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WATER PRODUCTIVITY AND THE RELATIVE EFFECTS OF SALINITY ON CROP YIELDS FOR A SURFACE IRRIGATION SCHEME – A CASE OF INSUKAMINI IRRIGATION SCHEME

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The undersigned certify that they have read and recommend to the Midlands State University for acceptance; a dissertation entitled 'Water Productivity and the relative effects of salinity on crop yields for a surface irrigation scheme – a case of Insukamini Irrigation Scheme", Submitted by Nabars Makwara in partial fulfilment of the requirements for the degree of MSc and Resources Assessment For Development Planning

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Dedication

This piece of work is dedicated to my Son, Leeroy Trust; my Daughter, Lilian Rutendo; my lovely wife Tendayi and Mom, Laiza Makwara.

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All the glory and honour belongs to the Almighty God for bringing me this far. I am grateful to my supervisors Mr. Mufute and Professor Masaka for their valuable guidance. All the Land and Water Resources Management Department, Lecturers, I thank you. Your fruitful criticism and patience is highly commendable.

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God bless you all.

Abstract

Increasing water productivity is generally explained as to either produce similar yield using less water or obtaining more crop yields using the same water resources. Water is becoming scarce due increase in population as well as competition with other non- agricultural demands. At Insukamini Surface Irrigation Scheme, farmers over apply water volumes with the idea that they can increase their yield. However the Scheme has been facing challenges of yield decline from 2009 to 2014. This study was therefore designed to quantify the current levels of water productivity and the relative effects of salinity to crop yield. Questionnaire survey and laboratory experiments were done to assess the crop water productivity, irrigation water and soil quality parameters and their impact on the yield of sugar beans and maize grain. The results indicated that the soil was saline with EC ranging from 0.52dS/m-0.58dS/m. A reduction in the yield over 7 years was noted and there was a low water productivity ranging between 0,37kg/m^3 to 0.68kg/m^3 for maize and 0.33kg/m^3 to 0.62kg/m^3 for sugar beans. The conclusion was that the salinity is as a result of salt accumulation from irrigation water, decline in yield is caused by salinity levels, crops being grown are not tolerable to the salinity levels, hence low water productivity. It was recommended that the farmers should grow more salt tolerant crops, correct the salinity, practice deficit irrigation and practice good irrigation management practices.

List of Acronyms

FAO : Food Agricultural Organisation

CWP : Crop Water Productivity

AGRITEX : Agricultural Extension

WUE : Water Use Efficiency

EC : electrical Conductivity

SAR: Sodium Absorption Ratio

ESP : Exchangable Sodium Potasium

SS : Soluble salts

ET : Evapotranspiration

ZINWA : Zimbabwe National Water Authority

SPSS : Statistical Package for Social Science

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CHAPTER 1: INTRODUCTION

This chapter seeks to introduce the research on water productivity in small scale surface irrigation scheme focusing on Insukamini Irrigation Scheme of Lower Gweru in the Midlands Province of Zimbabwe. The chapter sets out the introduction through a description of the background of the study, statement of the problem, justification, research questions and research objectives.

1.2 BACKGROUND OF THE STUDY

The agriculture sector is increasingly becoming one of the most key sectors of economic growth in the world (Bouman et al., 2003). As the world population is constantly increasing it is expected that agriculture should substantially increase its productivity. Producing enough food and generating adequate income in the developing world to better feed the poor and reduce the number of those suffering is likely to be a huge task. It is expected that with the global population that is projected to increase to 7.8b in 2025, more pressure will be mounting on food security, especially in developing countries where more than 80% of the population increase is expected to occur (Cai and Rosegrant, 2003). Thus a major challenge for the coming years is to provide a secure food supply to all newcomers. Food security is at risk and international organizations like the World Bank, United Nations and the Food Agriculture Organization (FAO) are calling for action (van Dam, 2003).

Despite the call for increased food security, in recent seasons, regional climate has been associated with an uneven rainfall distribution. The global warming effect is now adversely affecting most of the subtropical climate. This is witnessed by the erratic rainfall distribution, high temperatures, floods, the things which are making it difficult for crop production to mitigate food security (De Fraiture *et al*., 2008). Zimbabwe is not an exception to all these challenges. According to Magodo (2007), in Zimbabwe the available water for irrigation has become scarce over the last two decades and this has been attributed to declining rainfall, urbanization, and frequent drought. The scarcity of water is now compromising the underground water recharge and viability of irrigation (Molden et al., 2003). With the growing irrigation-water demand and increasing competition amongst different water-users, the country is now facing a challenge to produce more food with less water. It is therefore necessary to conserve and utilize the available water resources more productively.

In response to water challenges, conservation practices have been introduced in Zimbabwe. The Government has incorporated AGRITEX officers and Non-Governmental Organizations to train farmers at all levels in the society as a way of securing at least enough harvest per household, despite the unpredictable climate. In a report by FAO, (2009), it was stated that other researchers have advised on the use of smaller grains like rapoko, millet and sorghum, most of which are drought tolerant. However, these crops cannot meet domestic food reserves (nationally). Efforts are now underway on rehabilitating the existing irrigation structures and developing new structures. According to the Water Sector Board (2007), low productivity of many existing irrigation schemes has prompted a change in investment policy away from new infrastructure and toward programs that improve the performance of existing schemes.

Molden et al., (2005) have suggested increasing water productivity as a strategy to resolve this water scarcity challenge. Water productivity (WP) is defined as the physical or economic output per unit of water application. Some researchers also define it as the crop yield per cubic meter of water consumption, including 'green' water i.e. effective rainfall, for rain-fed areas and both 'green' water and 'blue' water i.e. the diverted water from water systems, for irrigated areas (Cai and Rosegrant, 2003).

Through the knowledge gained, irrigation efficiency was further investigated to imitate water productivity. This has led to the adoption of more localized than surface systems. However adopting a localized system requires more capital and appreciation of flexibility. Yet surface methods are appearing to be the longest serving modes which are durable. It is unfortunate that the productivity of surface systems is at stake due to salinity. Other researchers like Bharucha, (2005) and Kjine, (2003) suggested the use of salt tolerant crops as ways of mitigating salinity problems but less of them play a role in the food security crop range. Less research has been made on improving or finding ways to tackle salinity in surface irrigated lands.

Salinity is defined as a measure of the total amount of soluble salts in soil. High concentration of salts in the soil solution causes a reduction in plant water uptake by reducing soil water osmotic potential and consequently decreasing the growth rate (Munns, 2005). As soluble salt levels

increase, it becomes more difficult for plants to extract water from soil hence they become water stressed. According to the research carried out by Razzaghi et al., (2011), soil salinity reduces crop productivity especially in arid and semi-arid regions. No matter how low the salt index could be, the continuous deposition of these salts on the root zone eventually causes an increase in soil salinity which then adversely affects the crop production (FAO, 2009).

Research studies on water productivity issues, such as those done by van Dam and Malik, (2003) indicates that, of all the factors, the main limiting factor to increase the crop yields is water. When carrying out an irrigation water evaluation, more emphasis should be placed on the chemical and physical components of the water and only rarely are any other factors considered important. Thus the quality of water plays a very important role in the crop yield.

Some recent studies have shown that water productivity could be improved either by reducing the water losses that occur in various ways during water conveyance and irrigation practices or increasing the economic produce of the crop through efficient water management techniques (Magodo, 2007). The principle factors that influence water losses and water productivity of a command area include the soil type, the design and nature of construction of the water conveyance system, design of the field, extent of land preparation and grading, the choice of irrigation methods as well as the skill of irrigators (FAO, 2006).

This study is necessitated by the need to understand the magnitude of water consumption at Insukamini Irrigation Scheme which is currently faced by continuous yield decline due to salinity challenges. It is also in the mind of the researcher to try and relate the relationship between the water consumption and yield produced by the scheme. The salinity challenge is also going to be addressed by further investigating the source of salinity and to see whether the farmers at the scheme are growing crops that are salt tolerant. Other causes of the decline in yield are also being investigated.

Through an assessment of water productivity at the Insukamini irrigation scheme, the study will provide a framework for improving water productivity for the surface irrigation schemes even though they are prone to salinity challenges. It is hoped that through this research the findings

and recommendations can help in promoting water saving and increased water productivity among surface irrigation water users. This research is targeting users at all levels including farmers, water managers, national research agencies, irrigation planners and extension authorities by providing planning and management tools to improve productivity of scarce water resources.

1.3 Problem Statement

At Insukamini Irrigation Scheme, of Gweru district in the Midlands Province of Zimbabwe; there has been a significant decline in yields for the crops under irrigation even when high volumes of irrigation water are being applied. The area is known to be having salinity challenges and it is suspected that the salinity levels are now contributing to the decline in the crop yields. This decrease in production has forced farmers of this area to have less income and incur huge costs of irrigation due to the bias they have in increase of water to increase yields. Economically this alludes to the concept of 'Diminishing Returns' and hence a sign of low water productivity. The study therefore aims at assessing the water productivity and the relative effects of salinity on crop yield for the scheme and come up with recommendations on how to improve the water productivity.

1.4 Justification

Due to climatic change and variability, farming in Zimbabwe is now relying on irrigation more than rain fed agriculture. Crop yields have dropped drastically due to the severity of unreliable rainfall patterns. The Government through irrigation schemes has tried to lift the gap created along food security. However, issues of population increase and urbanisation has mounted pressure on the water resource, a key input of various sectors both in Agriculture and non-Agriculture. The higher demand interrelated to reduced inflows/supply will make water a very scarce resource which needs proper management. The national appreciation of Natural resources in sustainable management suggests an efficient use of all resources including water. Therefore in agriculture there is a need to find ways through research and implementation of viable techniques that enhance the output of higher yields per unit volume of water applied.

In irrigation, terms like water productivity were defined to enhance more crop output per drop of water. However, much focus was emphasised on the adoption of efficient irrigation systems particularly the localized (drip and sprinkler) over flood. Much research has also alluded that water productivity can be increased through use of localized sprinklers. In Zimbabwe, some

irrigation sites have been strategically constructed appreciating the constant supply from perennial rivers for instance the Ngamo River which supplies Insukamini Irrigation scheme. In this scenario, flood/surface has been appreciated better than other modes. The main factors that contributed were availability of water, enough slope/gradient to transport water through canals and unavailability of power source. A simple suggestive point will be to switch the system to localized system but this stance requires lots and lots of capital. Our government is facing some challenges in meeting financial demands. However, calls were made to enhance crop production through sponsoring farmers with inputs in a bid to raise water productivity. Unfortunately, no significant yield increase was realized. This therefore has created a gap on how yield can be enhanced in such systems, particularly on issues concerning soil and water quality.

Several researches have been carried out of late in trying to find methods on how to improve crop water productivity. Igbadun et al., (2005) focused on crop water productivity based on maize varieties in Tanzania. Magodo (2007) studied on the determination of water productivity in Zimbabwe but much focus was on sprinkler irrigation. The researcher appreciates other modes of irrigation other than surface irrigation which have been considered to be having higher efficiency; however, they also have their demerits. From the researches done so far, the researcher has identified that, little attention has been given on improving water productivity of established surface irrigation systems.

Insukamini is an established irrigation system using surface irrigation method. Though this method is evaluated as lowest in efficiency, the researcher has identified a need of focusing through research ways that would improve its water productivity. This was necessitated by the fact that changing the irrigation system to other modes of irrigation with higher efficiency would require a high capital investment. Also the flexibility and availability of other sources of power would be a great challenge again that will contribute in lower water productivity. With the above scenario in mind, the researcher noted a need to find ways through research to enhance crop water productivity.

In this light the researcher has been prompted to carry out a research to critically analyse the water productivity levels and its trend over the past years. The researcher looked into the soil quality parameters, particularly those that affect the crop yield carried out water quality analysis as it also contributes to soil quality. The quality parameters that were assessed put more

emphasis on salinity as it negatively affect crop perfomance. Any slight increase in salinity levels reduces the yield. The effect of salinity if uncorrected can reduce the numerator of the water productivity function (crop yield) and this automatically reduce the crop water productivity. The researcher was also interested in knowing the possible sources of salinity and possible corrective measures that would suit the cropping programme.

The findings for this research on water use and water productivity play a pivotal role for water managers to assess where scarce water resources are wasted and where the water productivity can be improved. The project targets users at all levels including farmers, national research agencies, water managers, irrigation planners, development and extension authorities by providing planning and management tools to improve productivity of scarce water resources. This research also add to the available literature by closing the gap that has been left by not researching on how to improve water productivity for the surface irrigation Schemes.

1.5 Research Questions

- What are the current levels of water productivity at Insukamini irrigation Scheme?
- What is the quality of irrigation water and the soils at Insukamini irrigation scheme?
- What are the sources of salinity at Insukamini Irrigation Scheme

1.6 Objectives

1.6.1 Overall objective

- The overall Objective was to assess the crop water productivity and the relative effects of salinity on yield at the Insukamini Surface Irrigation Scheme of Lower Gweru, Midlands Province of Zimbabwe.

1.6.2 Specific Objectives

- To quantify the water productivity levels being achieved by the farmers at Insukamini Surface irrigation Scheme.
- To assess the irrigation water quality and some selected soil quality parameters for the Insukamini Irrigation Scheme.
- To determine the source of salinity at Insukamini Irrigation Scheme.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter is aimed at reviewing existing literature on crop water productivity. It also looks into salinity and other factors that affect crop water productivity particularly in the surface irrigation schemes. Definitions, concepts and approaches of assessing water productivity and analysis of soil and irrigation water quality are also closely examined. The chapter also describes some methods and techniques on how to improve water productivity and also discuss the benefits of improving water productivity. Reference is also given to other researchers who have put their contributions in the same field.

2.2 Definition of Terms

Water productivity: is defined as 'crop production' per unit amount of water used (Molden, 1997).

Salinity: is a term used to measure the total amount of soluble salts in soil. As soluble salt levels increase, it becomes more difficult for plants to extract water from soil. Some plants are more resistant than others, but as the salt levels exceed their ability to extract water, they become water stressed.

2.3 Global Water Concern and Population Increase

One of the great challenges of the century is the sustainability and proper management of water resources. The world population has crossed the six billion mark. The demand for water would continue to increase significantly during the next few decades basing on the proportion of young people in the developing countries. This will end up creating an overwhelming demand on the world's limited fresh water supply (Bharucha, 2005). According to the United Nations (2008), the total amount of the water resources present on earth is estimated to be about 1400 M km^{3s}.The water resources available for crop production include groundwater, rainfall and canal water (Manzungu, 1999). Precipitation acts as a primary source of water for crops in command areas. Ground water through dug wells and bore wells supplement irrigation water requirement. Kijne, (2003) also postulated that a conjunctive use of surface and ground water can result in optimum utilization of water resources.

