with\ smallest\ depths}{total\ area\ of\ \frac{1}{4}\ of\ the\ total\ area\ of\ elements} \quad (1.0)$$

From Equation 1.0 the low-quarter distribution uniformity, DU_{lq}, can be defined as:

$$DUlq = \frac{Dlq}{Davg} \quad (1.1)$$

$$DUlq = \frac{Average\ low\ quarter\ depth}{Average\ depth\ of\ water\ accumulated\ in\ all\ elements} \quad (1.2)$$

Where; *Davg* [mm] is the total volume accumulated in all elements, divided by total area of all the elements

According to Ascough and Kiker (2002) the commonly used lower quarter fraction, which has been used by the USDA since the 1940s is as follows;

$DU = (M_{25}/M) * 100$ (1.3)

Where;

M_{25} = Average low quarter depth / lowest 25% of all the can readings

M = Average depth of water accumulated in all catch cans

2.6 Conclusion

The preceding sections highlighted that there was a general consensus amongst authors that smallholder irrigation performances are below than as expected due to a plethora of factors ranging from technical to socio-economic factors. It has also been indicated that the performance of smallholder irrigation schemes in Swaziland was also performing below acceptable standards. As a result the technical assessment of these schemes becomes an important focal area. In this study performance indicators have been already identified which include the frequency of irrigation, irrigation adequacy and irrigation uniformity.

CHAPTER THREE

3 STUDY AREA

3.1 Introduction

This chapter introduces the study background, the Lubombo region of Swaziland, particularly the region's physical geography. The chapter then provides a descriptive profile of the project area (LUSIP) and its climatic conditions. Then a brief description of the sites namely Imbali Yamadlenya FA, Nxutsamlo FA and Ziyanhle FA is outlined.

3.2 Lower Usuthu Smallholder Irrigation Project (LUSIP) Phase 1

The Lower Usuthu Smallholder Irrigation Project (LUSIP 1) is located in the lowveld ecological zone of Swaziland between Siphofaneni and Big Bend towns. The project which started in April 2003 involved the construction of three dams to form an off-river storage reservoir to impound 155 ML of water that will be diverted from wet season flood flows into the Lower Usuthu River for the irrigation of a total area of 11 500 ha of land.

Its main goal is to improve the livelihoods of the people and their communities in the project area, Lubovane, who are currently the poorest in the country. The project will achieve this goal by transforming the local economy from subsistence farming into sustainable commercial agriculture. The LUSIP project comprises four main components: i) Upstream Works (including 3 dams) and Distribution System, ii) Downstream Development, iii) Environmental Mitigation and iv) Project Management. It is divided into two phases but the first phase was considered for the study. **Phase 1** will provide irrigation to 2 600 households (for a total of 15 300 people) to convert more than 6 500 ha of land currently used for rain-fed subsistence agriculture to irrigated, cash-crop production (mainly sugar cane)

Each smallholder family is allocated an irrigated land holding of 3.5 ha. Smallholders are organized into Water User Groups (WUGs) and Farmer Associations (FAs). The responsibility of WUGs and FAs is to organize irrigation at farmer level, collection of revenues, and organization of maintenance activities in the command area.

The Lubovane block covers seven chiefdoms/villages namely; Gamedze, Maphilingo, Mphumakudze, Lesibovu, Mamba, Ngcamphalala and Bulunga. The study focused on only two (Ngcamphalala and Gamedze) developed chiefdoms. That is where most of the schemes are operating. Below in Figure 3.1 the project study area is shown.

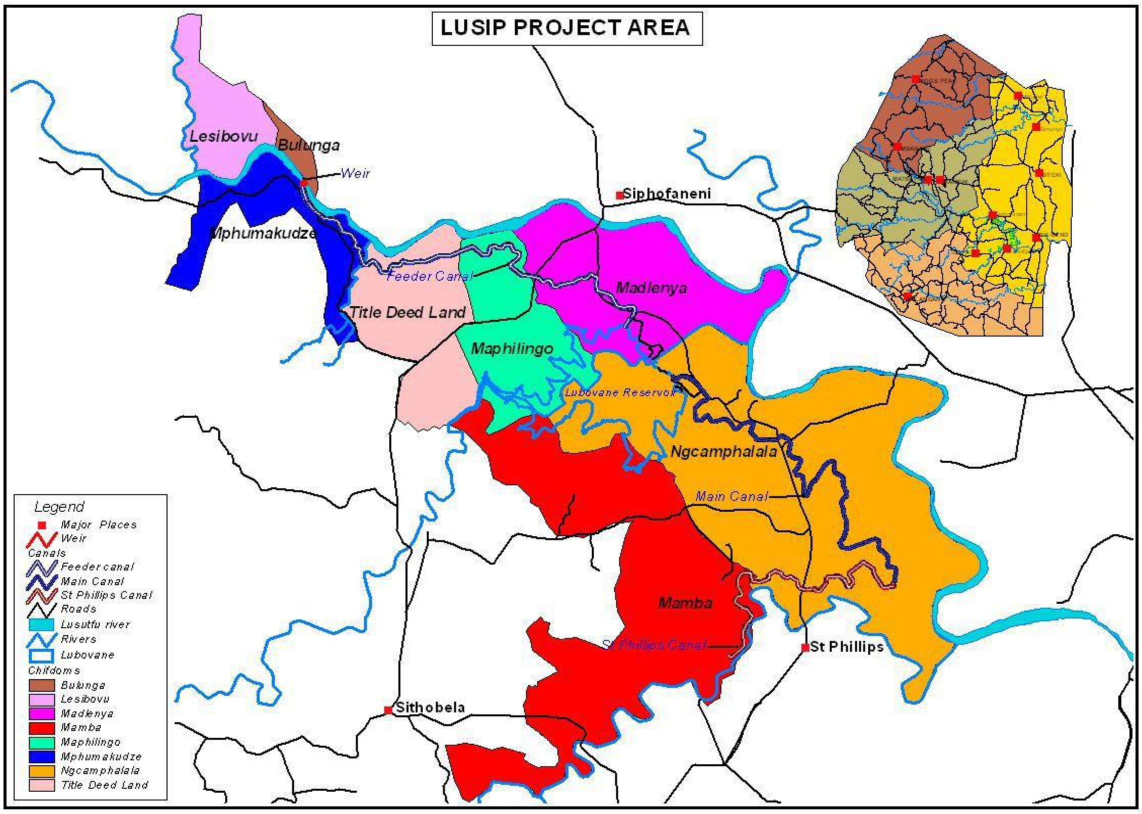

Figure 3.1: Project study area
Source: SWADE (2008)

Within the two areas, three irrigation schemes/farmer associations (FAs) were selected for the study namely; Imbali Yamadlenya FA, Nxutsamlo FA and Ziyanhle FA. In these schemes no assessment of the system had been done before, their performance was poor and they had lodged complaints about their systems (discharge, pressure and schedule practices) to management.

The FAs are legally registered as companies in Swaziland. They are governed by the Board of Directors (BoD) which consists of seven members. These members are democratically elected into office and the general term of their office is three years. Shareholding is based on household and it is irrespective of the one status. The landless, widowed and child headed households do participate in the project.

3.3 Climate and topography

Swaziland is normally characterized by a sub-tropical climate, with hot and wet summers and cold and dry winters (Murdoch, 1972). Temperatures in the country vary from 0^{o}C in mid-winter nights to 33^{o}C in mid-summer (Swaziland's National Report on Climate Change, 2000). The mean annual rainfall ranges from about 500 mm in the Lowveld to about 1500mm in the Highveld (Swaziland's National Report on Climate Change, 2000).

The climate in the project area is semi-arid with mean annual evaporation of 2 057 mm, compared with mean annual rainfall of 570 mm and 22.4^{o}C of mean temperatures. About 70% of the annual rain falls within the hot summer rainy season, from October to March, when maximum temperature exceeds 32.5^{0}C and mean relative humidity exceeds 60%. Rainfall is highly variable: for example, during the 1960 – 96 annual rainfall varied between 293 and 984 mm. Droughts have occurred frequently over the years, most recently in 1992 – 94 when total rainfall remained below 400 mm/year. The topography of the Lubovane block is gently undulating, with slopes ranging from 3 – 8%.

3.4 Vegetation and soils

The dominant soil sets in the study area are the so-called S, R, and K series. These soils are characterized by being shallow and spatially highly variable and frequently occur within larger areas of deeper soil sets. Several hundred hectares of S-set soils have been incorporated into existing irrigation schemes in the lowveld and are being successfully used for sugarcane production under estate conditions (Swaziland Sugar Association, 2009).

The vegetation has been classified as lowveld Savanna (Acocks, 1988), consisting of open to dense mixed (large trees and shrubs), broadleaved woodland and microphyllous (Acacia) savannas dominating the inlands, and riverine forest and creeping semi-woody shrubs dominating the wetlands along the rivers and major drainage lines.

3.5 Study sites

The three study sites are Imbali Yamadlenya FA, Nxutsamlo FA and Ziyanhle FA. They are shown below in Figure 2.