As large consumers of water, developments in irrigation have profound impacts on water use and availability. As a result, food insecurity, less water availability and soil degradation are now becoming a common problem especially in the third world countries including the sub-Saharan Africa (Molden et al., 1999). Ample evidence exists that climate change will exacerbate the challenge by increasing hydrologic variability which will result in more frequent and intense weather events like droughts, floods and major storms (Brauman et al., 2013).

Supplementary irrigation can help to maximize and stabilize yields by ensuring that fluctuations in rainfall amounts do not result in water stress in the crop (Magodo, 2007). It also contributes to agricultural growth by raising the productivity of land and labor (and augmenting input such as seeds and fertilizer). Unfortunately, the same irrigation consumes more water than any other human activity, and thus the challenges of water sustainability and food security are closely linked (Brauman 2013). Unless properly managed, lack of access to fresh water may well emerge as the key constraint to the food production. This is supported by the statement from the World Bank (2002) which says, "This alarming situation can only be resolved if water is managed more efficiently, so that crop yield per unit of water consumption increases".

2.4 Water and Irrigation Strategies in Zimbabwe

Irrigation development was and will always be a priority to the country by all the successive governments (Manzungu et al., 1999). In Zimbabwe, irrigation is important for successful crop production in the country, as greater part of the country receives inadequate rainfall, which makes rain fed agriculture difficulty in marginal areas. Even in wetter regions, mid-season droughts are a common phenomenon making supplementary irrigation necessary. Irrigation is also used to enable all year round production for certain crops and to ensure early planting of crops like tobacco and cotton. Irrigated crops constitute half of the total value of the crops marketed. Crop yields under irrigation are significantly higher than rain fed yields (Barker et al, 2003).

Irrigation and improved agricultural water management practice could provide opportunities to cope with impact of climatic variability, enhance productivity per unit of land, increase the

annual production volume significantly. However, a problem of low water productivity is very common with small scale farmers. Thus the introduction of better irrigation management practices to small holder farmers leads to higher productivity for both short term and in the long term run**.**

2.5 Water Productivity

2.5.1 The Concept of Crop Water Productivity

Molden et al., (2003) expressed the concept of water productivity (WP) as a robust measure of the capacity of agricultural systems to convert water into food. Although the term has been used mostly to assess the function of irrigation systems as the amount of 'crop per drop', it is also reasonable to broaden the concept such that it will take into account of other livelihood support, like the mixed cropping, fisheries, pasture or forests.

According to Keller et al. (2003), water productivity was introduced to complement already existing measures of the performance of irrigation systems, mainly the classic irrigation and effective efficiency. Classic irrigation efficiency focuses on establishing the nature and extent of water losses and included storage efficiency, conveyance efficiency, distribution efficiency and application efficiency. The concept of Crop Water Productivity (CWP) as described by Steduto and Albrizio, (2005) developed from what is traditionally known as the Water Use Efficiency (WUE) in the literature. Water use efficiency was initially used to describe irrigation systems' performance. Water use efficiency is defined in agronomic terms, as the amount of organic matter produced by a plant divided by the amount of water used by the plant in producing it (De Wit, 1995). However, the used term 'water use efficiency' does not tag along with the classical concept of 'efficiency', which uses the same units for input and output. For that reason, International Water Management Institute (IWMI) has proposed a change of the terms from 'water use efficiency' to 'water productivity'.

Water productivity varies with location depending on certain factors such as cropping pattern, climatic conditions, irrigation technology, field water management and infrastructure, and on the labour, fertilizer and machinery input. When assessing water productivity, it is very important to focus on other factors that influence productivity because water is not the only factor that influences productivity. This is supported by Cai (2003), who outlined the fact that for plants and

crops to respond to water, it is generally due to the availability of other inputs, like sunshine, nutrients and management effort. Thus farmers who seek to increase their yields must optimize over their inputs levels, as well as considering their market opportunities.

There exist several definitions of crop water productivity by different authors. Most authors seems to reach a consensus that crop water productivity is the ratio of crop yield or crop value, to a selected measure of water consumed, applied, or evaporated in the process of growing a crop. As such, the ratio represents the average productivity of the input, rather than the incremental productivity. In general, water productivity denotes the outputs (goods and services) derived from a unit volume of water. However, the growing pressure on fresh water resources gave a new direction to the water productivity concept. In physical terms, Kijne et al, (2003) described it as a ratio of the product which is usually the weight of biomass or harvestable component (fresh or dry) to that amount of water depleted or applied to achieve this production. From the economical point of view, Crop Water Productivity is concerned with the value of the product and the value of the water being diverted or being applied (Magodo, 2007).

Water productivity can be also defined in several ways according to the purpose, scale and domain of analysis (Molden et al., 2001; Bastiaanssen et al., 2003). This is summarized in the table 2.1

Table 2.1: A summary of Crop water productivity definitions according to purpose, scale and domain.

Stakeholder	Definition	Scale	Target
Plant physiologist	$Dry\ matter/Transpiration$	Plant	Utilize light and water resources
Agronomist	$Yield/Evapotranspiration$	Field	Sufficient food
Farmer	$Yield/Irrigation$	Field	Maximize income
Irrigation engineer	$Yield/Canal\ Water\ Supply$	Irrigation scheme	Proper water location
Policy maker	$\$/available\ water$	River basin	Maximize profits

Source: Palanisamy, et al (2006)

Bourman et al., (2001) also emphasized the variation in water productivity definitions by giving illustrations, for instance breeders are interested in the productivity of the amount of transpired water WPT whereas farmers and irrigation engineers will be more focused on optimizing the productivity of irrigation water. On the other hand, the water resources planners, who are

interested in the amount of food produced by total water resources (rainfall and diverted water) in the region will also deal with water productivity in respect of the total input (WPTWI).

Various researches have been carried already on water productivity issues. According to Brauman (2013), most recent studies have tied water scarcity to agricultural water consumption. Magodo (2007) managed to group these studies into two groups of researches, the first group of researchers have been concentrating on investigating different water regimes to maximize yield where as the others focused on maximizing the efficiency of water use. A consensus was reached by a number of researchers like Molden et al., (2003), Lilian Magodo (2007), Cai et al., (2011), Toung (2005) and many others, on the fact that increasing water productivity is the solution to the scarcity challenge that is affecting the main input for production being water. Most of them have agreed on certain terms but their findings vary depending on the objectives and their understanding of the denominator as well as the computation of their denominators. It is therefore important to specify the kind of water productivity the researcher is referring to and also to define how it is derived.

2.5.2 Water productivity versus scale of references

According to Palanisami et al., (2006), water productivity definition is scale dependent. Increasing water production is a function of various factors at different levels, that is, at plant, field, irrigation system and at a river basin. Palanisami et al., (2006) have noted that, increasing production per unit of water diverted at one scale does not necessarily lead to an increase in productivity of diverted water at a larger scale. Thus the classical irrigation efficiency decreases as the scale of the system increases (Seckler et al., 2003).

Palanisami et alal., (2006) cited that, plant scale water productivity normally varies from plant to plant depending on its photosynthetic efficiency. This was supported by Taiz and Zeigger, (2002) who indicated that, C3 plants like wheat, barley sugar beans etc. are the most common crop plants, but they are Ppoor assimilators of carbon dioxide from the atmosphere. Thus they must keep their stomata open more than other plants under the similar atmospheric conditions hence they have the lowest transpiration efficiency or water productivity (biomass per unit water transpired). Taiz and Zeiger (2002) also added that, crops like maize, sorghum, and sugarcane which are in the C4 photosynthetic mode have an enzyme that has twice the affinity for

absorbing carbon dioxide as that of the C3 plants. According to Palanisami et al., (2006), the C3 plants also have photorespiration which occurs with photosynthesis in light and requires oxygen. Craig et al., (2010) hypothesised that, the C4 plants have transpiration efficiency which is 2-3 times higher than the C3 hence that process does not occur in them.

2.5.3 The crop water Productivity Function

Stwart et al., (1977), in their study they pointed out that the crop water productivity function expresses the relation between the attained marketable yield (Ya) and the total amount of water evapotranspired (ETa). The water productivity function, indicates that highest water efficiency level is determined using WP as a benchmark. Within the crop water productivity function, different sections can be distinguished that may vary in width or that may even be absent. According to Sezen and Yazar, (2006), crops will generally not develop fully in case insufficient water is applied during the crop cycle, resulting in total loss of yield or low-quality yield for example fruits with low market value or shrivelled grains.

For instance, when the ratio of interest is the water productivity of applied water, the ratio often is defined as:

$$WPAW = Crop\ yield\left(\frac{t}{ha}\right)/appliedwater(\mathrm{m3/ha})$$ (Palanisami et al 2006)

If the crop yield is 4 tons per ha and the applied water is 8000m^3 per ha, then the crop water productivity is 0.0005 tons per m3.

In addition to neglecting consideration of other inputs, this measure of average productivity is not sufficient for determining whether the application rate of 8000m^3per ha is optimal from the farm-level or societal perspective. The question of optimality can be addressed only by considering the marginal (or incremental) productivity of water, in comparison with its marginal cost. If the marginal productivity of water is 0.004 tons per m^3, and the price of the crop is $1,000 per ton, the decision to apply the last m^3 of water is sensible, provided the marginal cost of water is less than or equal to $4.00 per m^3.

2.5.4 Factors influencing crop water productivity

According to Dam (2006), water productivity is a concept which expresses the benefits or value derived from using water and include the crucial aspects of water management like production for arid and semi-arid regions. Wart and Bastiaansen, (2004) described the increase in waterproductivity as to either producing similar yield using less water or obtaining more crop yields using the same water resources. The variability in Crop water productivity is influenced by a number of factors. These factors include:

- the crop variety,
- water management
- soil fertility,
- soil characteristics such as soil water storage,
- climate variables and
- the uncertainty of the crop growth model, which is connected with biophysical interactions.

a) Crop Variety

Igbadun et al., 2005 suggested that the crop water productivity is influenced by Crop Variety. He further stated that cultivars differ in their allocation of assimilates to various plant parts and in relation to the physiological development stage. Bessembider et al., (2005) also postulated that cultivars differ in the growing season length and generally a higher yield per unit of evapotranspiration is obtained with the short seasoned variety under rain fed conditions. In general terms, high yielding varieties will tend to have higher crop water productivity than the lower yielding varieties even if exposed to similar conditions (Magodo, 2007).

b) Water Management

According to FAO, (2002), the production of crops mainly depends on the status of the soil water throughout the growing season. Usually, a high level of soil water availability ensures the most favorable yield with maximum actual evapotranspiration (ET_a) with potential losses of water and Nitrogen fertilizer through leaching. Any restriction in the irrigation water supply is likely to reduce the crop yield. However, if deficit irrigation is timely applied to the crop during specific growth stage that are less sensitive to moisture deficiency, the impact on crop yield can be

insignificant yet will become more significant in terms of crop water productivity (Bennett, 2003). Deficit irrigation practices normally contribute towards the attainment of a higher crop water productivity.

The issue of deficit irrigation practices is buttressed by the study on maize carried out by Igbadun et al., (2005) which established that crop water productivity is maximised by withholding water every other week at vegetative and grain filling stages and better water utilisation is associated with adequate water application at tasseling and to silking stage (Magodo, 2007). Thus, crop yield response to water is dependent on water applied in a particular growth stage rather than the overall seasonal water applied.

c) Soil Fertility

The level of fertility, especially nitrogen affect the growing conditions and biomass production of a crop. Zwart and Bastiaanssen (2004) suggested that nutrients indirectly influence the physiological efficiency of the plant and generally optimum nutrients and irrigation maximises crop water productivity. According to Tuong et al., (2005), by practicing good crop husbandry that supplies an adequate and balanced nutrient amounts and reduces pest and diseases will enhance canopy development and increase yield hence a higher crop water productivity.

d) Other factors influencing Crop water Productivity.

From the research carried out by Howden and Jones (2004), it was concluded that changing of plant dates as well as the crop varieties is a very good measure of increasing crop benefit. They projected the median benefit to be US$158 million/year but within a range of US$70 million to over US$350 million/year. Increasing the agricultural infrastructure as well as research can be a very good means of improving water productivity rather than investing in the irrigation system (Molden et al., 2003). By reducing irrigation and induce crop water deficit, water productivity can be slightly increased.

2.5.5 Increasing Water Productivity

Nowadays, there is a trend to call for "an increase in water productivity" as a must (FAO 2002; Molden et al., 2003). Thus the attention which used to be paid to irrigation efficiency is being

transferred to water productivity. According to Zwart and Bastiaanssen (2004), increasing water productivity means either to produce similar yield using less water resources or to attain higher crop produce with the same water resources. Purposely reducing irrigation water applications and stressing crops to achieve higher water productivity (deficit irrigation) was introduced as a means of saving water (Fereres and Soriano, 2007).

In order to achieve greater water use efficiency in irrigation, most researchers have suggested the switching from the less efficient flood or furrow system to more efficient systems such as micro-irrigation or to adopt irrigation strategies such as deficit irrigation, in order to maximize crop yield and/or minimize water losses. According to Perry et al. (2009) switching from flood or furrow to low-pressure sprinkler systems reduces water use by an estimated 30%, while switching to drip irrigation typically cuts water use by half.

Another strategy that can be used to enhance crop water productivity is by reducing non beneficiary depletion. Weed control practices like good land levelling, timely flooding, manual weeding and use of herbicides help to reduce non beneficial transpiration from weeds. Toung et al., (2005) also postulated that mulching help to reduce water inputs and increase water productivity. Moreover, timely planting will increase the yield as opposed to untimely planting that may lead to sterility caused by chilling or very high temperatures that will result in yield loss.

Deficit irrigation Practices

Deficit irrigation methods are those irrigation methods that increases yield per given water unit (water productivity). These practices uses the basic principle of reducing the water usage as compared to the normal irrigation whilst giving particular attention to the critical plant growth stages such that none of these stages encounters drought stress. In some instances, such periods of reduced growth may trigger physiological processes that will actually increase yield and/or income. Examples of such processes include the flower-induction i.e., in the case of cotton, early ripening of grains, increased root development exploring deeper soil layers, and improved fruit quality and flavour. On the other hand, if stress is applied during reproductive growth, this can affect fruit or grain set, resulting in a decline in yields.

From the research by Kang et al., (2009), it was shown and concluded that regulated deficit irrigation at certain periods during maize growth saved water while maintaining yield. Subjecting crops to moisture stress periods with minimal effects on yields will also result in less evapotranspiration by the closure of stomata, decreased production of biomass and through the reduction in assimilation of carbon. Reduced biomass production does not greatly affect the final crop yields since the crop is able to compensate in terms of reproductive capacity. Beside the water productivity, quality of the crop could be improved by more tolerance to drought and salt stress as well as more nutritional quality.

Other researchers have suggested the following as methods of improving water productivity:

- Technological innovation
- Better governance and management
- Deficit irrigation strategies
- Decrease soil evaporation
- Irrigation scheduling
- Reduce runoff (and percolation)
- Consider all the inputs (i.e. water table)
- Water reuse
- Cropping system improvement

Since water productivity is a ratio, in many cases low water productivity is likely a function of low yield, so interventions to increase water productivity should focus more on improving yield than on decreasing water consumption. According to Kang et al, (2000), specific management strategies to increase crop water productivity must be tailored to local contexts; studies in Nigeria, Sudan, and Niger, for example, have shown that nitrogen and phosphorus limitation restrict millet and sorghum yields. Water productivity could be increased by increasing yields via improved soil nutrient conditions and reduced wind-driven erosion (Muns, 2005). Examples of other interventions that have demonstrated improvements in water productivity include: rainwater harvesting and local water storage, applying drip or deficit irrigation, adjusting planting dates, and modifying tillage practices to reduce evaporation

2.5.6 Problems encountered due to low water productivity

1. Gradual drying of rivers in the tail end thus having a direct effect on the flora and fauna

2. Water application beyond root zone, not used up by plants but wasted. This causes difficulties to other users who are unable to access water for irrigation.
3. Growing number of water related conflicts in the river basins. Disruption of activities as a result of conflicts leads to low food production, which in turn lead to food poverty and income poverty.
4. Low food production,
5. Failure to meet the ZIMRA charges and electricity for water extraction
6. Conflicts arising from continuous need of water though there's no change in yield
7. Change in soil structures, caused by large volumes of water flowing on the fields
8. Increase in the need of irrigation water thus making it a scarce resource that needs effective management

2.5.7 Previous research on Crop Water Productivity

Several studies on Crop water productivity has been carried out. Different researchers defined the Crop water productivity differently and with the numerator ranging from value or amount of grain yield to aboveground or total biomass yield and numerators ranging from value or amount of water input to water consumed (Kjine et al, 2003). Literature tends to concentrate on grain yield to evapotranspiration, the range of crop water productivity reported around the world is 0.3kg/m^3-2.7kg/m^3 for maize (grain yield).

In Zimbabwe, a water productivity of 0,6kg/m^3 for maize was reported in Marondera from a study carried out by Guzha et al., (2005) under rain fed conditions using conventional fertilisers in Chihota rural Community. Another research carried out by Magodo (2007) in her study to quantify water productivity and predicting the yield of 3 different maize varieties at the ART farm in Zimbabwe. The results for water productivity were in the range of 0,5kg/m^3-0,7kg/m^3 for the 3 maize varieties. The experiments were carried under rain fed.

FAO also gave a crop water productivity for maize as 1,6kg/m^3 (Doorenbos and Kassam 1979). Igbadun et al., (2005) in Tanzania s' Mkoji area, also recorded a crop water productivity ranging from 0,4kg/m3 -0,7kg/m^3 for 3 maize varieties under irrigation.

2.6 Surface irrigation systems

This is an irrigation type which uses the soil surface to spread water across a field to plants being irrigated. This includes furrow irrigation, border and basin irrigation. The surface irrigation system is based on the principle of moving water over the surface of the land in order to wet it, either partially or completely. This surface irrigation type is used in more than 80% of the world's irrigated lands yet the field level application efficiency is often only 40-50%.

The scheme layout up to field level, such as canals and drains, can be similar for each system. According to Toriman et al (2012), the low irrigation efficiencies are normally associated with poor land levelling, wrong stream size and change in soil type along the irrigated area both vertically and horizontally.

2.7 Salinity

Salinity is defined as the concentration of dissolved minerals salts in water and soil water as a unit of volume or weight basis (Toriman et al 2012). According to Rengasamy (2005), irrigation water have a combination of naturally occurring salts. The major ions present in water are:

- The anions of Chloride (Cl-)
- Sulphate (SO42-)
- Bicarbonate (HCO3-)
- Carbonate (CO32-)
- And Nitrate (NO32-)

And cations of

- Sodium (Na+)
- Calcium (Ca2+)
- Magnesium (Mg2+)
- Potassium (K+)

Tanji (1990) also cited that soil solutions have the same components of elements that are found in water. The ratios of the constituents in soil-water depends on the chemical reaction that takes place in soil-water-plant systems under different conditions.

Provin and Pitt (2011) hypothesised that these salts often originate from the earth's crust, they can also result from weathering processes, in which tiny rock particles and other deposits are dissolved overtime and washed away by water. This slow process of weathering may eventually cause the accumulation of salts in both surface and underground waters. The surface runoff of these dissolved salts is what gives the salt content to our oceans and lakes. Fertilizers and organic amendments also add salts to the soil. This is supported by Szabolcz, (1997) who stated that, most soils affected by salt problems have been developed by natural geological, hydrological, pedological processes and a great part of them existed for millennia. However, in most saline areas throughout the world, the salinity problem is caused by human activities.

2.7.1 Salt build-up

According to FAO, (2002), irrigation water always contains some dissolved salts, but the concentration and composition of the dissolved salts vary depending on the sources of the irrigation water. Rengasamy (2006) described salinization as a complex process that involves salts and water movement in the soils during seasonal cycles and interactions with groundwater. When water is being applied to soil surface, some of it will evaporate or will be taken up by plants, leaving some salts behind in root zone. More so, if the groundwater table is too high, a continuous capillary rise will take place into the root zone leading to the accumulation of salts in the root- zone especially if the groundwater is salty. According to Rengasamy (2002), salinity is of greatest concern in soils that are:

- Irrigated with water high in salts;
- Poorly drained, allowing for too much evaporation from the soil surface;
- Naturally high in salts because very little salt leaches out;
- In areas where the water table (the level or depth to free-flowable water in the soil) is shallow; or
- In seepage zones, which are areas where water from other locations (normally up slope) seep out.

The major source of salinity problems is usually irrigation water. This is a gradual process—the salts must accumulate over time before any effects are seen. Fortunately, plants take up many salts in the form of nutrients. But when more salt is added to the soil than is removed, the plants will eventually be affected.

For instance, assuming that the water being used for irrigation has a low salt concentration of 0,3g/l, (which is equivalent to 0,3kg/m^3 corresponding to an electrical conductivity of about 0,5FdS/m.) and a modest annual supply of irrigation water of 10,000m^3/ha (almost 3 mm/day) brings 3000kg salt/ha each year. If there is inadequate natural drainage, like the cases of water logged soils, and where there is no proper leaching and drainage programme to drain the salts, the result will be high soil salinity and a significant reduction in the crop yields in the long run. In many cases, irrigation water contains higher salt levels than given in this example and also in some cases, greater annual supply of water is required (e.g. sugarcane which needs about (20,000m^3/ha) and as a result irrigated areas often receives more than 3,000kg/ha of salts per year (ILRI, 2000).

In some soils, irrigation and rainwater move through the soil to leach out the salinity. Leaching occurs when water moves materials (such as salts or organic materials) downward through the soil. Several soil factors can inhibit leaching:

- a high clay content;
- compaction;
- a very high sodium content; or
- a high water table.

Salt problems occur when water remains near the surface and evaporates, and when salts are not dissolved and carried below the root zone. Soils naturally high in soluble salts are usually found in arid or semi-arid regions, where salts often accumulate because there is not enough rainfall to dissolve them and leach them out of the root zone. In areas with shallow water tables, water containing dissolved salts may move upward into the rooting zone. This occurs by capillary action (similar to the way a wick works), where evaporation serves as the suction of water up through the soil. Water moves the furthest through finer clay and clay loam soils; it moves less in medium-textured soils (loams); and least in coarser, sandy soils .

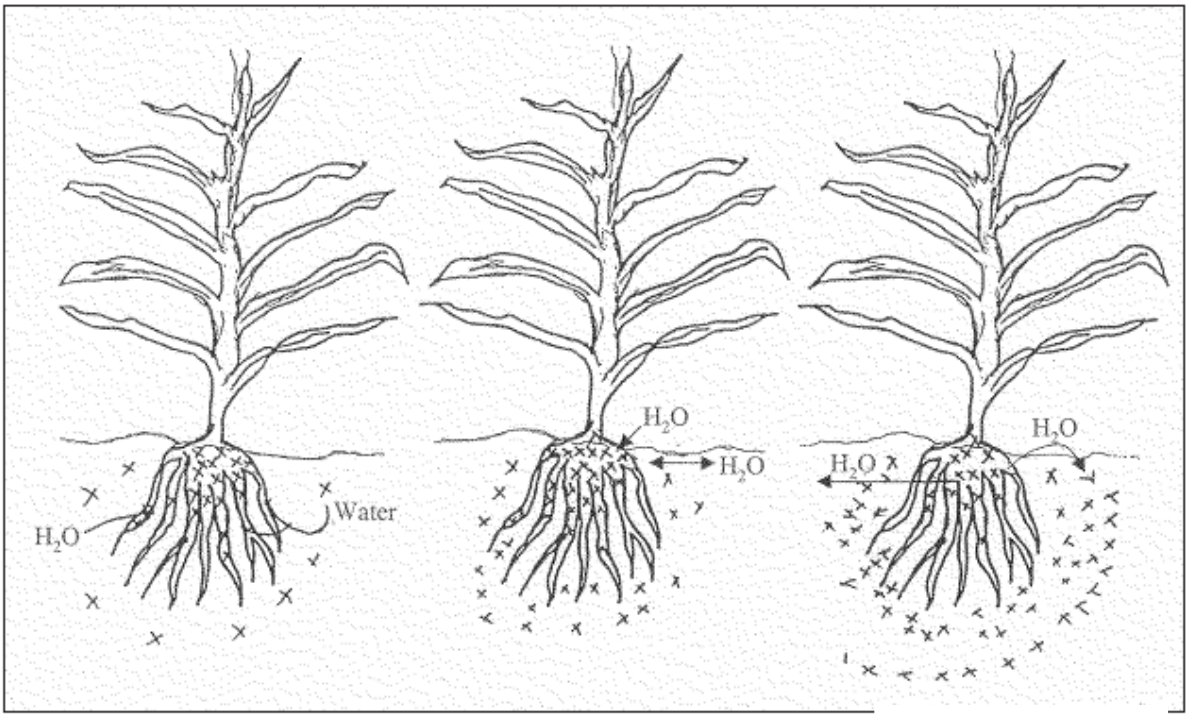

Figure 1. Increased salts in root zone can result in decreased water uptake by plant. (Provin and Pitt 2008)

2.7.2 Salinity Effects on Crops

Irrigation is primarily established so as to supplement crops with adequate and timely amounts of water, thereby avoiding the yield loss that may be caused by extended periods of water shortages during the sensitive crop growth stages. However, during repeated irrigation, salt accumulation from the irrigation water may reduce the water available to the crop and speeding up the onset of a water shortage. It is therefore important to understand how this occurs so that suggestions on how to counter the effect and how to reduce the probability of a loss in yield may be given. Considerable research has been directed towards defining the effects of salts on crop growth and development (Maas, 1990, Shalhevet, 1994, and Shannon and Grieve, 1999)

The salts in the soil-water increases the osmotic potential which is an additional force applied in soils that contain salts, for example, if two otherwise identical soils are at the same water content but one is salt-free and the other is salty, the plant can extract and use more water from the salt-free soil than from the salty soil. This is because salts have an affinity for water. If the water contains salt, more energy per unit of water must be expended by the plant to absorb relatively salt-free water from a relatively salty soil-water solution .

Fresh water stored in the subsoil is critical for crop production in dry-land cropping. The salt concentration in soils with transient salinity are sometimes not high as that of soils affected by seepage salinity, subsoil salinity usually ranges between ECe (electrical conductivity of the soil saturation extract) of 4 and 16 dS/ m. As the soil layer dries due to evapotranspiration, this amount of salinity can cause an increased osmotic effect. This low osmotic potential resulting from soil salinity can restrain the uptake of water by plants and by so doing it reduces plant's ability to survive and produce (Rengasamy, 2002).

Increasing accumulation of salts will decrease plant leaf area indices and their transpiration rates. Thus, soil processes are specific to each type of salinity and dictate the strategies for plant-based solutions to different forms of salinity. Although sodicity can also be a major problem, a number of soils have multiple problems in different layers of their soil profile (Rengasamy, 2002). An example given is that of the topsoil which can be sodic while its subsoil is saline. When a saline-tolerant durum wheat variety was grown in this type of sodic soil, the yield was similar to that of a less saline-tolerant variety. Cooper, (2004), in his study indicated that topsoil sodicity and alkaline pH (9.6) prevented the roots from reaching the saline subsoil layer .

According to Munns (2002), the effects that salinity have on salt-tolerant plants are similar to the effects of water deficiency. The salt-specific effects of salinity may not be visible within minutes and hours when plants are exposed but if the exposure lasts for many days, salt-induced injuries may become apparent on older leaves of salt-sensitive plants. Moreover, there will be reduced rate of leaf emergence. Thus the impacts will be heavier on leaves than on roots, which are symptoms typical for water-stress. According to Maggigo et al (2011), if the exposure to salts continues for weeks, the older leaves of sensitive genotypes will die and if exposure lasts for some months the younger leaves will die and the whole plant may eventually die before seed maturation. Multiple problems can arise when the salts accumulated contain borates and carbonates in toxic amounts with alkaline subsoil pH (Rengasamy, 2002) .

There is a general stunting of plant growth, foliage may be darker green than normal plants and sometimes leaves appear thicker and more succulent when affected by excessive soluble salt concentrations. For woody species that have been affected by toxic accumulations of Cl or Na there is noticeable leaf burn, necrosis, and defoliation. Chlorophyll formation is inhibited in citrus by specific ion toxicities and at times nutritional imbalances caused by salinity produce

specific nutrient-deficiency symptoms. The osmotic effect of salinity increases the osmotic potential of the soil solution and this makes soil water less available for plant uptake.

Both the growth rate and ultimate size of most plant species progressively decrease as the salt concentration in the soil solution increases. Salinity effects are frequently not recognized, even though yield reduction may be 20 to 30% because of the general decrease in growth rate and plant size. Not all plant parts are affected the same way, and any relationship between growth response and soil salinity must take this into account. Vegetative production is decreased more than seed or fiber production for crops such as barley, wheat, cotton, and some grasses. In contrast, grain yields of rice and corn may be greatly reduced without appreciable reduction in vegetative production. Root yields of root crops are generally decreased much more than top yields. In contrast, top growth is affected more than root growth with some other species.

The impact of reduced plant production caused by salinity depends upon the purpose for which the plants are grown. Total yield and quality of crops grown for sale or for feed are generally most important. However, the survival and growth of plants used for landscaping and ground cover may also be important under some conditions.