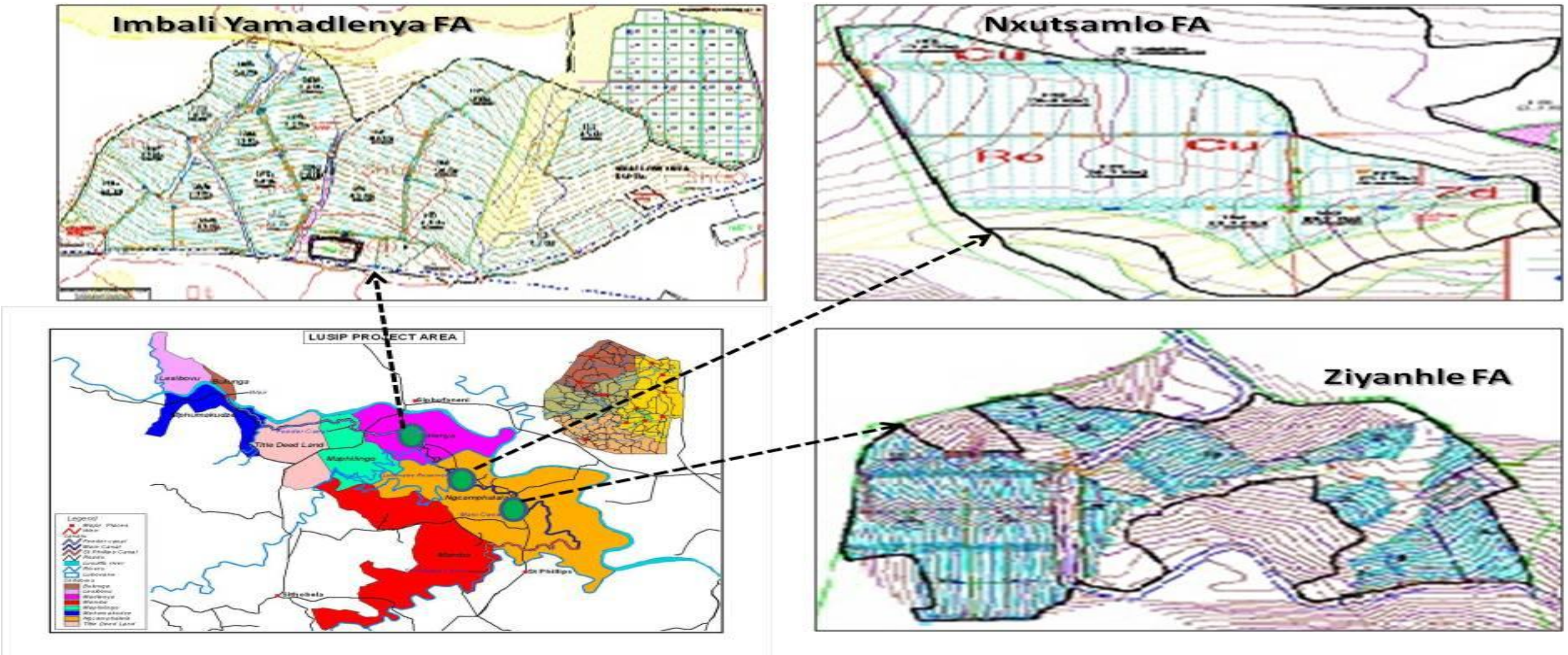

Figure 3.2: Study sites

3.5.1 Imbali Yamadlenya FA

The FA is located at the Gamedze chiefdom within the LUSIP Project Development Area (PDA). The total net area of this scheme is 58.7 ha which was designed for irrigation under the semi-solid system. Only 15.1ha of this area is reserved for commercial gardens and the rest is dedicated to sugarcane production. This irrigation scheme was developed in 2010 and is financed by the Swaziland Development Finance Corporation (FINCORP). It is dominated by Shebane (Sh) type of soils. These soils are marginally suitable for sugarcane production; they have good drainage and have a depth of up to 40cm. The Cuba (Cu) and Somerling (So) type of soils are also found in small quantities. Cuba soils are loamy soils suitable for sugarcane production; they are moderately drained and have a depth of up to 90cm while the Somerlings are marginally (clay loamy) suitable for sugarcane production, have good drainage and have a depth of up to 40 cm.

3.5.2 Nxutsamlo FA

The FA is located in the Ngcwaleni section under the Ngcamphalala chiefdom within the LUSIP Project Development Area (PDA). It is 29 km to the Ubombo sugar mill via the Maphobeni area. This is a 19 ha irrigation scheme which was developed in 2010 and designed for irrigation under the semi-solid sprinkler system. It is also financed by Swaziland's Development FINCORP. Only 3.2ha of this area is reserved for their commercial gardens and the rest is dedicated to sugarcane production. It is dominated by Rondspring (Ro) and the Cuba (Cu) type of soils. The Rondspring soils are loamy and are highly suitable for sugarcane production; they are deep and well drained soils and have a depth of greater than 90cm. The Cuba soils are loamy soils suitable for sugarcane production; they are moderately drained and have a depth of up to 90cm. The scheme is relatively flat with a slope range between 1% and 2%.

3.5.3 Ziyanhle FA

The FA is located in the Mnisi section under the Ngcamphalala chiefdom. It is 28 km from the Ubombo sugar mill via the Maphobeni route. It is accessible through the Siphofaneni, St Phillips route. The scheme area has a slope range from 3 to 6 %. The soils in the scheme ranges from the shallow clayey soils of the Shebane (Sh) series which are poorly drained, to the well drained, deep red soils of the Rondspring (Ro) series. The total net area of this scheme is 135 hectares which was designed for irrigation under the semi-solid sprinkler system. Only 53.3ha of this area is reserved for their commercial gardens and the 82.6 is dedicated to sugarcane production. This scheme is also funded by FINCORP and was started operating in 2011.

Table 3.1: Organization of irrigation practices for the three schemes

Irrigation Practice	Imbali Yamadlenya FA	Nxutsamlo FA	Ziyanhle FA
Shifts per day	2	2	2
Irrigation cycle (days)	3	6	3
Stand time (hrs)	8	9	6

3.6 Conclusion

The only crop grown at the moment was sugarcane but proposed gardens will soon be operational. Schemes were chosen based on; performance being poor, had lodged complaints with the managements about operations of their systems and their systems had not been assessed since they started operating. Organization of irrigation practices were prepared by the project management for the farmers to implement.

CHAPTER FOUR

4 METHODS AND MATERIALS

4.1 Introduction

This chapter describes methods and materials used to gather and analyze data. The methods are presented in line with the main objective of the study, which was to assess the technical efficiency of sprinkler irrigation in terms of design parameters, frequency of irrigation, irrigation adequacy and irrigation uniformity. Literature review was used in order to determine the factors that affected frequency of irrigation, irrigation adequacy and sprinkler irrigation uniformity on smallholder irrigation schemes.

4.2 Research design

The study focused on smallholder sugarcane farmers' associations under LUSIP 1 which were Imbali Yamadlenya FA, Nxutsamlo FA and Ziyanhle FA. The research design and sampling technique were clearly defined. Both primary and secondary data sources were used to collect information about the study.

Both primary and secondary data were used with a dependence on field measurements and observations for the former, and company documents and records for the latter.

4.2.1 Research methods

The study employed mixed methods which included both qualitative and quantitative approaches. The quantitative approach focused mainly on quantifiable data i.e measurements from discharge, pressure, environmental conditions, volumes of water collected from catch cans, operating sprinklers irrigation practices employed by the farmers that were analysed statistically and the deductive approach emphasized detailed planning prior to data collection and analysis (Newman, 2000).

Qualitative research was generally interpretive (Creswell and Miller, 2000). It focused on qualitative data through field observations (leakages from pipes, types of soils, functionality of flow meter devices, materials of pipes, vegetation of study area, landscape of fields and determination of soil moisture contents) during the operation of the systems and informal discussions with the project management and schemes personnel.

4.2.2 Sampling technique

The most important criterion in selecting a sample is to increase the validity of the collected data (Zeller and Carmines, 1980). In this study the sample selection criterion was designed to increase validity, rather than to ensure that the sample was representative of the given population. Validity ensures the selection of information-rich cases for study, where information-rich cases are those that provide a great deal of insight into the issues of central importance to the research (Patton, 1990). Therefore, the study used purposive sampling, which is most desirable when certain important segments of the target population are intentionally represented in the sample. Purposive sampling is a deliberate non-random method of sampling, which aims to sample a group of people or settings with a particular characteristic such as where they live in society, or specific cultural knowledge. Out of 34 operational schemes only three schemes were selected for the study.

4.3 Data Collection

In order to assess the technical efficiency of sprinkler irrigation, data on the designed parameters, frequency of irrigation, irrigation adequacy and water application uniformity was required. The following section discusses how data was collected and analysed.

4.3.1 Design parameters

The sprinkler discharge, operating pressure and the number of operating sprinklers in the different schemes were observed. These are the major parameters that could give a picture of how water is being applied in the field. Some have not been included because of the level of the study and due to time constraints to including all the parameters. Environmental condition measurements were taken every 15 minutes over a period of two hours during the field measurements. They are important because they can influence in the overall field measurements so that is why they were noted. These included the relative humidity, temperatures and the wind velocities and were measured at least two metres above the ground and not further than 50 metres from the test set-up. A portable anemometer and a portable thermo-hygrometer were used to measure wind speed, temperatures and relative humidity. During these field tests it was very windy and hot.

Discharge measurements were obtained through measuring nozzle discharge during sprinkler operation and recording the total irrigation duration per irrigation event. A 10 litre bucket was used to collect the water from the sprinklers and the time taken for it to fill was recorded. The process was repeated for at least three times on each sprinkler and the average was obtained after calculations were done. Sprinkler operating pressures were measured at the sprinkler nozzles using a pitot tube end pressure. The measurements were carried out 10 minutes after the system had started operating. This was necessary because the sprinklers had to attain their maximum operating pressures. Figure 4.1 shows the pressure measurement carried out at Ziyanhle FA.

Figure 4.1: Pressure measurement using a pitot tube end pressure gauge at Ziyanhle FA

4.3.2 Frequency of irrigation

Frequency of water application variables were assessed through undertaking field measurements and observations at the respective irrigation schemes. Information on irrigation cycles, stand times and shifts per day were obtained during the study. In addition, the irrigation schedule was observed. This method of data collection was necessary so the researcher can determine which tool and how it was used to determine the water application for the entire field. Informal discussions with the schemes supervisors and project management were also used to solicit further details on aspects relating to frequency of irrigation and farm operations and maintenance.

4.3.3 Irrigation adequacy

The crop water requirements, application depths and infiltration rates information was used for this subsection. The peak crop water requirement was observed from the designer's manual. The volumes of water to determine the application depths were obtained from field measurements. At Nxutsamlo and Ziyanhle irrigation schemes sixty three catch cans (90mm diameter and 140mm high) were used to collect water from the sprinkler whilst it was in operation in each scheme while 36 cans were used at Imbali Yamadlenya scheme. In all the schemes a grid test was the one used in collecting the volumes of water because such a test accounted for the wind effects. The tests for the three schemes were run for a period of 2 hours per test and water collected was measured using a graduated measuring cylinder and recorded in a sheet. A double ring infiltrometer 10.5mm diameter for inner ring and 40mm diameter for annular ring was used to measure the infiltration rate of the soils. An area free from obstacles, dry and not tampered by heavy machinery was identified within the field where the infiltrometer was installed. The infiltration tests were done in the same general areas as the catch-can field tests. Penetration of the rings (50mm for inner and 100mm for annular) were observed and the liquid depth of 100mm for both the inner and the annular rings was initially poured into rings and measurements were taken at time intervals. In all the sites 8 measurements were taken for a period of 2 hours. They were recorded in the infiltration form for analysis. Observed water application rates were compared to the system's designed specifications and also compared to determined infiltration rates.

4.3.4 Irrigation uniformity

To determine the sprinkler irrigation uniformity, field water application measurements were required. The catch can method was used in collecting data required to determine the uniformity of water application for the system. Catch cans (90mm diameter and 140mm high) were used to collect water from the sprinkler whilst it was in operation. The same numbers of cans used for collection of water were the ones also used in determining the irrigation uniformity of the schemes. The sprinkler risers used in all the schemes had heights of 3m and the tests runtime was two hours for each scheme. This assessment was conducted on blocks where vegetation (less than 150mm in height) could not influence the water application in the catch cans and recently harvested blocks were used. The tests were run for a period of 2 hours per test and water collected was measured using a graduated measuring cylinder. Environmental conditions were also observed as outlined above.

4.4 Data Analysis

During the study period, field water application measurements were carried out on sugarcane growing schemes. Data were analyzed using Microsoft Word and Microsoft Excel (spreadsheet) and presented in table and graph formats.

4.4.1 Design parameters

The data for field water application on the sprinkler irrigation system was analysed as given by equations 1-2.

Using the amount collected into the container and time taken to fill the container, the sprinkler discharge was the given by equation 1

$$Dsp = \frac{Csp}{t}$$ **Equation 1**

Where

Dsp is Sprinkler discharge in litres per second (l hr^{-1})

Csp is Container size in litres (l)

t is time taken to fill the container (Csp) in seconds (hr*s*)

4.4.2 Irrigation adequacy

Using the amount collected into the catch can containers and time taken to fill the container, the sprinkler mean application rate was the given by equation 2.

$$MAR = \frac{Average\ sprinkler\ discharge\ recorded\ during\ test}{Mainline\ spacing\ X\ Lateral\ spacing}\ X\ 1000$$ **Equation 2**

Where

MAR Mean Application Rate

The basic soil infiltration rate was calculated in the infiltation form (*see Appendices 2A, 2B and 2C*).

4.4.3 Irrigation uniformity

The purpose of an irrigation system is to apply water evenly over the surface of the soil in such a manner that there can be absorption without runoff. Both the distribution uniformity and coefficient of uniformity were analyzed as described below.

4.4.3.1 Distribution Unifomity (DU)

According to Ascough and Kiker (2002), the distribution uniformity gives an indication of the magnitude of the uneven distribution of water in the soil profile and can be defined as the percent of average application amount in the lowest quarter of the field. Equation 3 was used to determine the distribution uniformity.

$DU= (M_{25}/M) * 100$ **Equation 3**

Where;

M_{25} = Average low quarter depth / lowest 25% of all the can readings

M = Average depth of water accumulated in all catch cans

4.4.3.2 Christiansen Coefficient of Uniformity (CU)

The CU provides a quantitative measure of the average deviation from the mean application depth (Sadler *et al.*,, 2000). It was determined using equation 4.

$$CU = 100[1 - \frac{\sum_{i=1}^{n}|\mathrm{Di} - \mathrm{D}|}{\sum_{i=1}^{n} Di}$$

Equation 4

Where;

D_i is the catch-can depth of application [mm],

D is the mean catch-can depth [mm], and

n is the number of catch cans

CHAPTER FIVE

5 RESULTS AND DISCUSSIONS

5.1 Introduction

This chapter presents results of the study on assessment of the technical efficiency of Imbali Yamadlenya, Nxutsamlo and Ziyanhle irrigation schemes between June and September 2013 in terms of designed and measured parameters, frequency of water application, adequacy of water application and irrigation uniformity.

5.2 Design parameters

Parameters which were observed under this subsection included the sprinklers discharge, sprinklers operating pressure and the number of operational sprinklers in the field.

5.2.1 Discharge

The measured sprinkler discharges at Imbali Yamadlenya FA, Nxutsamlo FA and Ziyanhle FA were found to be 1.17m^3/hr, 1.66m^3/hr and 0.53m^3/hr respectively compared to 1.07m^3/hr, 1.4m^3/hr and 0.86m^3/hr respectively which were outlined in the design manual (Figure 5.1). At both Imbali Yamadlenya FA and Nxutsamlo FA the high discharges may be due to increased pressures observed during the field measurements. No hydraulic valves were installed in the field which the farmers can use to note the pressure that reaches the lateral lines. Farmers could not determine the pressure that reaches the laterals and thus could not control the operating pressures of the sprinklers. They also used pipes which were not specified by the designer when repairing broken pipes in the field. They were cheap pipes of different sizes because they wanted to save money from repairs. This, however, affected the sprinkler discharge at the end. At Ziyanhle FA the discharge was very low because of lots of leakages which were observed during the tests. Pipes busted and farmers took long time to fix them. They also cited that they are not experts on the specifications of the pipes so they take the broken pipe to the supplier when they want to make a purchase.

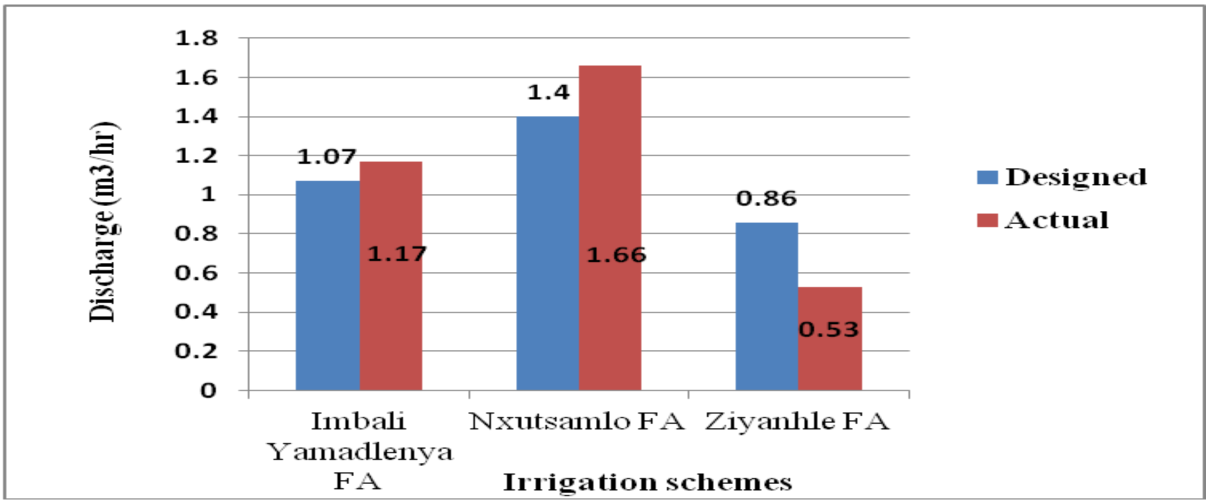

Figure 5.1: Designed and measured sprinkler discharge at Imbali Yamadlenya, Nxutsamlo and Ziyanhle schemes.

The discharge variations observed at Imbali Yamadlenya FA was 9.3%, 18.6% at Nxutsamlo FA and it was -38.4% for Ziyanhle FA (Figure 5.2). The variation for Nxutsamlo FA was double that recorded for Imbali Yamadlenya FA. The findings depicted that there was an over irrigation observed both at Imbali Yamadlenya FA and Nxutsamlo FA while Ziyanhle FA was under irrigated. This was due to the reasons already cited above on causes of differences in sprinkler discharge.

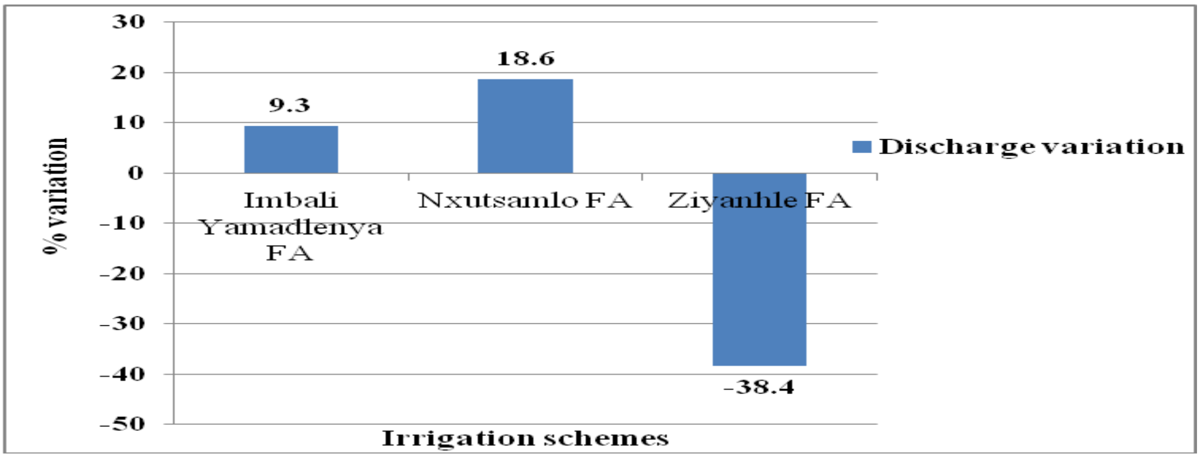

Figure 5.2: Discharge variations at Imbali Yamadlenya, Nxutsamlo and Ziyanhle schemes

5.2.2 Operating pressure

Operating pressures at Imbali Yamadlenya FA, Nxutsamlo FA and Ziyanhle FA were found to be 330 kPa, 380 kPa and 180 kPa respectively compared to 300 kPa, 350 kPa and 300 kPa respectively which were the design specifications (Figure 5.3).