2.7.3 Salinity measurement

- **Pocket-sized, electrical conductivity (EC) meter (salinity meter).**

According to Cocozza et al., (2012), this instrument is accurate enough for preliminary estimates of water salinity and is suitable for most farm purposes as long as it has an adequate measurement range. Most salinity meters have a range of 0–20 dS/m, which is suitable for testing most surface water. Provin and Pitts, (2008) stated that groundwater may be above 20dS/m which will then require diluting or laboratory testing. The Salinity meters measure the electrical conductivity of water which is related to the total dissolved salts present, however, types or ratios of soluble salts present is not detected.

- **Laboratory testing**

According to US. Salinity Laboratory Staff (1954), laboratory testing is essential, especially if it is the first time the water is being used, for verification of high surface-water readings.

a) Soluble Salts

As the soluble salts test is measured on a diluted extract, a more realistic measure of the actual

salt levels encountered by plant roots in the soil solution is achieved by doing a 'saturated paste extract" (SPE). The SPE method is a procedure where the soil is brought just to the point of saturation, and the resultant extract obtained by vacuum-filtration. This extract is therefore much less diluted than alternate routine methods and is thought to more closely resemble the soil solution occurring naturally in the field (Muns 2005)

b) Electrical Conductivity (EC)

The standard test for soil salinity is made by measuring the electrical conductivity (EC) of a 1:5 soil:water extract. For soils with high levels of salts, a high electrical conductivity will be observed in these extracts. The saturation extract is the soil solution removed from saturated soil by suction or pressure. Measuring EC, has become widely accepted because the saturation percentage is easy to determine and reproduce in the laboratory over a wide soil textural range. According to US. Salinity Laboratory Staff (1954), a saline soil has an EC of paste extract of more than 4dS/m of value that corresponds to approximately 40mmol salts per litre. Plant tolerance to plant to salinity is generally based upon EC, values rather than osmotic potential or total salt concentration. The EC is measured as mS/cm (dS/m) in the extract and converted to Soluble salts % by equation:

$$SS\% = EC\left(\frac{mS}{cm}\right)x0.35$$

Equation assumes an approximate relationship between EC and salts as700mg/L).

c) Osmotic potential (P) can be measured directly by freezing point depression, vapour pressure osmometers, or thermocouple psychrometers, or it can be calculated from the electrical conductivity of soil saturation extracts (EC,) by the equation = –0.36 (ECe)

This extract is therefore much less diluted than alternate routine methods and is thought to more closely resemble the soil solution occurring naturally in the field. According to Ayers, (1985), the Saturated Paste Profile reports nutrients (phosphorus, potassium, calcium, magnesium, sodium, nitrate-nitrogen and ammonium-nitrogen) and also Total Soluble Salts and Sodium Absorption Ratio (SAR).

The saturated paste profile requires a very large sample to be submitted as it requires ~ 300g dried and ground sample for this group of tests (about 500g fresh soil). It is a very labour-

intensive test in the laboratory and as such is considered a non-routine test designed for special investigation purposes only. Soils with total soluble salts in the saturated paste extract of less than ~1000 mg/L (ECspe<1.5 mS/cm) are unlikely to cause salinity issues unless for very sensitive crops.

These salts found in the soil are chemical compounds made up of sodium, magnesium, calcium, chloride, sulphate, bicarbonate or carbonate ions. The intended use of the water sampled determines the acceptable salt level. Not all salts are detrimental and in appropriate proportions salts improve soil structure and do not affect water quality. For example, calcium carbonate may improve soil structure and soil pH. An excess of one or more salts can have detrimental impacts. For example, water can be moderately saline, but have a high concentration of specific ions such as chloride, sodium or magnesium. Under spray irrigation, water with high chloride levels can cause leaf burn, while high levels of sodium or magnesium ions can cause soil structure decline.

d. Sodium Absorption Ratio

The sodium absorption ratio (SAR) is defined as a measure of assessing the potential of excess sodium to cause structural damage to soil. The excessive levels of sodium in the soil can destroy the soil structure (soil sodicity). Sodium deflocculates the soil, resulting in a soil which dries into large hard clods separated by a few wide, deep cracks. A deflocculated soil has very undesirable physical properties, for example, decreased water permeability (Provin and Pitt, 2008).

The structure of many irrigated soils will become unstable when exchangeable sodium exceeds 15 per cent of the soil's total cation exchange capacity. According to Richards (1954), the exchangeable sodium test is included in the Basic Soil profile, reported as sodium base. The sodium hazard involved depends on both the exchangeable sodium level and the sodium absorption ratio; problems increasing when the SAR exceeds 6 (Waitlink, 2007). If water contains a high level of sodium, soil testing will reveal any build-up of sodium in the soil.

2.7.5 Recommended Tests

For initial assessment of suspected soil salinity or where routine monitoring of soils is required e.g. soils receiving waste water on a regular basis, then the recommended approach would be to request the Basic Soil Profile + Soluble Salts tests. For special investigations the Basic Soil Profile and Saturated Paste Profile or SAR only tests can be requested. Note, as stated above, a minimum of 500g fresh soil is needed for tests carried out on a saturated past extract.

2.7.6 Characterizing Salinity

There are basically two water quality assessments that characterizes the salinity of irrigation water. These are:

- **Total dissolved solids (TDS)** - the units of TDS are usually expressed in milligrams of salt per litre (mg/L) of water. The term is still used by commercial analytical laboratories and represents the total number of milligrams of salt that would remain after litre of water is evaporated to dryness. It is often reported as parts per million (ppm) and is the same numerically as mg/l. The higher the TDS, the higher the salinity of the water.

- **Electrical conductivity (EC)** – Saline soils have an EC of more than 4 dS/m and either a SAR of less than 13 or an ESP of less than 9% (Rengasammy, 2005).However, the threshold value above which deleterious effects occur can vary depending on several factors including plant type, soil water regime and climatic condition (Maas and Hoffman,2004).

2.8 Salinity and Crop Water Productivity

Different crops vary in their tolerance to different salinity levels. A lot of research has been done in the past 30 to 40 years with the aim of determining the tolerance of crops to salinity. The salinity tolerance data available from the 1960s was compiled by Bernstein in 1964. This compiled data have been cited and applied throughout the world. A number of new salinity tolerance studies have been conducted since then, there is also new management practices that have been proposed, evaluated and some of them have been put into practice so as to reclaim salt-affected soils to improve crop production (Munns, 2005).

Maas and Hoffman (2004) evaluated the existing tolerance data for agricultural crops and presented the data graphically so that the relative tolerance among crops could be easily compared. Under controlled conditions, crops have salinity threshold values below which crop yields are not affected. However, under field conditions, evidence is presented that where plants are subjected to periodic and simultaneous water and salt stress and to non-uniform water application; yields are lowered by salt concentration below the assumed threshold values (Muns, 2005).

2.8. 1Factors Influencing the Effects of Salinity on Crop Productivity

Generally factors influencing the effects of salinity on plant productivity include the following:

Growth stage: Sensitivity to salinity varies with the growth stage for many plants, particularly cereal crops, for example rice is tolerant during germination however, it is sensitive during early seedling growth, and then becomes more tolerant as it matures (Muns, 2005). Barley, wheat, and corn are more sensitive during emergence and early seedling growth than during germination and grain development where as sugar beets are sensitive during germination and become tolerant after that.

Availability of plant nutrients: conversely, salinity and specific ion toxicities can cause nutritional disorders. Conflicting results of some salinity-nutrient interactions are found in the literature. According to Russell (1973), applications of P have increased plant production under saline conditions in some investigations but not in others. There have been reports that excess P in sand cultures may decrease salt tolerance of some crops. However, P concentrations would seldom be excessive in soils because P is adsorbed and precipitated in the soil. As the salt concentration increases, N requirements of plants generally decrease (Cocozza, 2012).

Climatic factors: Many crops are less tolerant when grown under dry, hot conditions. Relative yields of alfalfa, beans, beets, carrots, cotton, onions, squash, tomatoes, strawberry clover, and salt grass are lower in warm than in cool climates. According to Wattling (2007), high atmospheric humidity increases the salt tolerance of some crops, and benefits salt-sensitive plants more than tolerant crops. Irrigation management influences plant productivity in several ways. As previously mentioned, all irrigation waters contain some salt, and as the water passes into the atmosphere through evapotranspiration processes, salts remain in the soil or the soil solution. Unless extra water is added for leaching salts from the root zone, salts will accumulate from irrigation during the season.

2.9 Management of Salinity Problems

The extent to which the salts accumulate in the soil will depend upon the irrigation water quality, irrigate on management and the adequacy of drainage. If salts become excessive, losses in yield will result. To prevent yield loss, salts in the soil must be controlled at a concentration below that

which might affect yield. According to Rengasammy (2005), the objective of salinity control is to maintain an acceptable crop yield. Water which is used for irrigation is normally of good to excellent quality and is unlikely to pose serious salinity problems. As water quality becomes poorer, salinity control will become more difficult.

As water salinity increases, greater care must be taken to leach out salts from the root zone depth before their accumulation reaches a concentration that might affect yields. Alternatively, steps must be taken to grow crops that are tolerant to the expected root zone salinity. According to Muns (2005), the frequency of leaching and the depth of water required depends on water quality and the crop sensitivity to salinity. Adequate drainage is equally important otherwise long term salinity control is not possible.

When salinity is too high, the depth of leaching water needed may be too high, making it necessary to change to a more salt tolerant crop, provided market economics will allow this. This is supported by Akpabio, (2012) who emphasised that, in dealing with a major salinity problem related to water quality, a cropping change is considered a drastic step and will only be taken when less severe options have failed to maintain economic production. Great care must be however taken to practice leaching when necessary in order to avoid salt accumulation that could ultimately affect production. It can only be done if the drainage below the crop root zone is sufficient to prevent a rise in the water table so that it is not a source of salt by itself.

In addition to drainage, leaching and changes to more salt tolerant crops, other cultural practices may also be needed to deal with possible short-term or temporary increases in salinity which may be equally detrimental to crop yield. Examples of cultural practices as alluded by Seeboonruang (2012), include more frequent irrigation, land grading, timing of fertilization and methods of seeding make salinity management easier.

In support of the above, Provin and Pitt, (2008) also noted that salt affected soils can be corrected by improving drainage, leaching, reducing evaporation, applying chemical treatments or a combination of these methods.

CHAPTER 3

RESEARCH METHODOLOGY

3.1. INTRODUCTION

This chapter presents the methodology which was adopted by the researcher to gather information on the problem area. The chapter discusses the study area, research design, population of the study, sampling methods, research instruments and the methods used to present and analyze data.

3.2 THE STUDY AREA

The study was conducted at Insukamini Irrigation Schemes which is located in Lower Gweru communal lands that is in the Gweru district of the Midlands province of Zimbabwe. The scheme is in the agro-ecological region IV. Its latitude is: $19^0$21'14.59"S; and longitude is 29^0 35'33.45"E. The average annual rainfall is 650mm, with average temperatures of 16˚C (Gumbo, 2006).Thus, irrigated agriculture plays a significant role in terms of any meaningful crop production. The soils are characterized as clay loam soils and sandy loam soils from Siallitic group derived from Mafic Gneiss of the order Calcimorphic. The soils generally have large reserves of weatherable minerals with a high Base Saturation. These Siallitic soils are mainly found in low rainfall areas and hence have a high base status and clay content (Nyamapfeni, 1991).

The Scheme was established in 1988 as part of the government of Zimbabwe funded national resettlement programme. It covers an area of 41ha with 125 beneficiaries owning small pieces of land ranging from 0,1ha to 0,5ha. The scheme draws its water from Insukamini dam via an open concrete canal which is 1,6km long using the gravitational force. Initially the scheme was designed to accommodate 41 beneficiaries and due to expansion, it's now serving 125 beneficiaries. The Scheme is divided into 3 main blocks (A, B and C), with 25ha, 6.6ha and 9.4ha respectively. Block A is further subdivided into A1, A2 and A3; and Block B into B1, B2 and B3 respectively. The farmers mainly grow maize, sugar beans, groundnuts and horticultural crops such as cabbages, tomatoes, and green beans.

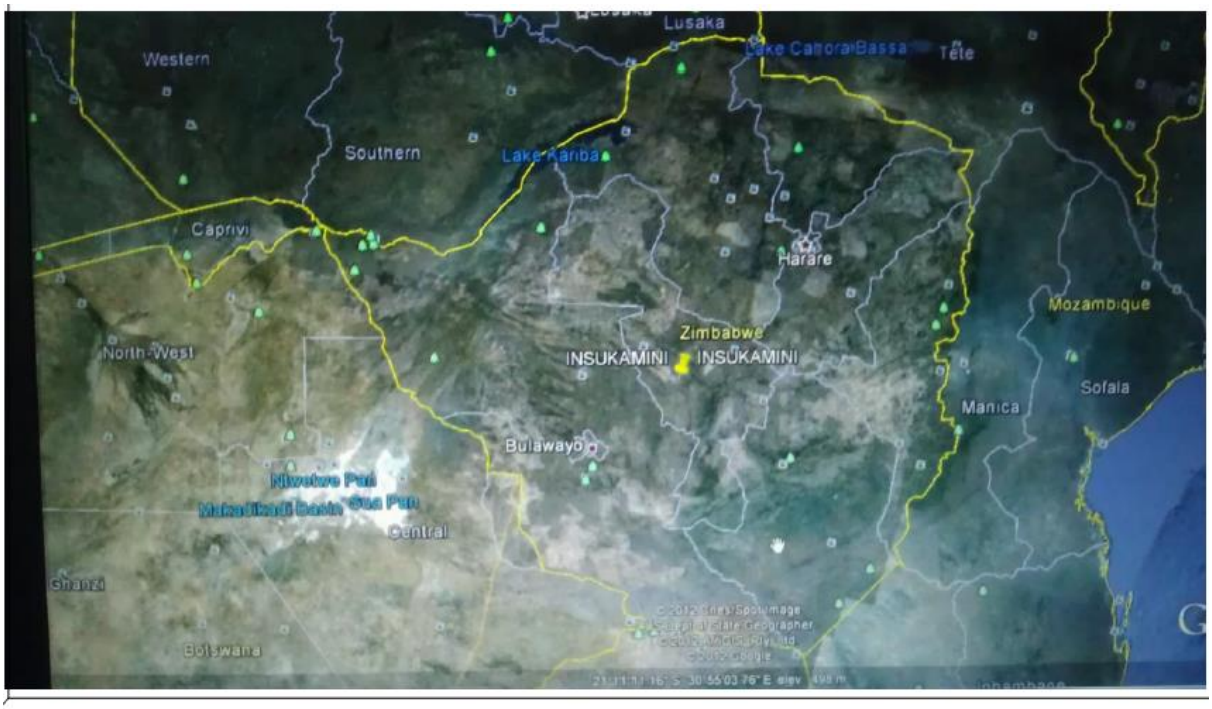

Figure 3.1: Location of Insukamini: Google Earth 1:1000km

3.3 DATA COLLECTION METHODS AND PROCEDURES

Methodology is defined as the specification of methods and procedures of acquiring the information needed. In a bid to formulate a map or a blue -print for achieving the research objectives, survey and laboratory experiments were employed. Thus, the research was sub-divided into two stages as follows:

1. Stage 1 – Survey
2. Stage 2 – Soil and Water analysis

The methodology employed was intended to fulfil the following objectives:

- To assess the crop yield and water productivity levels being achieved by the farmers at Insukamini Surface irrigation Scheme.
- To assess the irrigation water quality and some selected soil quality parameters for the Insukamini Irrigation Scheme.
- To determine the source of salinity at Insukamini Surface Irrigation Scheme.

A survey was carried out using questionnaires and interviews. The major sources of information consist of records of various government agencies. Cross sectional data were collected through a questionnaire survey from a sample of farmers from Insukamini Irrigation Scheme. The objective of the survey was to gather facts from farmers that include the volumes of water being consumed, current yield, and challenges affecting yield as well as possible solutions to these challenges.

Structured interviews were held with the irrigation management committee, Zimbabwe National Water Authority (ZINWA) officials, Agricultural Research and Extension (AGRITEX) Officer and the Department of Irrigation Officials. These were purposively chosen as the key informants of the research. A mixture of closed and open-ended questionnaires were also self-administered and were used as instruments for the data collection from the farmers.

3.3.2 Target Population

A target population is defined as a segment of the population in which research sample is taken. The population includes all individuals who the researcher is interested in obtaining information from and making references on. For the purpose of this research, the target population was all farmers at Insukamini Irrigation Scheme and government employees who work for the scheme as key informants. The total number of target population was 128 people, being 125 farmers and3 resident government workers. This is summarized in the diagram below:

Tables 3.1 illustrates the target group and the sample size

Subject	**Target**	**Actual (sampled)**
Farmers (irrigators)	125	92
Government resident employees	3	3
Total	128	95

Source: Field work, 2015

3.3.3 Sampling Methods and Size of sample

A sample is a small part of anything designed to show style, quality and nature of the whole (Ferber, 1974). The purpose of a sample is to approximate the measurement of the whole

population well enough within acceptable limits. For many research questions and objectives, it is impossible to collect and analyze data due to limited time and money and often access. For this reason therefore a small group of elements are chosen from the population and this will be the sample representing the population

The Insukamini Irrigation scheme has a total of 125 beneficiaries. The scheme was subdivided into 3 blocks namely block A, block B and block C for the purpose of this research. In obtaining sample size, the researcher applied the formula recommended by Bhandari and Grant (2007) as shown below:

$$n = \frac{NZ^{2*} P *(1-p)}{Nd^2 + Z^{2*} p (1-p)}$$

$$n = Z$$

Where:

n= sample size

N= total number of beneficiaries

Z= confidence level (at 95% level Z= 1, 96)

p= estimated population proportion (0.5, this maximizes the sample size)

d= error limit i.e. 5% (0.05).

NB N=125

Using the same formula, the sample size was 95 respondents. Two sampling methods were employed being convenient sampling and purposive sampling methods to select farmers who participated in the study. The irrigation management committee members were deliberately targeted to respond to the extensive interviews and to respond to the self-administered questionnaires. In choosing the farmers, it was made a point that all the blocks were represented by farmers who were conveniently chosen.

According to Leedy and Ormrod (2001), convenience sampling is a technique that makes pretence of identifying a representative subset of the population. As the name entails research was only conducted to those people who were nearest and most convenient. It was a bit mixed with purposive sampling to those who were available. This was done purposefully so as to verify if the challenges mentioned by the extension officers apply to all blocks. This will therefore make the

convenience sampling produce valid results by avoiding the chances of asking farmers from the same block.

3.4 DATA COLLECTION INSTRUMENTS

According to Ulin et al., (2002), no single research method can capture all dimensions of a complex research problem; it is therefore, prudent to combine two or more methods drawing conclusion from a synthesis of the results. For the purpose of this research, triangulation of multiple data collection method was used during data collection. This was done through the use of questionnaires, interviews as well as observation during the survey.

Questionnaires were self-administered to the sampled farmers as well as the government officials who are directly involved in the day to day operations of the scheme. According to Chiwore (1990), self-administration of questionnaires has many advantages of yielding high response rate, accurate sampling and minimum interview bias. The literacy challenge was overcame by the AGRITEX officials who assisted by interpreting and filling in some of the questionnaires for those who had challenges in filling the questions.

3.4.1 Data collected through the survey included:

- Total volume of water used per season ($m^{3)}$
- Yield pattern for the past seven years (kg/ha)
- Factors affecting water productivity at Insukamini Irrigation Scheme,
- Challenges being faced by the farmers at the scheme,
- Possible solutions
- Age of the sample irrigators
- Male against female farmers

3.5 Soil quality analysis

3.5.1 Collecting Soil Samples for Salinity Testing

The goal of salinity testing is to determine the salt level of soil from which roots extract water. The scheme was divided into three blocks for purposes of soil sampling namely block A, B and C. From each of the three blocks twenty soil samples were randomly collected and thoroughly mixed to make one composite sample. Therefore, three samples were collected from the irrigated part of the scheme. Further 3 samples were collected just outside each of the three blocks to be

analyzed as the control sample that would indicate the condition of the soils under rain fed system. Thus soil samples were collected from the irrigated parts as well as from the non-irrigated parts of the scheme so as to answer objective number 3 which determines the source of soil salinity. During the soil sampling process, great care was considered for any of agricultural practices done, for example where Gypsum and manure were applied, those areas were being avoided. The samples were collected using an auger digging to the root zone of 30cm of depth. Peripheries and anthills were also avoided in the process. The samples after being mixed and weighed to 1kg composite sample per block, were bagged, labelled and sent for laboratory experiments.

The soil samples were sent for analysis at the Soils and Chemistry Research Institute in Harare. The samples were analyzed to collect the following parameters:

- Electrical Conductivity (EC) in dS/m
- Total Exchangeable Bases (TEB)
- Calcium (Ca^{2+})
- Magnesium (Mg^{2+})
- Potassium (K^{+})
- Sodium (Na^{+})
- pH($CaCl_2$)

3.6Water quality analysis

3.6. 1 Water Sampling for quality analysis:

One water sample was collected for analysing the irrigation water to determine its quality. The sample was collected from the Insukamini dam which is a source of irrigation water. During sampling, the container that was used was sterile and clean from any source of impurities. The sample was not taken from the peripheries so as to avoid bias. A boat was used to get inside the dam to the midst of the dam where the sample was collected. The water sample was collected by directing the mouthpiece of the container in the direction where water is flowing from and the sample were taken from a depth of 30cm below water surface. A transparent container was

avoided so as to avoid any chances of algae growth. A 2litre container was used to collect the water sample and was labelled for laboratory experiments. The water sample were sent for analysis at the Soils and Chemistry Research Institute in Harare. The water sample was analyzed for pH, EC, Ca^{2+}, Mg^{2+}, Na^{+}andCl^{-}.

3.6.2 Soil and water testing

The quality of the water and the soil were assessed using SAR and ESP, calculated from ionic concentrations of Na^{+}, Ca^{2+}, $Mg^{2+}$and CEC.

3.7 Data analysis

Student's t-test was used to analyse for differences in chemical concentrations inside and outside the scheme. Correlation analysis (two-tailed) was performed among the variables using the Pearson correlation coefficient while linear regression analysis was conducted to measure the strength of relationships between some variables. All data analysis was done in Environment v. 3.0.1 and all significance tests were at 95% confidence level.

3.7.1 Statistical analysis

The quantitative and qualitative data collected from both primary and secondary data sources were analyzed using qualitative methods and descriptive statistics. Statistical Package for the Social Sciences (SPSS) software was used for the analysis of quantitative data. Data collected from key informant interviews and observations were qualitatively assessed using thematic analysis. Themes were derived from the research objectives. Finally outputs of the statistical analysis were discussed using tabulation, means, frequencies and percentages.

3.8 Crop Water Productivity at Insukamini Irrigation Scheme

i) Estimation of yield

Data on the following parameters was collected from the Insukamini farmers as well as from the resident AGRITEX Officer though the questionnaires and interviews. The farmers were referring from their yearly farm records:

- Maize yield (kg/ha) for the past 7 years
- Previous sugar beans yield (kg/ha) for the past 7 years
- Inputs applied on seasonal basis

- Other agronomic practices being done at the scheme

The yield for each crop was then estimated by calculating the average on a seasonal basis for the three blocks (block A, B and C).

ii) **Irrigation water supplied by the dam**

From the dam, the water is being released for eight hours per day with an irrigation cycle of 7 days. Sometimes farmers are requesting for more hours depending on the crop as well as the water requirements. Water passes through a flume where it is measured and recorded on daily basis by the ZINWA employee (Water Bailiff). Water is also equally distributed amongst the farmers since their cropping pattern is similar and is being influenced by the AGRITEX Officer. Records are well kept and they are showing the volumes of water that has been released by the dam over the past 7 years being studied. For the purpose of this study, the Water Bailif was interviewed and data on water released per year was collected from his records. Some calculations were also done on the water utilised by the two crops under study per hectare throughout the growing season.

iii) Determination of Crop Water Productivity

For the sake of this study, water productivity is defined as the physical output per unit of water applied. The water lost due to evaporation and deep percolation could not be measured because of lack of equipment hence the water balance could not be closed. However the research was based on the water productivity formula used by the irrigation engineer as shown in the literature review. The water applied is implying to the water released from the dam. And the physical output refers to the yield of the maize grain and the sugar beans crops. The following formula was used to calculate the crop water productivity.

$$WP = \frac{Yield(kgha^{-1})}{TotalWaterApplied(m^3ha^{-1})}$$

3.9 Determination of salinity source

To achieve this objective the study used the literature on the standard salinity levels. Thus both primary and secondary data was used here. The following extract was used to characterize the levels of salinity from both irrigation water and soils.

Criteria used to describe the salinity

- Class EC (ds/m)
- Negligible <2
- Light 2-4
- Moderate 4-10
- Moderately severe 10-16
- Severe 16
- Very severe <30

After Salcedoetal 1977

Basing on the above criteria, the soils and irrigation water at Insukamini were analysed on their levels of salinity. A comparison was also made on the soils collected from irrigated plots to the soils sampled outside the irrigated plots.

3.9 Effects of Salinity on crop yields

In order to determine the effects of salinity on the maize and sugar beans, both field data and secondary data sources were used. After assessing the salinity levels using the information from the laboratory experiments, the crops grown by the scheme were assessed on how tolerable they are to the current salinity levels.

Using the extract below, the obtained salinity levels were compared with the given standards to see if they are some variation. If the obtained salinity levels from the soil tests are higher it means the crops are already suffering a reduction in yields.

	Relative yield decrease % as a result of increase in EC			
	0	**10**	**25**	**50**
Field Crop	**dS/m**	**dS/m**	**dS/m**	**dS/m**
Sugar beans	5.0	5.5	6.2	7.5
Maize (grain)	5.7	2.5	3.8	5.9

Extracted from FAO 2006: Crop salt tolerance data

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter aims to report on the findings of the study conducted on water productivity and the relative impacts of salinity on crop yield for the surface irrigation scheme. In this chapter, the results are analysed and discussed basing on the data collected from the Insukamini Irrigation Scheme. Firstly, the chapter gives the response rate of the study, and will then provide the findings from interviews and questionnaires for each objective both qualitative and quantitative data. Further, results from the tests carried out on irrigation water as well as the soil tests results will be presented and analysed. It also presents descriptive statistics in the form of tables, graphs and charts to enhance easy understanding of the research findings. Lastly, the chapter concludes with the discussion of the major findings of the study.

4.2 Response rate

a) Questionnaire response rate

Of the 95 questionnaires distributed, 89 were completed and returned, giving a response rate of 94%. The remaining 6 questionnaire were not completed. Since Punch (2005), has suggested a response rate of 51% and above as adequate to validate the findings of a research, the questionnaire's response rate of 94% therefore was very high such that meaningful conclusions on the findings can be drawn. This is shown in table 4.1 below:

Table 4.1: Table showing response rate from the distributed questionnaires

Category of respondent	Targeted respondents	Actual respondents	Response rate
Farmers	92	86	93
Key informants	3	3	100%
Total	95	89	93.6%

The overall response rate of 93.6% was high enough to justify the use of the responses as a basis for drawing conclusions and making recommendations on the water productivity of the Insukamini surface irrigation.

b) **Response rate from the interviews**

Out of the 6 scheduled face to face interviews with the key informants who consist of 3 irrigation Committee members,1 AGRITEX Officer, 1 Water Bailif and 1 Irrigation Technician, only four interviews were contacted. The responds rate was 66.6%. This was because two irrigation committee members were not available on the day of interviews. However, since the chairman of the irrigation scheme was there, the required information was obtained. Moreover, a response rate of 66.6% is acceptable and is considered as reliable for the selected sample size.

4.3PROFILE OF RESPONDENTS

From the sampled farmers, the Irrigation schemes have a higher percentage of female irrigators to male irrigators as shown in table 4.2 below. The main group who responded where between the age of 41 - 50 years (55%), 35 % were between the age of 30 to 40 years and the other 10 % were between 51 -60 years. This is presented in the pie chart below:

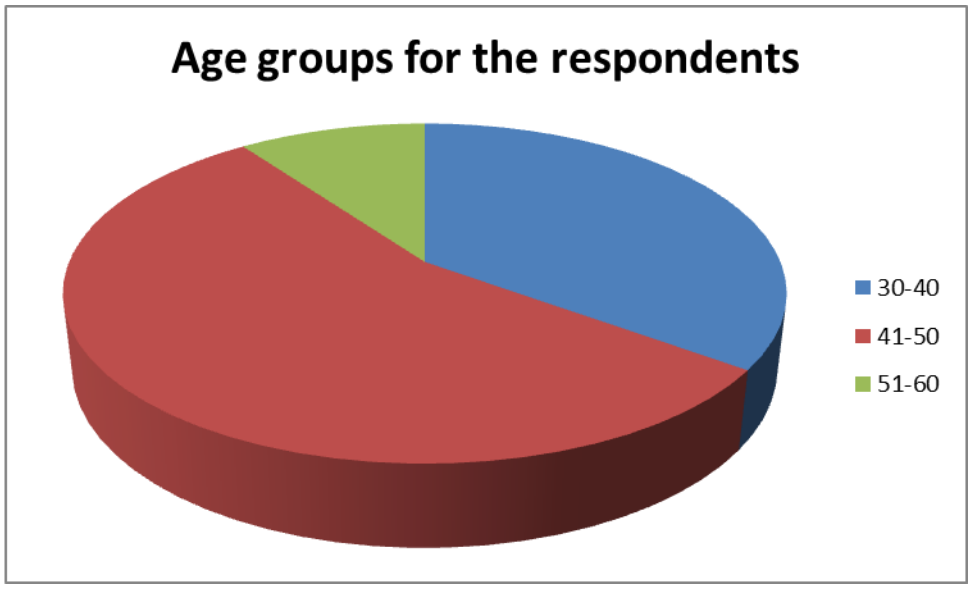

Figure 4.1 Pie chart Showing age groups for the respondents

4.4 Results from the Questionnaire

a) Farming experience

From the questionnaires, it was deduced that 13.5% of the respondents have less than 5 years at the scheme, 16.9 % are now within the period range of 5 to 10years, and 35.9% are within the range of 10 to 15 years at the scheme. And lastly, 33.7% have more than 20 years farming experience.