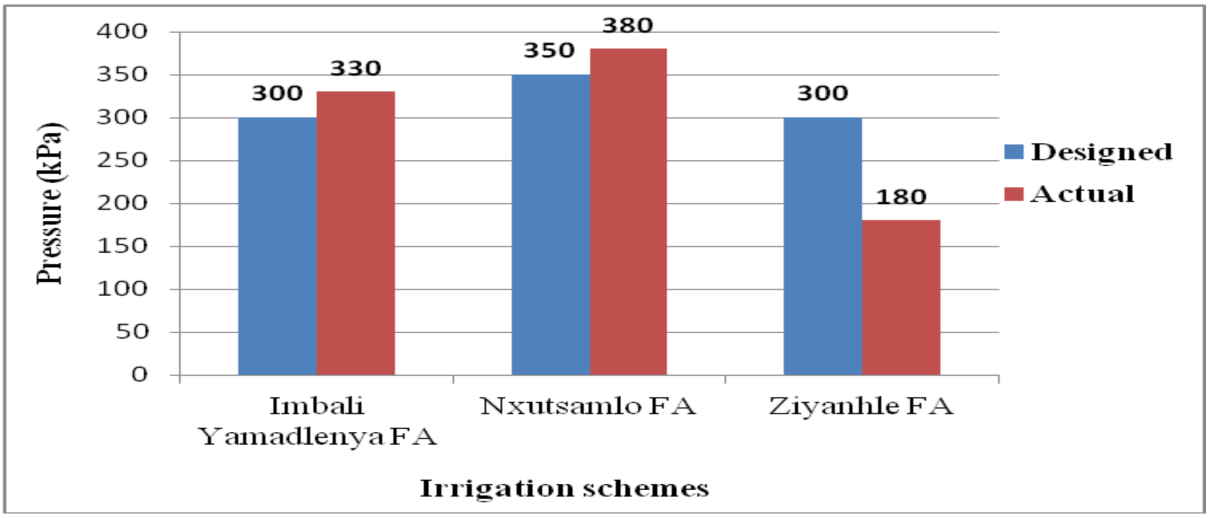

Figure 5.3: Differences between designed and measured operating pressure at Imbali Yamadlenya, Nxutsamlo and Ziyanhle schemes

The computed pressures variations were 10%, 8.6% and -40% for Imbali Yamadlenya FA, Nxutsamlo FA and Ziyanhle FA respectively (Figure 5.4). At Ziyanhle FA there were a lot of leaks in the system. The field was also steep (slope ranged from 3%-6%) which drastically reduced the operating pressure. These leaks were observed mainly along the dragline connections. At Nxutsamlo the pressures were high because the system was operating with inadequate number of sprinklers. A few number of sprinklers had to share the already designed operating pressure for the whole field.

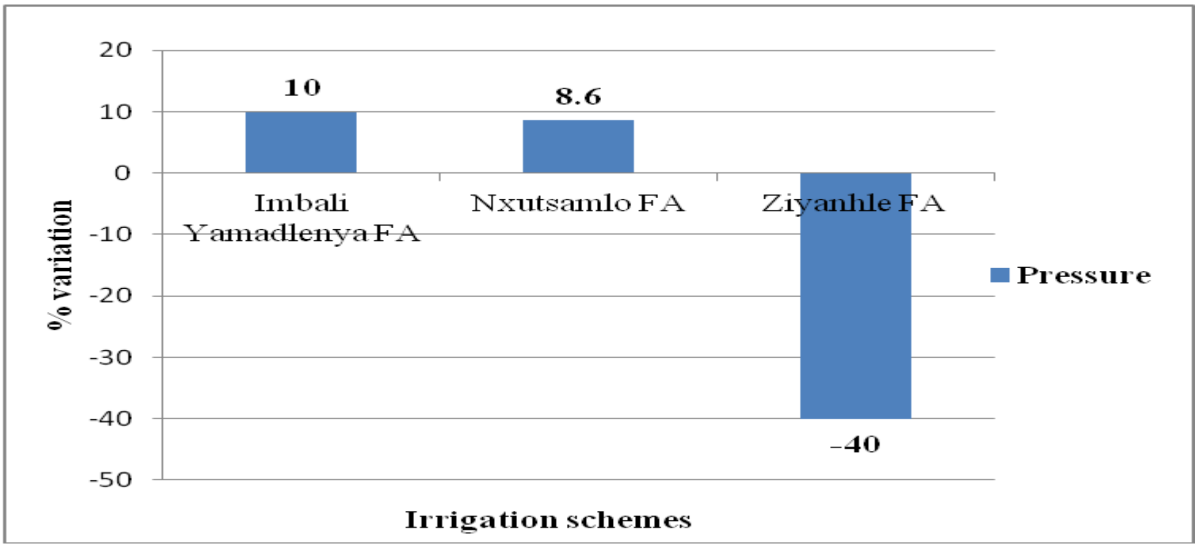

Figure 5.4: Pressure variations at Imbali Yamadlenya, Nxutsamlo and Ziyanhle schemes

The majority of the sprinklers nozzles were worn out as they were observed at Nxutsamlo FA where nozzles were of plastic material instead of brass. The pipes and fittings also leaked profusely. Both Ziyanhle FA and Imbali Yamadlenya FA did not have functioning flow meters to determine the outflow from the pump station to the field. This made it difficult to ascertain how much water was distributed to the field which could have directly affected the sprinkler operating pressures.

5.2.3 Number of operating sprinklers

The number of sprinklers simultaneously operating in the field can also affect the discharge and operating pressure. In two schemes, the number of sprinklers operating in the different fields varied from the one determined by the manufacturer's manual (Figure 5.5).

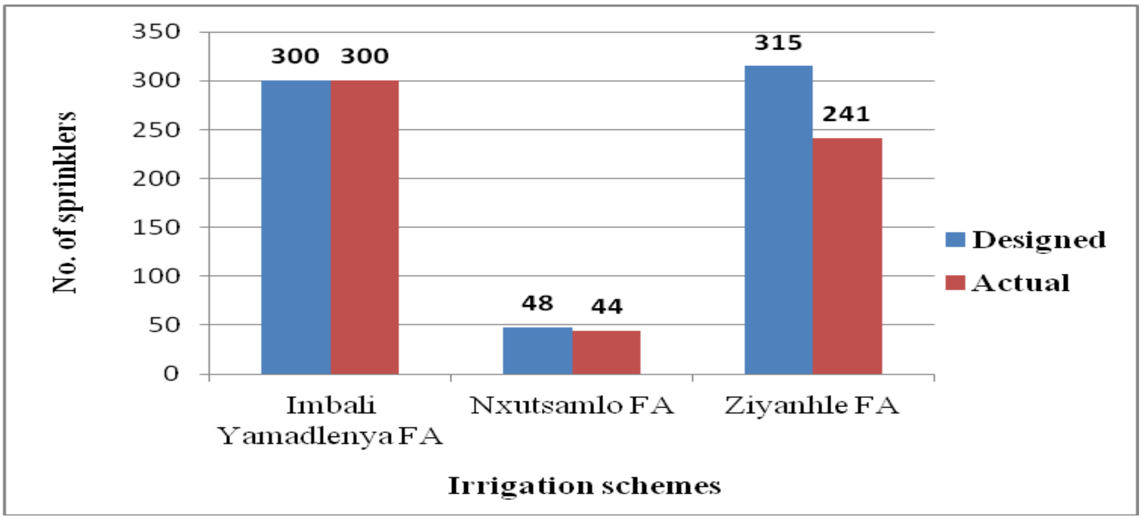

Figure 5.5: Differences between designed and observed number of sprinklers at Imbali Yamadlenya, Nxutsamlo, and Ziyanhle schemes

At Imbali Yamadlenya FA all the designed number of operating sprinklers matched the number from the designer's manual. At Nxutsamlo FA the shortage of sprinklers in the field contributed to the high discharge variation and pressure from the available sprinklers thus more water was applied into the field at a time. At Ziyanhle FA the sprinklers had not been installed because they don't have heads.

5.3 Frequency of water application

The frequency of water application was assessed in all the three irrigation schemes. Parameters which were observed included the soil moisture determination and irrigation routine (includes the irrigation cycle, set time and shifts per day) implemented.

5.3.1 Timing of irrigation

Farmers in all the three schemes pointed out that they were supposed to use the profit and loss method to determine how much soil moisture content was available in the field before they could irrigate. The project management was in charge of preparing the irrigation schedules and provided them to the farmers. Farmers would irrigate once a soil moisture depletion of 50% was attained. Information on how the profit and loss method was used in order to determine on how much water should be applied was lacking. A traditional method (‘feel’ method) of digging a small soil sample from the field and rolling it against the hands was used in the different schemes. If the soil particles come together and form a circle shape without breaking then it means the soil moisture is high. If it breaks it means the field needs to be irrigated. This soil moisture determination process was conducted by the scheme supervisors. He then decides when to irrigate and how much should be applied in the field at that time. Practically there was no systematic irrigation scheduling followed in all of these schemes. This method is not accurate and farmers cannot exactly determine the extent of moisture in the soil profile.

In addition, the different soil types on which the schemes were developed have different water holding capacities and require different irrigation schedules. This also made it difficult to rely to such a method because of the different soil properties found within the entire field. This has led to over irrigation in blocks where some sections are dominated by soils with low holding water capacities. At Nxutsamlo FA and Imbali Yamadlenya FA the blocks (Figure 5.7) which were tested were dominated by shallow soils and during the tests which took 2 hours each there were already water ponds observed in the fields. Both schemes are over-irrigated and this was evidenced by water ponds that were observed some minutes after the systems were operated.

Figure 5.6: Water ponding observed at Nxutsamlo FA and Imbali Yamadlenya FA during field measurements

5.3.2 Irrigation practice

The irrigation practice is important because it is a way adopted to ensure that the crop receives the required amount of water at the right time without it being subjected to water stress. It refers to the set times, frequency cycles and the shifts administered during irrigation.