Table 4.2: showing the respondents' farming experience

Number of years at the scheme	**Frequency**	**Respondents**	**%**
Less than 5 years	12	89	13.5
5-10years	15	89	16.9
10-20years	32	89	35.9
>20years	30	89	33.7
Total	**89**	**89**	**100**

Source: Survey data (2015)

b) Agricultural Training

From the questionnaires, it was found that just a few farmers 6.7% have agricultural training with certificates. About 28.1% have attained the Master Farmer training course and 65.2% have on job farming experience as well as informal training they get from their AGRITEX Officer as well as the knowledge they gain during Green Shows.

Table 4.3: showing the response on agricultural training

Agricultural Training	**Frequency**	**Respondents**	**%**
Attained a certificate/ diploma or degree in Agriculture	6	89	6.7
Master Farmer Training	25	89	28.1
Other informal training	58	89	65.2
Total	**89**	**89**	**100**

Source: Survey data (2015)

c) Challenges faced at the Scheme

During the questionnaire survey, farmers listed a number of challenges they are facing at the scheme. Some of the mentioned challenges include:

- Lack of capital
- Lack of inputs
- Quarrels amongst water users
- Failure to manage pest and diseases due to financial challenges
- Lack of markets
- High water bills
- High costs of scheme management

4.5 Results from Laboratory Tests

4.5.1 Irrigation water

The tested water quality parameters include the EC, pH, Ca^{2+}, Mg^{2+}, and SAR. The results has shown that the dam water being used for irrigation is slightly saline with an electrical conductivity (ECw) value of 2.4dS/m, has a pH of 7.5, a Ca^{2+} of 2.62, Mg^{2+} of 0.5 and SAR of 0,8. The results were tabulated as shown below:

Table 4.4 Water quality results

EC (dS/m)	PH	Ca2+	Mg2+	SAR
2.4	7.5	2.62	0.5	0.8

4.5.2 Soil physical and chemical parameters

The results for the tested soil quality parameters, from the 3 irrigated blocks and the non-irrigated areas around the 3 blocks are shown in table 4.1 below.

Table4.5: Soil analysis results.

Reference: Insukamini Samples	Block A Irrigated	Block A Non-Irrigated	Block B Irrigated	Block B Non – Irrigated	Block C Irrigated	Block C Non – Irrigated
Texture	Sa Cl	Sa L	Sa L	Sa L	Sa Cl	Sa L
Clay%	21	25	27	30	15	17

pH (Ca CL_2)	6.9	7.2	6.7	7.1	6.1	6.5
ESP	2.6	4.0	3.4	4.0	5.5	3.0
E C (dS/m)	5.8	3.7	5.5	3.4	5.0	3.4

1. **pH**($CaCl_2$)

The soils in the Insukamini irrigated blocks are in the pH range of 6.1 to 7.2.For the irrigated blocks, Block A recorded the highest pH of 6,9 followed by Block B with 6,7 and lastly Block C with 6,1. The irrigated blocks has a mean pH of6.6. The pH for the soils from the non irrigated areas were ranging from 6,5 to 7,2 and their mean pH was 6,9.The pH for the irrigated area is slightly lower than the pH for the non irrigated area.

2. **Electrical Conductivity (EC) in dS/m**

The electrical conductivity for the irrigated blocks was ranging from 5dS/m to 5.8 dS/m. For the non irrigated area, the electrical conductivity was in the range of 3.4dS/m to 3.7dS/m with a mean value of 3.5dS/m. The block which recorded the highest EC is block A (irrigated) with 5.8dS/m, followed by Block B (irrigated) with 5.5dS/m and lastly block C (irrigated) with 5dS/m. The mean EC for the irrigated area is 5,4dS/m. This is also presented in fig 4.2

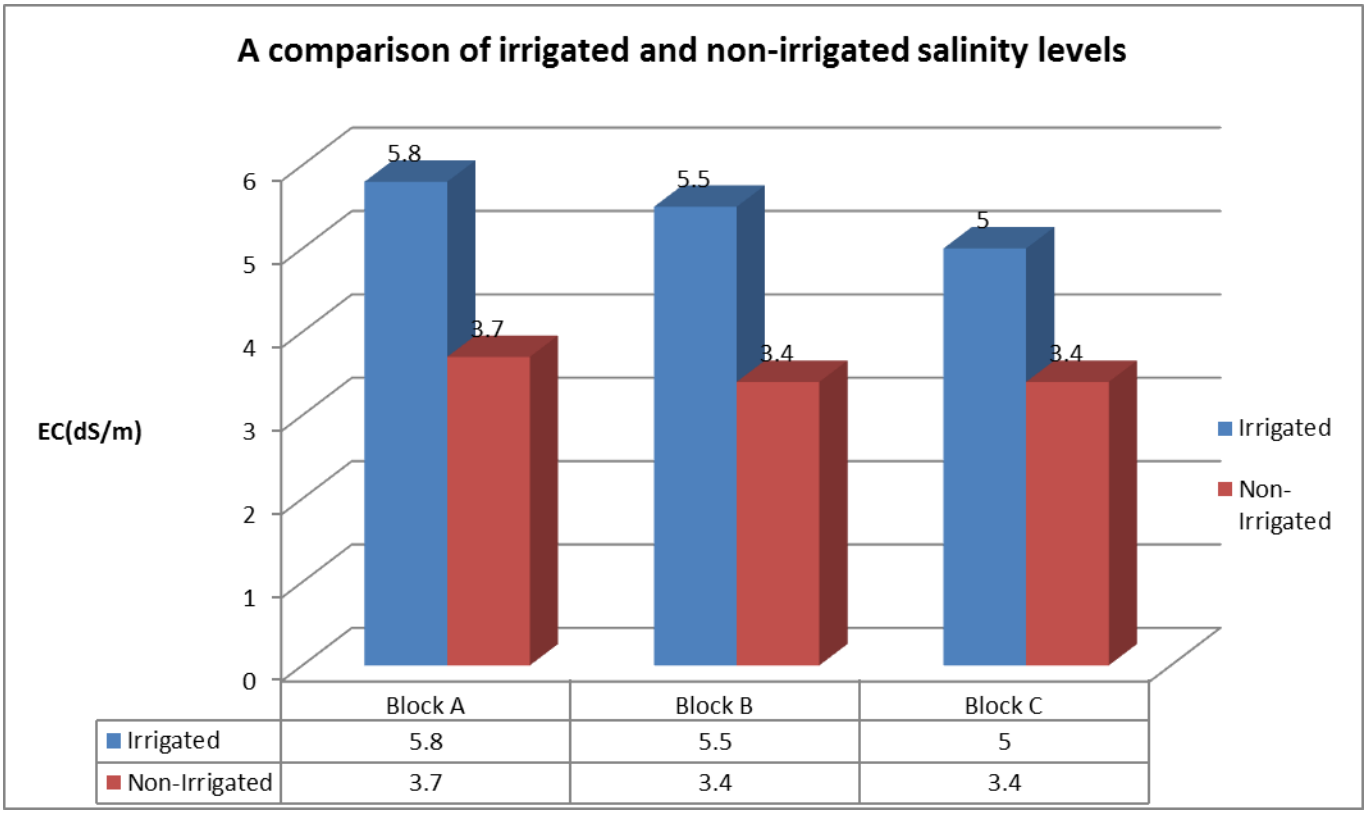

Figure 4.2: Comparison of EC levels for the Irrigated and Non-irrigated blocks

The obtained levels of EC from the irrigated was also compared to the standard levels from the literature as shown below in fig 4.3

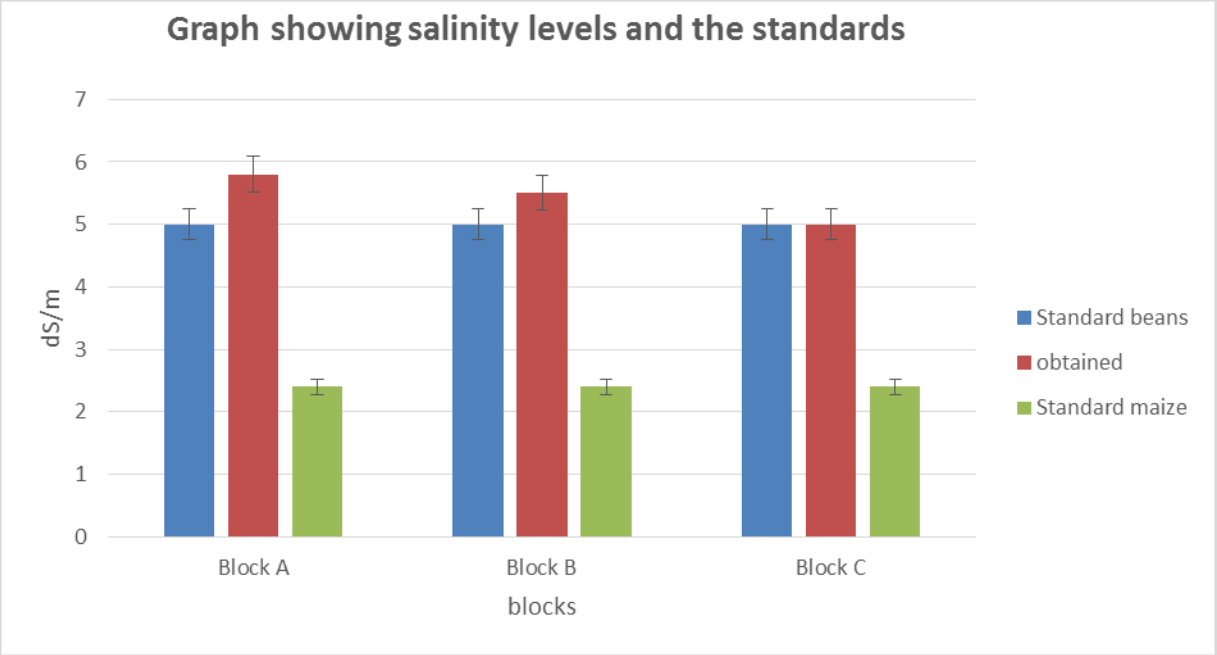

Figure 4.3 Relationship of obtained salinity levels and the tolerable standards on sugar beans and maize

4.5.3 Crop yields results

The average yields results for maize grain and sugar beans from the 3 blocks of Insukamini for the past 7 years are presented in the following graphs (fig 4.4, 4, 5).

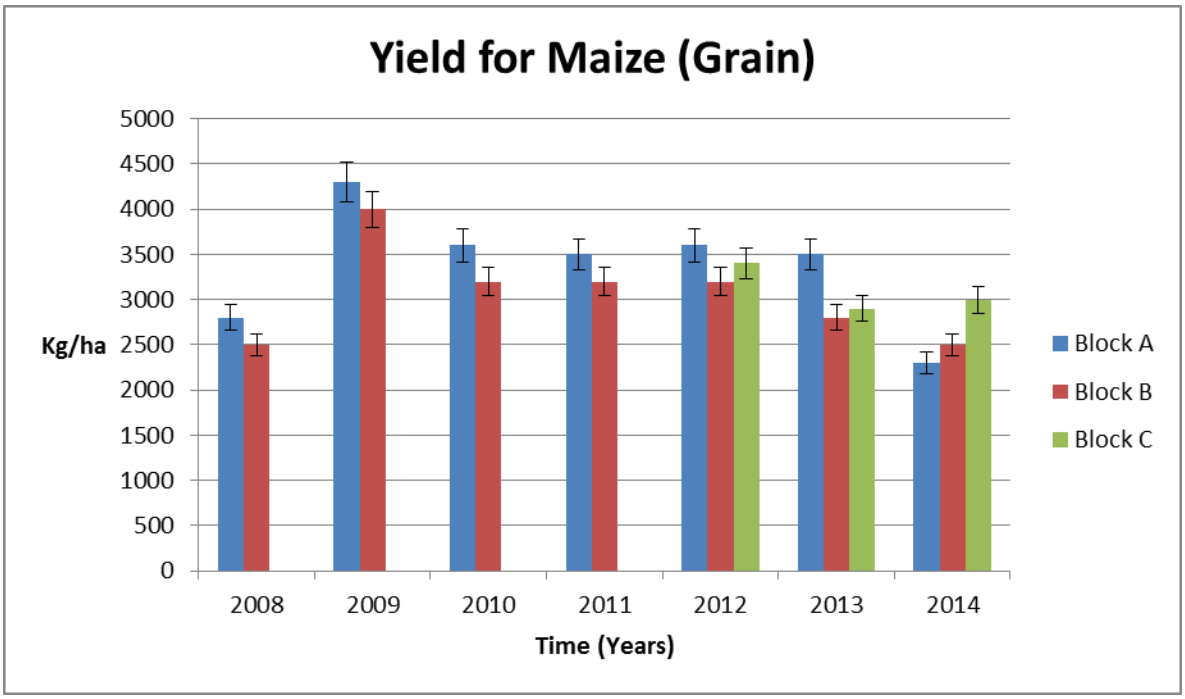

Figure 4.4: Average Maize yield

The results are showing that in 2008, the maize yield for Block A and B were very low (2700kg/ha and 2500kg/ha respectively). From 2008 to 2011, only two blocks (block A and Block B) were being irrigated. Block C started operating in 2012. There was a rise in yield in 2009 and then from 2010 to 2014, there was a significant decrease in yield for the blocks. As for the blocks, there are yearly variations in the obtained average yield. On average, the yields are varying with the highest yield being 4,400kg/ha that was attained in Blocks B and C in 2009 and also in Block A in 2010. The lowest average yield of 2300kg/ha was attained in the year 2014 by the farmers in Block A. The overall average yield for the whole scheme was 3194kg/ha

Average Sugar beans yield

From fig 4.6 below, the sugar beans yield ranged from 2,400kg/ha to 3,700kg/ha. The highest average block yield of 3,700kg/ha was recorded in Block B in the year 2009 whereas the lowest average yield of 2400kg/ha was recorded in the year 2014 in Block B. The overall scheme mean yield for sugar beans is 2,915kg.The results are presented in the graph below:

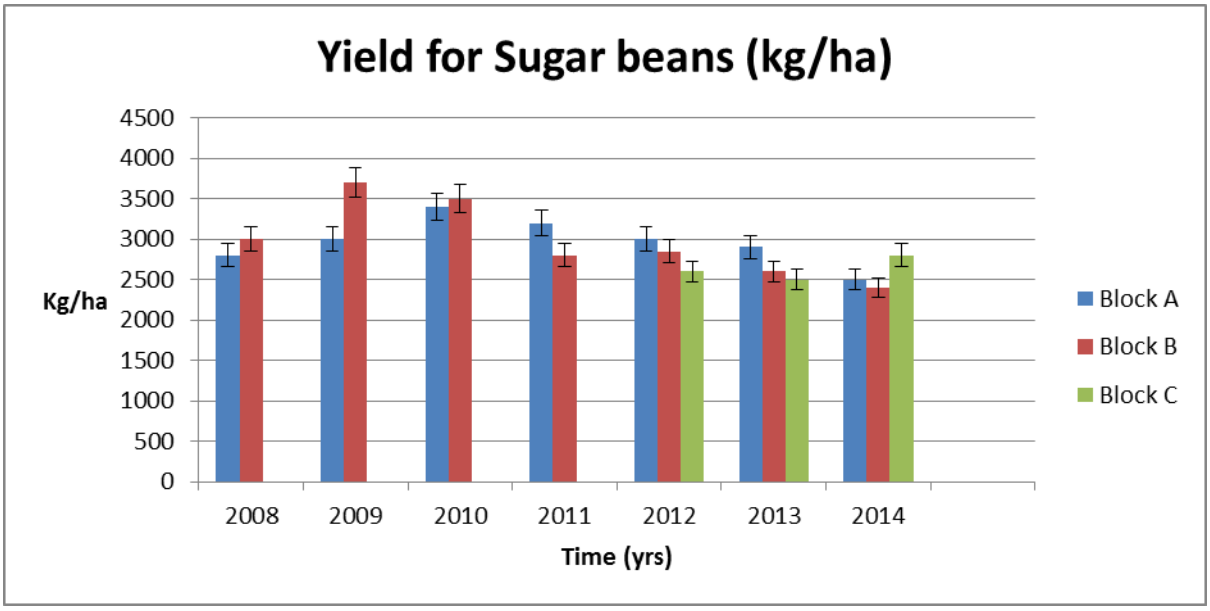

Figure 4.6: Average sugar beans yield/ha/season

Water Released by the dam

The water released by the dam per growing season is as shown in the table 4.3 below. After some calculations (see Appendix 3), the volumes being utilised by each block throughout the growing season were also deduced and are shown in cubic metres per hectare in figure 4.4.

Table 4.4 Water released by the dam in the 3 blocks for the period from planting to harvesting

2008 (m^3)	2009 (m^3)	2010 (m^3)	2011 (m^3)	2012 (m^3)	2013 (m^3)	2014 (m^3)
6494.53	6494.53	7115.29	5125.29	6941.92	7402.06	5156.45
6494.53	6494.53	7115.29	5125.29	6941.92	7402.06	5156.45
6494.53	6494.53	7115.29	5125.29	6941.92	7402.06	5156.45
CWR –Beans		$3000m^3$ to $5000m^3$		$3000m^3$ to $5000m^3$		
CWR-Maize		$5000m^3$ to $8000m^3$		$5000m^3$ to $8000m^3$		

The released water per season is a bit higher than the crop water requirements. The highest released water was in 2013 with $7402.06m^3$ followed by 2010 with $7115.29m^3$. the least water released was in 2011 with $5125.29m^3$

4.6 Water Productivity

The water productivity for both crops were calculated as

follows: $WP = \frac{Yield(kgha^{-1})}{TotalWaterApplied(m^3ha^{-1})}$

(See Appendix 3)

Water productivity for Maize

The results on water productivity for maize is showing some fluctuations. The water productivity ranges from 0.37 to 0.68. The lowest recorded water productivity of 0.37 was recorded in the year 2013 by Block B. The mean water productivity for maize is 0.5 the results were presented graphically as shown below:

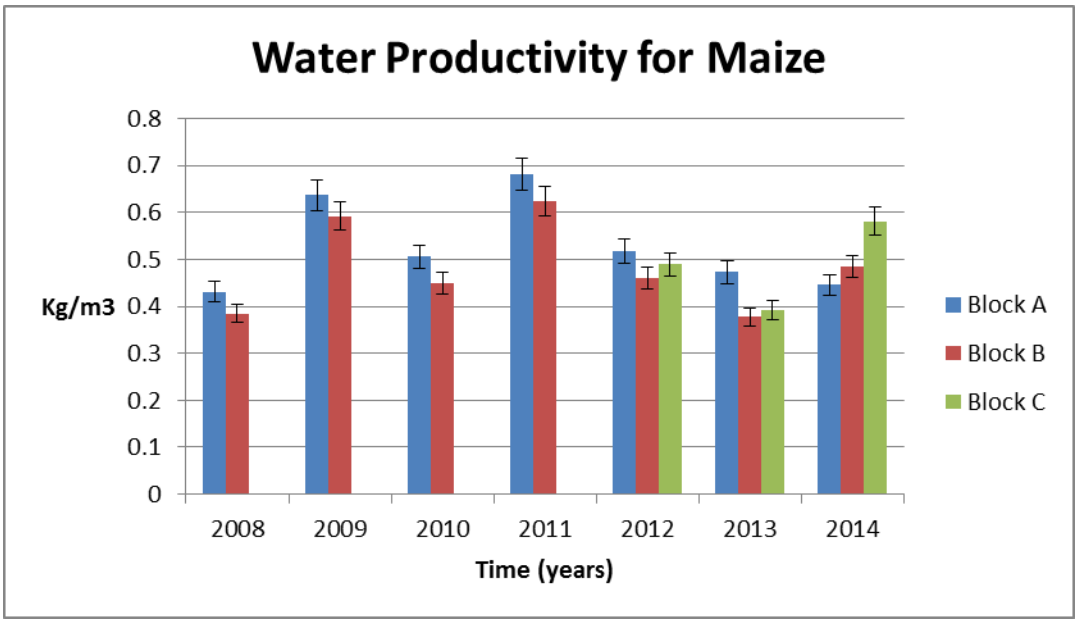

Figure 4.7: Water productivity for maize

Water productivity for Sugar Beans

From the graph given below on the sugar beans water productivity, the trend is showing some variations in the crop water productivity. The water productivity ranges from 0.33 to 0.62. The lowest recorded water productivity of 0.33 was recorded in 2013 by Block B. The mean water productivity for Sugar beans is 0.46. The results were presented graphically as shown below:

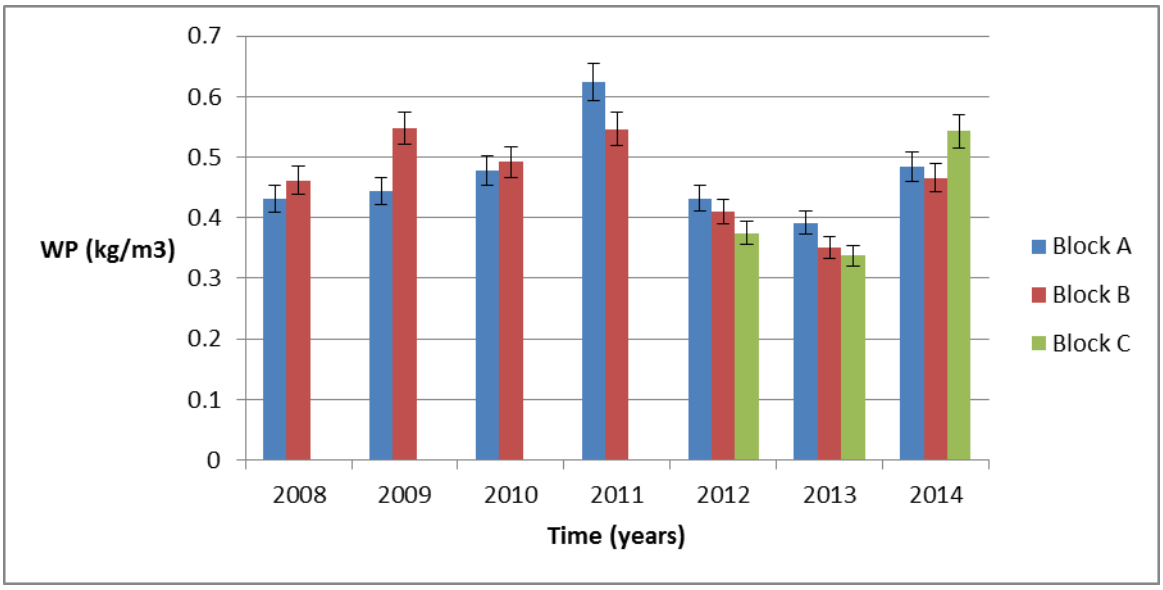

Figure 4.8 Water productivity sugar beans for the 3 blocks

4.8 DISCUSSION

4.8.1 Soil physical and chemical analysis

The soil pH for the Insukamini Irrigation Scheme ranges from 6.1 to 6.9 for the irrigated blocks where as the non irrigated area recorded pH which ranges from 6.5-7.2. According to literature, this range of soil pH is ideal for the life and plant growth. Normally, when the pH is between 6.0 and 6.5, most plant nutrients are in their most available state. In addition to that, the nitrogen has its greatest solubility between pH 4 and pH 8. The findings for this research on the soil pH for Insukamini Irrigation scheme compares well with the results obtained by Chemura et al., (2013) at the Mutema Irrigation Scheme in Zimbabwe and those obtained at Makanya irrigation scheme by Mutiro et al., in Tanzania. Chemura's results were showing that the soils for the irrigated area were alkaline ranging from 8 to 8.8. However the difference with these results is that, Insukamini irrigation scheme recorded lower pH in the irrigated whilst the results obtained at Mutema were showing low pH in the soils outside the irrigated area. As for the Makanya irrigation Scheme in Tanzania, the results recorded were showing that the pH levels for the irrigated area were ranging from 7.9-8.8. This was as a result of cattle manure use with a high pH of around 8.5. At Insukamini Irrigation scheme, the results from the questionnaire has shown that, cattle manure is rarely used by the farmers, instead, they use inorganic fertilisers.

The electrical conductivity (EC) for the irrigated blocks was ranging from5dS/m to 5,8dS/m with a mean value of 5.4dS/m. For the non irrigated area, the electrical conductivity was in the range of 3.4dS/m to 3.7dS/m with a mean value of 3.57dS/m. From the study, it was found that the electrical conductivity values for the irrigated were significantly higher ($p<0,05$) as compared to the non irrigated areas. From these results, this is an indication that irrigation water has an influence on the soil characteristics in the irrigated plots. The irrigation water had an EC of 2.4dS/m showing that it is slightly saline. As irrigation intensity increase, salinity will build up over a number of years. From the literature, it was highlighted that, no matter how low the salt index could be, the continuous deposition of these salts on the root zone will eventually cause an increase in salinity (FAO, 2006). For the irrigated blocks the results are already showing that the soils are saline. From the questionnaire results, it can be also suggested that fertilisers being applied by the farmers to their plots in a way of trying to improve the nutrient content are also

contributing towards the salt build up. This is in tandem with the postulation by Provin and Pitt (2011) which says that "salts can be also as a result of organic amendments and fertilizers". The salinity levels for the irrigated blocks which is now ranging from5dS/m to 5,8dS/mh as an adverse effects on crop production. However, different crops respond differently to the different salinity levels.

4.8.2 Crop Yields

According to Landon, (1991), maize is relatively sensitive to salinity and it does well in well drained soils with pH range of 5.5-7 but can tolerate pH up to 8. From the above statement, this implies that the reduction in yield levels that was recorded from the period 2009 to 2014 might be as a result of salinity built up as opposed to the pH levels. This suggestion is also supported by the FAO (2006) as shown in the extract below.

	Relative yield decrease % as a result of increase in EC			
	0	**10**	**25**	**50**
Field Crop	**dS/m**	**dS/m**	**dS/m**	**dS/m**
Sugar beans	5.0	5.5	6.2	7.5
Maize (grain)	1.7	2.5	3.8	5.9

Extracted from FAO 2006: Crop salt tolerance data

From the above table, it is clearly indicated that the maize crop is not affected by yield loss if the salinity level ranges from 1,7dS/m to the level of 2,4dS/m. The maize yield will start decreasing if the salinity level gets to 2.5dS/m. Between the range of 2,5dS/m and 3,7dS/m, there is a possibility of 10% yield decrease. From 3.8dS/m to around 5.8dS/m a possibility of 25% yield decrease may be also attained. If the EC levels becomes 5,9dS/m, then 50% decline in yield may be also realised. Looking at the obtained EC levels of 5,0dS/m (Block C), 5,4dS/m (Block B) and 5,8dS/m (Block A) for the Insukamini Irrigation scheme it means that, the yield for the whole scheme is already in the range of 25% yield decrease range. If there is no intervention, the scheme will eventually be at a loss as the salts continue to build up.

Sugar beans is also another crop with yield which is declining. Many factors may be contributing to the decline of the sugar beans yield as mentioned by the farmers and the key informants during interviews as well as questionnaire surveys. Some of the factors mentioned include the

financial challenges to buy adequate inputs, poor system performance due to the expansion taking place at the scheme, poor crop varieties, pests and diseases and also lack of experience especially in Block C which was constructed last. All these factors also contribute to the decline in yield for the maize crop but the main contributing factor to the decline in the two crops is salinity build up. Beans do well in pH ranges of 5.5-6.5. From the results obtained at Insukamini irrigated blocks, the pH is ranging from 6.1 to 7.2 such that beans yield might be affected by these pH levels as well. However the main challenge here is on the salinity levels. From the above table, the obtained EC level results are showing that the salinity levels for block A (5.8d/s/m) and Block B (5.5dS/m) has already reached a range of 10% yield decline. This means if we add the 10% loss to the other factors listed above which affect the yield of sugar beans we are likely to get a very low yield in these blocks. With these results, it might not be beneficiary for farmers to continue growing the bean crop which is regarded as a high value crop because of the salinity level and pH levels unless if the corrective measures are implemented. The research has also shown that since the establishment of the scheme, no soil tests has been done. The farmers were just advised to use the blanket recommendations.

4.8.3 Water productivity

The water productivity for sugar beans and maize was fluctuating during the period of study. For both crops, a very low water productivity was experienced in the year 2008. These results best explain the issue of financial challenges that were being experienced by the country. Farmers mentioned the issue of unavailability of inputs even to those who had cash to purchase the inputs. Due to that fact, most farmers thought that if they could increase the volumes of water use they can increase their yield. This is evidenced by the high figures of water released by the dam during that same period. This is against Zwart and Bastiaanssen (2004)'s definition of increasing water productivity. They described "increasing water productivity" as either to produce similar yield using less water resources or to attain higher crop produce with the same water resources. As mentioned earlier on in the literature, yield is a function of various inputs and can be expressed with the following equation:

$$O = f(I1, I2, I3, \dots In)$$

Where: *O* is the output

I1, I2, I3 and *in* are the production factors (land labour, capital, energy and other inputs used in production)

At any given case, yield can drop even when other inputs are considered optimal or above optimal. In the case of Insukamini, the volumes of water are increasing but causing low significance or diminishing returns are obtained on yield. Moreover, if excess water is applied, looking at the mode of irrigation being used at the scheme, this will facilitate erosion of nutrients down the soil profile into the sub profile making the nutrients to be unreachable to plants.