An irrigation routine of 12 hours stand time, and a 6 day cycle was adopted throughout the growing season for Nxutsamlo FA. Two shifts per day starting at 6am – 6pm – 6am were implemented. This routine differed from the designer's specifications of 9 hours stand time and a 6 day cycle. At Ziyanhle FA the adopted water application routine throughout the season was of 6 hours stand time and a 6 day cycle instead of 6 hours stand time and a 3 day cycle from the designer's manual. Two shifts per day starting from 6am-12 noon-6pm were also adopted. For Imbali Yamadlenya FA 9 hours stand time and a 6 day cycle was implemented throughout the season which was different from the 8 hours of stand time and a 3 day cycle provided in the designer's manual. This scheme also had two shifts per day which started at 6am-3pm-12 midnight.

The irrigation practiced did not take into account the crop developmental stages. The schemes at Nxutsamlo FA and at Imbali Yamadlenya FA were over irrigated which had implications in the overall performance of the scheme. This was due to the increase set time they were implementing. It took many days for the cycles to be completed when already the crop was water stressed and the soil very dry. This affected the growth of the crop. At Ziyanhle FA the irrigation cycle took 6 days to be completed which exposed the crop to prolonged period of time without having water. This was caused by the shortage of operating sprinklers in the field.

5.4 Irrigation Adequacy

The sugarcane crop water requirements (CWR) calculations were derived by a private consultant hired by the project management. The peak ET_C of 5.8mm/day was used to derive irrigation frequencies for all the developed irrigation schemes.

Table 5.1:Crop water requirements observed at Imbali Yamadlenya, Nxutsamlo and Ziyanhle schemes.

Parameters	Name of Farmers Associations		
	Imbali Yamadlenya FA	Nxutsamlo FA	Ziyanhle FA
Peak ET_c (mm/day)	5.8	5.8	5.8
Actual net application per cycle (mm)	24.3	66.5	10
Actual irrigation cycle (days)	6	6	6
Observed CWR (mm/day)	4.1	11.1	1.7

The calculated CWRs for the three schemes were 4.1mm/day, 11.1mm/day and 1.mm/day for Imbali Yamadlenya FA, Nxutsamlo FA and Ziyanhle FA respectively and at Imbali Yamadlenya FA the calculated CRW varied by -29.3% while that observed at Nxutsamlo FA varied by 91.4% and at Ziyanhle FA the CRW variation was -70.7%. In all the three schemes the calculated crop water requirements did not match the already derived peak CRW by the project management. The variations from the designed ETc were due to the variations in sprinkler application depths which resulted into varied gross application depths. At Ziyanhle FA less water was applied. The variation from the designed ETc was -70.7%. At Imbali Yamadlenya the variation (-29.3%) was decreasing because the water application from the sprinklers nearly matched the designed sprinkler application rates. The calculations at Nxutsamlo FA showed that the sprinklers applied water almost double the designed sprinkler application rate. This showed that there was over application of water by the system which led to over irrigation (see Appendix for detailed results).

The CWR variations observed from field measurements that were taken from the three different schemes (Figure 5.8).

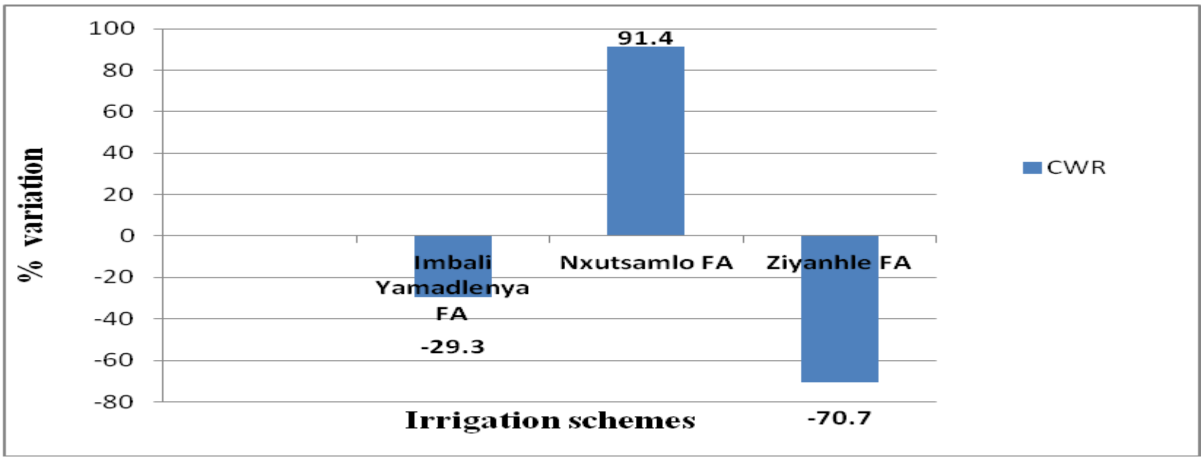

Figure 5.7: % variation in CWR at Imbali Yamadlenya, Nxutsamlo and Ziyanhle schemes.

5.4.1 Application depth

The total depth of water caught at Nxutsamlo, Ziyanhle and Imbali Yamadlenya irrigation schemes were 30.3mm, 23.8mm and 191mm respectively. The mean depths of water measured were 1.2 mm, 1.0 mm and 5mm respectively. The difference could be attributed to the relatively high wind speed and relatively low humidity recorded during the field measurements. The wind drift left some areas dry without water collected from the catch cans. In addition, the temperatures were high during the field tests which increased evaporation. Detailed data obtained from these sprinkler tests are shown in Appendix 1, 2 and 3.

The basic infiltration rates calculated from the three sites (Nxutsamlo FA, Ziyanhle FA and Imbali Yamadlenya FA) were 19.8mm/h, 31.8mm/hr and 10.2mm/hr respectively. This indicated that all water from the sprinklers could be absorbed without runoff. The detailed results of the infiltration tests for all the schemes are presented in Appendix 1, 2 and 3. Figure 5.9 shows the comparisons between the calculated application rates and infiltration rates for all the three schemes.

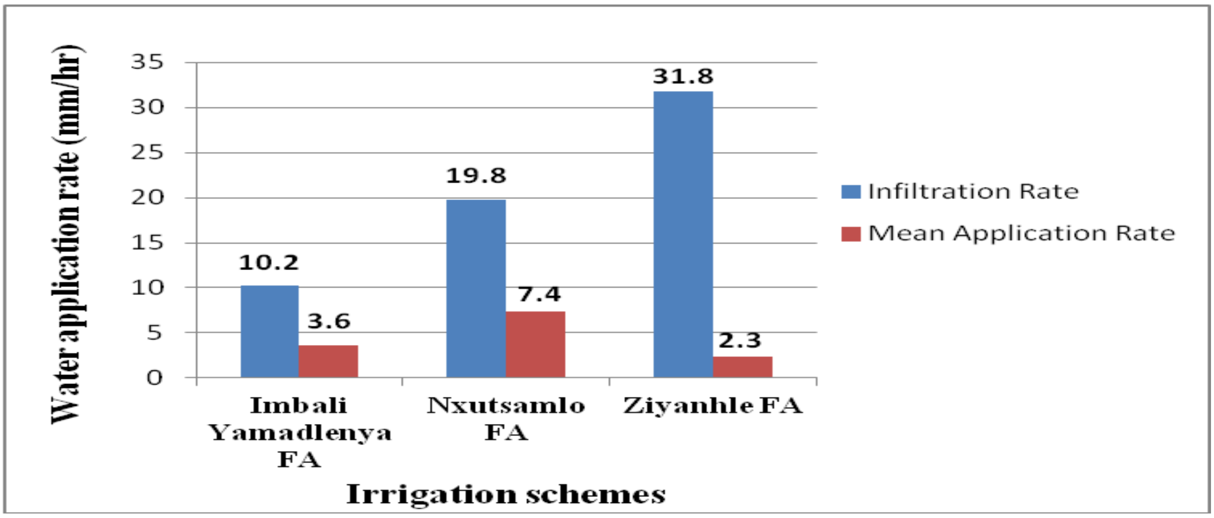

Figure 5.8: Comparisons between the mean application rates and the infiltration at Imbali Yamadlenya, Nxutsamlo and Ziyanhle schemes

5.5 Irrigation uniformity

The Christiansen's uniformity (CU) coefficients and the distribution uniformity were computed from the data derived in the fields for all the three irrigation schemes. Figure 5.10 below shows the measurements of irrigation uniformity obtained from the different sites.

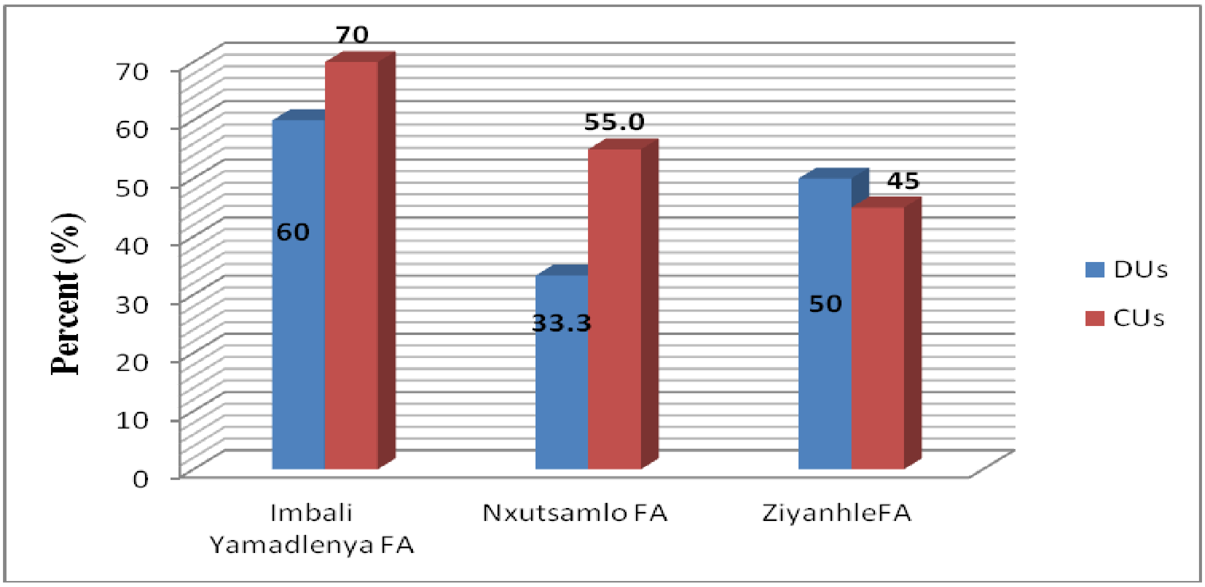

Figure 5.9: Measurements of irrigation uniformity for Imbali Yamadlenya, Nxutsamlo and Ziyanhle schemes

5.5.1 Christiansen's coefficient of uniformity

The CU provides a quantitative measure of the average deviation from the mean application depth. Data from the three study sites (Nxutsamlo FA, Ziyanhle FA and Imbali Yamadlenya FA) depicted CUs of 55%, 45% and 70% respectively. The CUs for the three schemes were below the standard value of at least 85% stated by Keller & Bliesner (1990) for agricultural sprinklers. This was due to the observed high winds, leakages from pipes, pipes fittings and the differences in sprinkler discharge experienced during the field measurements.

The observed average wind speed during the field tests for Imbali Yamadlenya, Nxutsamlo and Ziyanhle were 14km/hr, 13.6km/hr and 14.8km/hr respectively at relative humidity of 30.1%, 19.7%.and 30.4% respectively. The highest average temperature recorded during the tests was 33.1^{o}C at Nxutsamlo FA. Wind speed in combination with sprinkler spacing has impact on the uniformity of set-move sprinkler irrigation systems. The problem is pronounced especially when wind speed exceeds 8 km/h (King *et al.*, 2000).

5.5.2 Pattern Efficiency/ Distribution Uniformity

The pattern efficiency (PE) also known as the distribution uniformity (DU) was also computed for the three sets of data. Rogers *et al*., (1997) stated that the distribution uniformity gives an indication of the magnitude of the uneven distribution and can be defined as the percent of average application amount in the lowest quarter of the field. The calculated Nxutsamlo FA distribution uniformity was 33.3%, Ziyanhle recorded 50% and for Imbali Yamadlenya scheme it was 60%. The distribution uniformity observed for all the three schemes was below the standard value of 75% stated for agricultural sprinklers (Ascough & Kiker, 2002). According to Keller and Bliesner, (1990), a DU value of less than 60% is unacceptable and a value of more than 75% is recommended so the calculated values were below those recommended by these authors.

The sprinklers from the three schemes operated at unsatisfactory pressures and the environmental conditions (high wind velocities, low relative humidity and high temperatures) during the field measurements were adverse so they affected the overall irrigation uniformities for the different schemes. The observed average readings are presented in Figure 5.11. The strong winds observed during the tests left dry zones during irrigation because of the wind drift and high temperatures increased evaporation that led to less water that infiltrated into the soil profile.

5.6 Conclusion

Both Imbali Yamadlenya FA and Nxutsamlo FA had their emitters discharging more water than the designed specifications while at Ziyanhle the discharge was very low. This was the same in all the schemes with their operating pressures. These findings depicted that both Imbali Yamadlenya FA and Nxutsamlo FA were over irrigated while Ziyanhle FA was under irrigated. Nxutsamlo FA and Ziyanhle FA had a shortage of operating sprinklers in their fields.

Imbali Yamadlenya FA and Ziyanhle FA are dominated by shallow soils which quickly get soaked during irrigation. Though Nxutsamlo was dominated by deep soils, there were also sections within the field where shallow soils existed. In all the schemes there was no systematic irrigation scheduling. There was only one irrigation practice adopted for the entire season for each particular scheme. The farmers in all the schemes did not have a scientific tool of determining the soil moisture content. They could not tell how much water the crop requires on daily basis and could not tell or calculate how much water they are applying in the field per day. This had negative impacts on the yield and sucrose content of the crop thus leading to reduced profits from the enterprise.

In all the three schemes it was observed the crop water requirement was not met. Both Imbali Yamadlenya FA and Ziyanhle FA' systems applied less water than what the plant required for its optimum growth. At Nxutsamlo FA the crop water requirement was met but then the crop was over irrigated since more water was applied at a time. The calculated basic infiltration rates for all the schemes showed that the soil can absorb all the water applied without water runoff. The sprinklers application rates were less than the calculated basic infiltration rates.

All the three schemes, the irrigation uniformities were poor. They were all below the asserted standard values which were highlighted by other scholars. The distribution uniformities (ranged from 33.3% to 60%) and Christiansen uniformities (ranged from 45% to 70%) were all below the set standards. This was caused mainly by the high wind velocities, low relative humidity, high temperatures, high flow variations and pressure variations experienced during the field measurements.

CHAPTER SIX

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

The purpose of this study was to assess the technical efficiency of sprinkler irrigation of three smallholder sugar cane schemes based in the Lubovane area of Swaziland under the Lower Usuthu Smallholder Irrigation Project (LUSIP) phase 1 in terms of design parameters, frequency of water application, irrigation adequacy and irrigation uniformity. The irrigation schemes assessed were Imbali Yamadlenya FA, Nxutsamlo FA and Ziyanhle FA.

The chapter summarizes the findings of the study and provides recommendations for future work in this field.

6.2 Summary of findings

The summary of findings is in line with the objectives of the study. They included the design parameters, frequency of irrigation, irrigation adequacy and irrigation uniformity.

Both Imbali Yamadlenya FA and Nxutsamlo FA had their emitters discharging more water than the designed specifications while at Ziyanhle the discharge was very low. This was the same in all the schemes with their operating pressures. The flow variations for Imbali Yamadlenya, Nxutsamlo FA and Ziyanhle FA were 9.3%, 18.6% and -38.4% respectively. The operating pressure variations observed were 10%, 8.6% and -40% for Imbali Yamadlenya FA, Nxutsamlo FA and Ziyanhle FA respectively. These findings depicted that both Imbali Yamadlenya FA and Nxutsamlo FA were over irrigated and Ziyanhle FA was under irrigated. Nxutsamlo FA and Ziyanhle FA had a shortage of operating sprinklers in their fields.

The farmers in all the schemes used the “feel” method to determine soil moisture content, a method that could compromise the accuracy. They had no systematic irrigation scheduling. One irrigation routine was adopted for the entire season. The three schemes were constituted by different types of soils in their fields and the lowest water holding soil properties were not used as the yardstick in designing of the irrigation scheduling.

Both Imbali Yamadlenya FA and Ziyanhle FA’ systems applied less water than what the plant required for its optimum growth. At Nxutsamlo FA the crop water requirement was met but then the crop was over irrigated by 91.4%. The CWRs were 4.1mm/day, 11.1mm/day and

1.7mm/day for Imbali Yamadlenya FA, Nxutsamlo FA and Ziyanhle FA respectively. In all the schemes the soils can absorb all the water applied without water runoff. The sprinklers application rates were less than the calculated basic infiltration rates. The basic infiltration rates for Nxutsamlo FA, Ziyanhle FA and Imbali Yamadlenya FA were 19.8mm/hr, 31.8mm/hr and 10.2mm/hr respectively while the sprinkler applications rates were 7.4mm/hr, 2.3mm/hr and 3.6mm/hr respectively. This depicted that the soil properties could afford to absorb the application of water from the sprinklers.

All the three schemes poor irrigation uniformities were. They were all below the asserted standard values which were highlighted by other scholars. The distribution uniformities ranged from 33.3% to 60% and the Christiansen uniformities ranged from 45% to 70%. This was caused mainly by the high wind velocities, low relative humidity, high temperatures, high flow variations and pressure variations experienced during the field measurements.

6.3 Recommendations

Based on the findings a number of recommendations can be made

All missing sprinklers should be installed at Ziyanhle FA and Nxutsamlo FA because that greatly affected the output pressure of the sprinklers. All leakages should be attended as quickly as possible within the system as they also affected the flow rates at Ziyanhle FA.

A proper and simple scheduling strategy should be adopted for all the schemes. The irrigation routine should not be the same throughout for the entire field. Farmers need to be capacitated on irrigation scheduling to minimize yield and sucrose losses due to either over-irrigation or under-irrigation. Irrigation stand times and irrigation cycles must be calculated based on individual soil physical properties. The sections dominated by soils with low water holding capacity must determine the stand time and cycle length. There could also be a study on soil moisture determination which was not covered in this research.

Flow meters at Ziyanhle FA and Imbali Yamadlenya FA need to be fixed. The number of people changing the sprinklers and fixing leaking pipes at Ziyanhle FA need to be increased and an irrigation technician hired to provide technical advice to arising problems and challenges faced in the operations of the system.

Full account should be taken of the effects of strong winds, high temperatures and low relative humidity when selecting the type of sprinklers to be used since it was observed after data analysis that under windy conditions the fields were not uniformly irrigated. Sprinklers with short (1.6m) risers could be an option though they may be costly.

Further research may be conducted on the subject by considering the effects of non uniformity irrigation application on crop yield and farm income.

Overall conclusion and recommendation

According to the findings from the study, the overall conclusion was that the sprinkler irrigation system used in the three schemes was not efficient in terms of water application, irrigation adequacy and irrigation uniformity.

Therefore there is a need that the project management develop technical interventions for capacity building of the smallholder farmers to better manage their irrigation schemes in order to achieve the project's goal of reducing poverty and improving their livelihoods and that of their communities. Improvement on the three important areas (operations, maintenance and management) within the farms could yield positive results.