In the year 2009, the scheme recorded the highest water productivity of 0,68 for maize and 0.78 for sugar beans. During that period, things had improved and that's when multicurrency was introduced in the country. Some fluctuations which were realised there after from the period 2010 to 2014 were as a result of other different factors mentioned by the farmers and the key informants during the research. Some of these factors has been mentioned under the yield section.

From the research findings, the crop water productivity for maize was ranging from 0,37kg/m^3 to 0,68kg/m^3 while a range of 0.33kg/m^3 to 0.62kg/m^3 was recorded for the sugar beans. The recorded water productivity is on the lower side as compared to the water productivity reported in literature around the world which ranges from 0, 3kg/m^3 to 2,7kg/m^3 for grain yield. More so, the FAO gives crop water productivity for maize as 1,6kg/m^3 (Doorenbos and Kassam 1979). However, these results are within the range of other researches carried out in Zimbabwe. For example, a water productivity of 0,6kg/m^3 for maize was reported in Marondera from a study carried out by Guzha et al., (2005) under rain fed conditions using conventional fertilisers in Chihota rural Community. In addition to that, Magodo (2007) also came up with a range of 0,5kg/m^3-0,7kg/m^3 (which is within this study's range) in her study to quantify water productivity and predicting the yield of 3 different maize varieties at the ART farm in Zimbabwe. In addition to this, the water productivity results from this study compares well with reported results for sub-Saharan Africa, which ranges from 0.1kg/m^3 to 0.6kg/m^3 with an average of 0.3kg/m^3 for cereals (excluding rice) (Rosegrant et al., 2002). These results are also in tandem with those recorded in a study carried out by Igbadun et al., (2005) in Tanzania s' Mkoji area, under irrigation whereby a crop water productivity of 3 maize varieties were ranging from 0,4kg/m^3 -0,7kg/m^3.

Overally, the results on water productivity is showing some variation in the crop water productivity. The water lost due to evaporation and deep percolation could not be measured because of lack of equipment hence the water balance could not be closed. The low water productivity are resulting from the fact that sugar beans and maize are sensitive to the salinity levels which was building up over the period. As for the Block C, the block was still new yet water productivity was low. This is also as a result of the poorly levelled field which is failing to uniformly spread the water throughout the field. This is now causing high water application and in return the yield is very low that is also causing a reduction in the overall productivity. Moreover, salinity is also building up in the same block leading to a decline in the overall productivity trend over the seven year period.

Water released was also a bit higher as compared to the list crop water requirements for the crops in question. For example water used by sugar beans is higher than its crop water requirements thereby leading to a low water productivity.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

This chapter seeks to relate the research findings discussed in chapter four to the main objectives of this research. The chapter will start by giving a restatement of the research objectives and will then give the conclusions drawn from the research findings.

The main objectives of the study was to quantify water productivity for the Insukamini Irrigation Scheme and to assess the relative impacts of salinity at the Insukamini irrigation Scheme. From the findings, it was concluded that Insukamini irrigation scheme has low crop water productivity levels. The maize water productivity ranges from 0,37kg/m^3 to 0,68kg/m^3 while sugar beans water productivity is ranging from 0.33kg/m^3 to 0.62kg/m^3. The overall mean water productivity for maize is 0.5kg/m^3 and 0,46kg/m^3 for sugar beans. This is low when comparing it to the world standard as well as the FAO standards. According to Bastiaansen et al., (2003), the range of crop water productivity for maize reported around the world is 0,3kg/m^3-2,7kg/m^3 (grain yield), which makes the conclusion that water productivity is in the lower side.

In terms of the soil and irrigation water quality parameters, Insukamini Irrigation scheme has been affected by salinity, with EC levels ranging from 0.54dS/m to 0,58dS/m. Although the irrigation water quality has low levels of salinity characterised by 2,4dS/m, there is a very high possibility that it is causing the soils to be saline. This conclusion is based on the fact that the salinity levels for the irrigated area is much higher than the salinity levels of the non irrigated area yet is within the same area. More so, the salinity levels for the irrigated plots are detrimental to the crops under study. Maize and sugar beans are sensitive to salinity hence a decline in yield. However, the pH for most soils in the Insukamini irrigation scheme are in the range of 6.1 to 7.2. This range of soil pH is ideal for the life and plant growth. Normally, when the pH is between 6.0 and 6.5, most plant nutrients are in their most available state. In addition to that, the nitrogen has its greatest solubility between pH 4 and pH 8.

Lastly, in terms of the source of salinity, it was concluded that salinity is coming from the irrigation water. Although some other factors like fertiliser application and poor drainage are playing a role in the salinity accumulation, the overall conclusion is that water is the main player. This is evidenced by the fact that yield has been declining over the period and also the salinity levels within the irrigated area is significantly higher than that of the non irrigated area. The levels of 2,4dS/m (irrigation water) was not being treated and has eventually led to the accumulation of salts over the past period (from 1988 when the scheme was established to 2014). It is also concluded that the crops grown at the scheme are not compatible to the salinity levels at the scheme hence the continuous reduction in yield and the overall low water productivity.

There has been a substantial decline in yield from the year 2009 to 2014. Although the decline trend is not confined to the salinity challenge only, the analysis suggests that salinity challenge has highly contributed to this decline in the yield. This is evidenced by the fact that when comparing the salinity levels of obtained and the standards from literature, there is also a significant difference which implies that maize yield has a potential loss of 25% caused by salinity only and sugar beans has a potential yield loss of 10% as discussed under the discussion section.

5.2 Recommendations

It is therefore recommended that extension workers should train the farmers on sustainable management practices such as a, use of salt tolerant crop varieties, use of gypsum for salinity correction, construction of drainage system that facilitate leaching out of salts from the root zone and periodic soil analysis to get detailed nutrient status of the soil and recommendations on fertiliser requirements for specific crops.

It is also recommended that t land levelling should be done by farmers for maximum utilisation of water and land resources, farmers should incorporate deficit irrigation when water is applied when the soil reaches the critical soil moisture status which can improve water productivity. Incorporate organic manure as it might reduce the use of fertilisers which contribute to an increase in salt index near the soil rooting zone.

Lastly farmers are encouraged to seek assistance always from technocrats so that they do their soil testing so as to determine the link between the soil chemical properties and crop yields. Good irrigation management practices are also required in order to improve farmers' practice and water use. Farmers should also improve their cropping patterns like planting on raised beds so as to facilitate the leaching out of salts**.**

Suggestions for future research

It is strongly recommended that further investigations on the sensitivity of water productivity to salinity levels should be carried out under experiments over a long period of time. More so a comparison of surface system and other localised systems should be done by comparing the salinity levels and their effects to similar crop types and varieties.

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Appendix 1

QUESTIONNAIRE FOR FARMERS

*My name is **Makwara Nabars**; I'm a final year student at Midlands State University studying for MSC Land Resources Assessment for Development Planning degree. As partial fulfilment of the requirements of my degree program, I am carrying out a research project on the W**ater productivity and relative effects of salinity on crop yield**. I am therefore appealing for your assistance in responding to the questionnaire which is part of my research work. Your information and responses are confidential and will be used for academic purposes only.*

Please kindly answer the following question with an ☒or☑ and fill open spaces

1. Gender :
   - Male ☐
   - Female ☐
2. Age Less than30 years
   - 30-40 years ☐
   - 41-50years ☐
   - 51-60 years ☐
   - Over 60 years ☐
3. Farming Experience
   - Less than 5 ☐ars
   - 5-10years ☐
   - 10-20years ☐
   - >20years ☐
4. a) Do you have any agricultural background?
   - Yes ☐
   - No ☐

   b) If yes specify

   ……
   ……
   ……
   ……
   ……

4. Size of plot
   ……
   ……

5. Crops grown.
   i)…….
   ii)……
   iii)……

iv)…….
v)…….
vi)……

6. Are the crops grown for subsistence or for sale
   - For subsist
   - For Sale
   - Both

7. Yield per crop

	Yield per crop/ year				
CROP	2010	2011	2012	2013	2014
1					
2					
3					
4					
5					

8. Total income for the past 5 years in dollars ($)

	Income / year				
CROP	2010	2011	2012	2013	2014
1					
2					
3					
4					
5					

9. Do you pay water bills
   Yes
   No

10. If yes state the fees paid per year for the past 5 years

	Water Fees / year ($)				
CROP	2010	2011	2012	2013	2014
1					
2					
3					
4					
5					

11. Do you practice crop rotation?
    - Y
    - N

12. Who determine the cropping pattern?

- Self ☐
- AGRITEX Off ☐
- Both ☐

13. Do you get some training? Yes ☐
NO ☐

If yes specify
……
……
……

14. Indicate the agronomic practices that you practice at your plot
- Integrated weed management ☐
- Integrated pest and disease management ☐
- Fertility management ☐
- Other (specify)

15. How do you do land preparation?
- Tractor ☐
- Hoes ☐
- Cultivator ☐
- Ridger ☐
- Ploughs ☐
- Harrows ☐
- Other (Specify)……

16. Are there any leakages along the canals
- No leakages ☐
- Moderate leaka ☐
- Heavy leakages ☐

17. How do you maintain the irrigation infrastructure
- Routines maintenance by farme ☐
- Impromptu attention ☐

18. What are the sources of finance for repairs and maintenance in the scheme
- Self-sponsored ☐
- Government ☐
- NGOs ☐
- Co-operatives ☐

19. a) How often do you irrigate

- daily ☐
- after every 2 days ☐
- after every 3 days ☐
- after every week ☐
- other (specify) ☐

……
……

b) What determine the irrigation interval?

- Irrigation scheduling ☐
- After identifying signs of str ☐
- Other (specify)

……
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……
……
……

20. What are the challenges being faced at the irrigation scheme

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……..

21. What do you think are the possible solutions to the challenges mentioned above

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……
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……
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……
……
……

THANK YOUR FOR YOUR COOPERATION

Apendix 2

Table showing Sugar Beans yield

Block	2008 (kg/ha)	2009 (kg/ha)	2010 (kg/ha)	2011 (kg/ha)	2012 (kg/ha)	2013 (kg/ha)	2014 (kg/ha)
A (irrigated)	2800	3000	3400	3200	3000	2900	2500
B (Irrigated)	3000	3700	3500	2800	2850	2600	2400
C (irrigated)					2600	2500	2800

Table 4.2: Maize yield (grain)

Block	2008 (kg/ha)	2009 (kg/ha)	2010 (kg/ha)	2011 (kg/ha)	2012 (kg/ha)	2013 (kg/ha)	2014 (kg/ha)
A (irrigated)	2800	4300	3600	3500	3600	3500	2300
B (Irrigated)	2500	4000	3200	3200	3200	2800	2500
C (irrigated)					3400	2900	3000

Data on water

Year	2008	2009	2010	2011	2012	2013	2014
Total Irrigated Area (ha)	21.5	21.5	21.5	28.5	36.5	36.5	41
Released water/year	418897	435678	458950	438212	760140	810526	634244
Water used/season (3 season/yr)	139632	145226	152983	146071	20826	270175	211415
Water used/ha/season	6494.53	6754.7	7115.5	5125.29	6941.92	7402.06	5156.45

Appendix 3 : water productivity calculations

Table showing calculations done using excel sheet

Calculation of Water Productivity For Sugar Beans							
Year	2008	2009	2010	2011	2012	2013	2014
Total Irrigated Area (ha)	21.5	21.5	21.5	28.5	36.5	36.5	41
Released water (m^3/year)	418897	435678	458950	438212	760140	810526	634244
Water used (m^3/season (3)/yr)	139632	145226	152983	146071	20826	270175	211415
Water used (m^3/ha/season)	6494.53	6754.7	7115.5	5125.29	6941.92	7402.06	5156.45
Sugar Beans Yield (Kg/ha)- Block A	2800	3000	3400	3200	3000	2900	2500
Sugar Beans Yield (Kg/ha) - Block B	3000	3700	3500	2800	2850	2600	2400
Sugar beans Yield (Kg/ha) Block C					2600	2500	2800
Water Productivity Block A	0.431132	0.444135	0.47783	0.624355	0.432157	0.391783	0.48483
Water Productivity Bloc B	0.461927	0.547767	0.491884	0.546311	0.410549	0.351254	0.465436
Water Productivity BlockC					0.374536	0.337744	0.543009

Calculation of Water Productivity For Maize							
Year	2008	2009	2010	2011	2012	2013	2014
Total Irrigated Area (ha)	21.5	21.5	21.5	28.5	36.5	36.5	41
Released water/year	418897	435678	458950	438212	760140	810526	634244
Water used/season (3) yr)	139632	145226	152983	146071	20826	270175	211415
Water used/ha/season	6494.53	6754.7	7115.5	5125.29	6941.92	7402.06	5156.45
Maize Yield (Kg/ha)Block A	2800	4300	3600	3500	3600	3500	2300
Maize Yield (Kg/ha) Block B	2500	4000	3200	3200	3200	2800	2500
Maize Yield (kg/ha) Block C					3400	2900	3000
Water Productivity Block A	0.431132	0.636594	0.505938	0.682888	0.518589	0.472841	0.446043
Water Productivity Block B	0.384939	0.59218	0.449722	0.624355	0.460968	0.378273	0.48483
Water Productivity Block C					0.489778	0.391783	0.581796

Working assumptions and additional informationThe Scheme has 3 seasons/ year

i) **The water released is equally distributed for the three seasons**

ii) **The water is also equally distributed for each hectare**

iii) **Block C was introduced in 2012**

Source : Field Work 2015

Appendix 4

Interview Check list for the AGRITEX officer and Irrigation Technician

1. Irrigated area .....
2. Number of blocks.....
3. Plot size per farmer.....
4. Total irrigable in (ha).....
5. Required annual water volumes.....
6. Any training done to farmers.....
7. Agronomic practices

   .....

   .....

   .....
8. Average yield per ha

   .....

   .....
9. Is there any trace of salinity

   .....
10. Challenges being faced by the scheme

    .....

    .....

Appendix 5

Check list for the Water Bailif

1. How often do you release water for irrigation?

   .....

2. What is the volume of water applied per year

Year	2008	2009	2010	2011	2012	2013	2014
Total Released water/year							

3. Who determine the amount released.....
4. Is your dam water treated.....
5. Is it adequate for the scheme .....
6. What are the challenges faced by your organisation in connection with the scheme operations.....
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