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APPENDICES

7 Appendix 1A: Field tests results and computations-Imbali Yamadlenya FA

Field Details

Total Design Area: 58.7 Ha

Block Number: Block C, Number 104

Block Area: 1.6 Ha

Table 7.1: Time and environmental conditions during field measurements-Imbali Yamadlenya FA

Time (am/pm)	Wind speed (Km/hr)	Temperature (^{o}C)	Relative Humidity (%)
1345	18	31.4	33.1
1400	16.8	31.8	31.9
1415	10.5	32.6	30
1430	10.1	32.5	28.8
1445	14.1	32.2	29.8
1500	9.7	32.3	28.9
1515	13	31.4	29.1
1530	15.9	31.6	29.9
1545	18.6	31.6	29.7
Average	**14**	**31.9**	**30.1**

Table 7.2: Measurements and observations during field tests- Imbali Yamadlenya FA

Parameters	Comments/Remarks
Source of irrigation water	Reservoir (Lubovane Dam)
Crop height	1.1m
Crop stage	Early stage (12weeks)
Catch can diameter	90mm
Height of sprinkler riser	3m
Height of catch can	140mm
Volume of catch can	500mL
Topography of selected block	Gently sloping
Condition of selected site	Vegetation less than 150mm in height, very windy and hot
Quality of irrigation water	Clean, free from dirt (solids)
Flow Meter Device	Not functioning
Other	Some sprinklers showing misty discharge

Appendix 2A: Infiltration tests– Imbali Yamadlenya FA

Site Location: Imbali Yamadlenya FA (Block 104c) **Soil type:** (Sh) – clay loam **Test date:** 9th September 2013

Table 7.3: Soil infiltration test results - Imbali Yamadlenya FA

Reading on the clock hr min sec	Time differenc min	Cumulative time min	Water level reading		Infiltration mm	Infiltration rate mm/min	Infiltration rate mm/h r	Cumulative infiltration mm
			Before filling (mm)	after filling (mm)				
11:16:00	Start=0	Start= 0		*100*				*Start=0*
	2				*10*	*5*	*300*	
11:18:00		2	*90*	*100*				*10*
	3				*10*	*3.3*	*200*	
11:21:00		*5*	*90*	*100*				*20*
	10				*8*	*0.8*	*48*	
11:31:00		*15*	*92*	*100*				*28*
	10				*4*	*0.4*	*24*	
11:41:00		*25*	*96*	*100*				*32*
	10				*3*	*0.3*	*18*	
11:51:00		*35*	*97*	*100*				*37*
	30				*5*	*0.17*	***10.2****	
12:36:00		*65*	*95*	*100*				*42*
	30				*5*	*0.17*	***10.2****	
13:06:00		*95*	*95*	*100*				*47*
	30				*5*	*0.17*	***10.2****	
13:36:00		*120*	*95*	*100*				*52*

**Basic Infiltration Rate=10.2mm/hr*

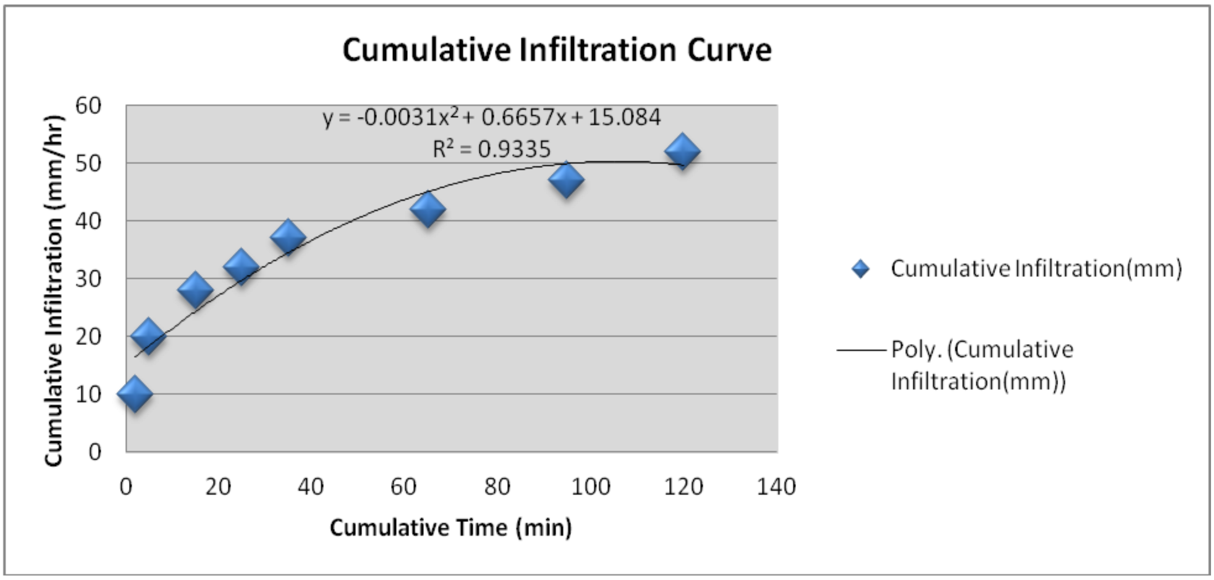

Figure 7.1: Determined cumulative infiltration curve for Imbali Yamadlenya FA

Appendix 3A: Computation of DU and CU - Imbali Yamadlenya FA

Table 7.4: Computation of DU and CU for Imbali Yamadlenya FA

Catch Can No.	Volume (mL) Xi	X	Xi – X
1	25	33.9	8.9
2	32	33.9	1.9
3	22	33.9	11.9
4	20	33.9	13.9
5	22	33.9	11.9
6	23	33.9	10.9
7	30	33.9	3.9
8	50	33.9	16.1
9	57	33.9	23.1
10	44	33.9	10.1
11	25	33.9	8.9
12	19	33.9	14.9
13	20	33.9	13.9
14	59	33.9	25.1
15	38	33.9	4.1
16	45	33.9	11.1
17	28	33.9	5.9
18	23	33.9	10.9
19	45	33.9	11.1
20	55	33.9	21.1
21	44	33.9	10.1
22	35	33.9	1.1
23	33	33.9	0.9
24	20	33.9	13.9
25	37	33.9	3.1

26	37	33.9	3.1
27	42	33.9	8.1
28	40	33.9	6.1
29	35	33.9	1.1
30	24	33.9	9.9
31	20	33.9	13.9
32	22	33.9	11.9
33	40	33.9	6.1
34	27	33.9	6.9
35	29	33.9	4.9
36	54	33.9	20.1
Sum	**1221**		**360.8**
Mean	**33.9**		

$$CU = 100\left[1 - \frac{\sum_{i=1}^{n}[Xi - \bar{X}]}{\sum_{i=1}^{n} n * \bar{X}}\right]$$

CU=100 (1-360.8/1220.4)
CU=100(1-0.3)
CU=100*0.7
<u>CU=70%</u>

DU = (M25/M)*100
(3/5)*100
0.6*100
<u>DU=60%</u>

$$MAR = \frac{Average\ sprinkler\ discharge\ recorded\ during\ test}{Mainline\ spacing\ X\ Lateral\ spacing}\ X\ 1000$$

Average sprinkler discharge= 1.17m^3/hr
Mainline spacing X Lateral spacing = 18m X 18m
1.17/324=0.0036m/hr
0.0036 m/hr * 1000mm/hr
<u>MAR=3.6mm/hr exceed the designed 3.3mm/hr</u>

Appendix 1B: Field tests results and computations - Nxutsamlo FA

Field Details

Total Design Area: 19 Ha

Block Number: Block A

Block Area: 10.8 Ha

Table 7.5: Time and environmental conditions during field tests - Nxutsamlo FA

Time (am/pm)	Wind speed (Km/hr)	Temperature (^{o}C)	Relative Humidity (%)
1110	12.1	32.9	24.5
1125	12.9	32.7	23.4
1140	14.3	32.8	20.6
1155	10.5	34.8	19.8
1210	16.8	32.4	17.7
1225	16.1	33.1	17.8
1240	13	33.2	17.5
1255	12.8	32.8	16.7
1310	14.2	33.4	19.6
Average	**13.6**	**33.1**	**19.7**

Table 7.6: Measurements and observations during field tests - Nxutsamlo FA

Parameters	Comments/Remarks
Source of irrigation water	Reservoir (Lubovane Dam)
Crop height	0.7m
Crop stage	Early stage (3weeks)
Height of sprinkler riser	3m
Catch can diameter	90mm
Height of catch can	140mm
Volume of catch can	500mL
Topography of selected block	Relatively flat
Condition of selected site	Vegetation less than 150mm in height, windy and hot day
Quality of irrigation water	Clean, free from dirt (solids)
Type of soil under test	Shallow soils prevalent

Appendix 2B: Infiltration tests – Nxutsamlo FA

Site Location: Nxutsamlo FA (Block 106) **Soil type:** Shallow and clayey soils (Zd) **Test date**: 5th September 2013

Table 7.7: Soil infiltration test results - Nxutsamlo FA

Reading on the clock hr min sec	Time difference min	Cumulative time min	Water level reading		Infiltration mm	Infiltration rate mm/min	Infiltration rate mm/h	Cumulative infiltration mm
			Before filling (mm)	after filling (mm)				
10:13:00	Start=0	Start= 0		*100*				*Start=0*
	2				*16*	*8*	*480*	
10:15:00		3	*84*	*100*				*16*
	3				*14*	*4.7*	*282*	
10:18:00		*5*	*86*	*100*				*30*
	5				*12*	*2.4*	*144*	
10:22:00		*10*	*88*	*100*				*42*
	10				*10*	*1*	*60*	
10:32:00		*20*	*90*	*100*				*52*
	10				*9*	*0.9*	*54*	
10:42:00		*30*	*91*	*100*				*61*
	30				*10*	*0.33*	*19.8**	
11:12:00		*60*	*90*	*100*				*71*
	30				*10*	*0.33*	*19.8**	
11:42:00		*90*	*90*	*100*				*81*
	30				*10*	*0.33*	*19.8**	
12:12:00		*120*	*90*	*100*				*91*

**Basic Infiltration Rate=19.8mm/hr*

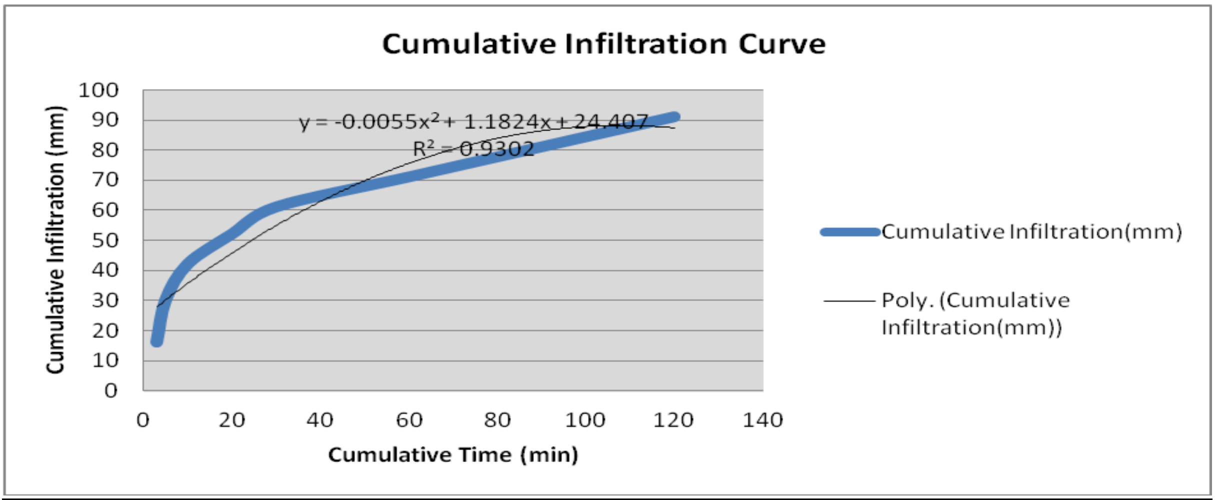

Figure 7.2: Determined Cumulative infiltration curve for Nxutsamlo FA

Appendix 3B: Computation of DU and CU - Nxutsamlo FA

Table 7.8: Computation of DU and DU - Nxutsamlo FA

Catch Can No.	Volume (mL) Xi	X	Xi – X
1	X		
37	X		
38	8	7.5	0.5
39	10	7.5	2.5
40	9	7.5	1.5
41	7	7.5	-0.5
42	10	7.5	2.5
43	22	7.5	14.5
44	8	7.5	0.5
45	8	7.5	0.5
46	11	7.5	3.5
47	11	7.5	3.5
48	5	7.5	2.5
49	10	7.5	2.5
50	6	7.5	1.5
51	2	7.5	5.5
52	1	7.5	6.5
53	3	7.5	4.5
54	1	7.5	6.5
55	10	7.5	2.5
56	9	7.5	1.5
57	11	7.5	3.5
58	4	7.5	3.5
59	9	7.5	1.5
60	3	7.5	4.5
61	5	7.5	2.5
62	1	7.5	6.5

63	10	7.5	2.5
SUM	**194**		**87**
MEAN	**7.5**		

(From catch can 1-37, volume = 0mL)

CU=100[1-87/195]
100[1-0.45]
100[0.55]
CU=55%

DU = (M25/M)*100
(0.4/1.2)*100
DU=33.3%

$$MAR = \frac{Average\ sprinkler\ discharge\ recorded\ during\ test}{Mainline\ spacing\ X\ Lateral\ spacing}\ X\ 1000$$

Average sprinkler discharge= 1.66m^3/hr
Mainline spacing X Lateral spacing = 15m X 15m
1.66/225=0.00738m/hr
0.00738 m/hr * 1000mm/hr
MAR=7.38 mm/hr far exceed the designed 4.33mm/hr

Appendix 1C: Field tests results and computations - Ziyanhle FA

Field Details

Total Design Area: 82.6 Ha

Block number: Block 18

Table 7.9: Time and environmental conditions during field tests - Ziyanhle FA

Time (am/pm)	Wind speed (Km/hr)	Temperature (°C)	Relative Humidity (%)
1130	19.6	33	29.2
1145	20.4	32.6	31.6
1200	11.2	33.1	29.7
1215	10.8	32.4	29.1
1230	16.1	33.2	29.8
1245	14.8	32.9	30
1300	11.2	33	31.4
1315	13.6	32.8	29.9
1330	15.4	33.1	30.8
Average	**14.8**	**32.9**	**30.2**

Table 7.10: Measurements and observations during field tests- Ziyanhle FA

Parameters	Comments/Remarks
Source of irrigation water	Reservoir (Lubovane Dam)
Crop height	1.2m
Crop stage	Early stage (8 weeks)
Height of sprinkler riser	3m
Catch can diameter	87mm
Height of catch can	140mm
Volume of catch can	500mL
Topography of selected block	Slightly steeper
Condition of selected site	Vegetation less than 150mm in height, very windy, hot day
Quality of irrigation water	Clean, free from dirt (solids)
Flow meter device	Not functioning
Other	74 sprinklers are not installed since 2011, they don’t have heads, most underground pipes are leaking, sprinklers show different throws,

Appendix 3B: Infiltration Tests – Ziyanhle FA

Site Location: Ziyanhle FA (Block 18) **Soil type:** Loam (Cu) **Test date**: 4th September 2013

Table 7.11: Soil infiltration test results - Ziyanhle FA

Reading on the clock hr min sec	Time difference min	Cumulative time min	Water level reading		Infiltration mm	Infiltration rate mm/min	Infiltration rate mm/h	Cumulative infiltration mm
			Before filling (mm)	after filling (mm)				
13:30:00	Start=0	Start= 0		*100*				*Start=0*
	3				*23*	*7.7*	*462*	
13:33:00		3	*77*	*100*				*23*
	5				*18*	*3.6*	*216*	
13:38:00		*8*	*82*	*100*				*41*
	7				*14*	*2*	*120*	
13:45:00		*15*	*86*	*100*				*55*
	10				*12*	*1.2*	*72*	
13:55:00		*25*	*88*	*100*				*67*
	10				*13*	*1.3*	*60*	
14:05:00		*35*	*87*	*100*				*80*
	25				*15*	*0.6*	*36*	
14:30:00		*60*	*85*	*100*				*95*
	30				*16*	*0.53*	*31.8**	
15:00:00		*90*	*84*	*100*				*111*
	30				*16*	*0.53*	*31.8**	
16:35:00		*120*	*84*	*100*				*127*

Basic Infiltration Rate: 31.8mm/hr

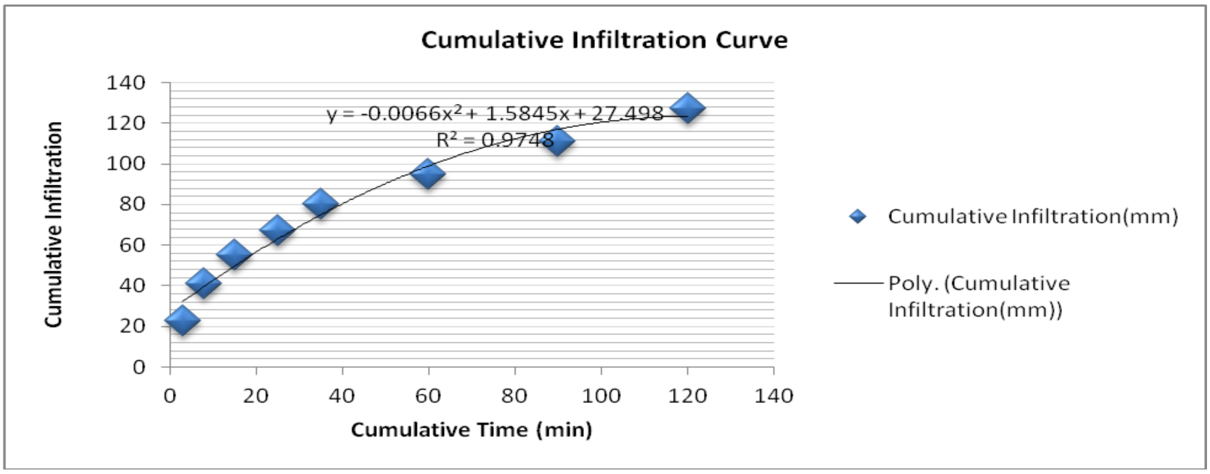

Figure 7.3: Determined Cumulative infiltration curve for Ziyanhle FA

Appendix 3C: Computation of DU and CU- Ziyanhle FA

Table 7.12: Computation of DU and CU for Ziyanhle FA

Catch can No.	Volume (mL) Xi	X	Xi – X
39	X		
40	4	6.3	2.3
41	2	6.3	4.3
42	4	6.3	2.3
43	4	6.3	2.3
44	4	6.3	2.3
45	10	6.3	3.7
46	4	6.3	2.3
47	4	6.3	2.3
48	25	6.3	18.7
49	4	6.3	2.3
50	8	6.3	1.7
51	4	6.3	2.3
52	5	6.3	1.3
53	12	6.3	5.7
54	4	6.3	2.3
55	4	6.3	2.3
56	14	6.3	7.7
57	6	6.3	0.3
58	8	6.3	1.7
59	8	6.3	1.7
60	4	6.3	2.3
61	2	6.3	4.3
62	4	6.3	2.3
63	4	6.3	2.3
SUM	**152**		**81**
MEAN	**6.3**		

(From catch can 1-39, volume = 0mL)

$$CU = 100\left[1 - \frac{\sum_{i=1}^{n}[Xi - \bar{X}]}{\sum_{i=1}^{n} n * \bar{X}}\right]$$

CU=100(1-13.2/24)
CU=100(1-0.55)
CU=45%

DU = (M25/M)*100
(0.5/1.0)*100
DU=50%

$$MAR = \frac{Average\ sprinkler\ discharge\ recorded\ during\ test}{Mainline\ spacing\ X\ Lateral\ spacing}\ X\ 1000$$

Average sprinkler discharge= 0.86 m3/hr
Mainline spacing X Lateral spacing = 15m X 15m
0.53/225=0.00164m/hr
0.00235 m/hr * 1000mm/hr
MAR=2.25 mm/hr below the designed 3.82mm/hr