ASSESSING THE EFFECT OF IN-FIELD RAINWATER HARVESTING ON SOIL PHYSICO-CHEMICAL PROPERTIES AND CROP YIELD IN COMPARISON WITH THE TRADITIONAL FARMERS' PRACTICE

By

Mduduzi Khuzwayo

209503395

Submitted in fulfilment of the academic requirement for the degree of Master of Science in Soil Science

School of Agricultural, Earth and Environmental Science

University of KwaZulu-Natal

Pietermaritzburg

September 2017

ABSTRACT

Most communal farmers in South Africa rely on rain-fed agriculture. However, the country is experiencing rainfall variability as well as low soil fertility. These are major limiting factors to food production especially since South Africa is dominated by a semi-arid climate. It is for this reason that rural communities must optimally utilise their limited water reserves. Rainwater harvesting (RWH) technologies are amongst possible alternatives to maximise agricultural crop production. The aim of this study was to assess the effect of in-field rainwater harvesting on selected soil physico-chemical properties and maize crop yield in comparison with the traditional farmer practice. The study was conducted in homestead gardens in Kwa-Zulu Natal (KZN) province, under Msinga local municipality and in Eastern Cape Province (EC), under Tsolo local municipality. The study was set up at five homestead gardens namely Madosini, Beya, Mjali, Quvile and Sokhombe in the Eastern Cape and three field trials in Kwa-Zulu Natal (Mntungane, Xoshimpi and Mxheleni). It was designed as randomised complete block design, that compared in-field rainwater harvesting (contour ridges) with the traditional farmer practice (control) over two seasons (2013/14 and 2014/2015). Data was collected for soil chemical and physical properties as well as for crop grain and dry matter yields. Soil samples were collected at 0 - 10, 10 - 20 and 20 - 30 cm depths for analysis of soil pH, exchangeable bases, micronutrients and aggregate stability, and for analysis of bulk density at 0 -10 cm. These samples were collected at planting (2013) and at harvesting (2015). Gravimetric soil moisture content was periodically monitored at different stages of maize growth (planting, vegetative growth, tasselling and harvesting) in 2015. Biomass and grain yield were determined at harvest. Results showed that rainwater harvesting improved soil moisture content, aggregate stability, grain and dry matter yields. No clear trend was observed on the effect of rainwater harvesting on exchangeable bases, soil pH and micronutrients across all study sites in Kwa-Zulu Natal and Eastern Cape. It was therefore recommended that rainwater harvesting be used by resource constrained rural farmers who are experiencing unfavorable precipitations to improve crop yields and soil productivity.

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I, Mduduzi Khuzwayo declare that:

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Dr. Rebecca Zengeni (Supervisor)

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Mr Jon McCosh (co-supervisor)

ACKNOWLEGMENTS

I thank the holy place uMuzi waseKuPhakameni that God created for us. I further thank God for His mercy and grace throughout the time of this study, especially sound health, protection, provisions and preservation. I travelled a lot on the road for data collection and conference presentations. I thank Him for journey mercies, divine provision and protection all through the study. I also appreciate members of Mayandiswe for their encouragement and emotional support. A special thanks to Mrs Mwelase (Mkhokheli MaChithwayo), Bawelile Purity Langa and Carol Mpisi. Your contributions towards my success was noted and appreciated.

I also appreciate my mother (Zikhokhile Ntuli) and siblings (Lindokuhle Emmanual Khuzwayo, Njabulo Lucky Khuzwayo and Snenhlahla Khuzwayo) whom God had used to be a source of provision, encouragement and emotional support. My son Avela Siyamini Asibonge Khuzwayo that God blessed me with during the course of this study. I do celebrate all my friends. Appreciate their concerns, care, kindness and emotional support (Lindokuhle Phakathi, Richard Mhlongo, Njabulo Makhoba, Mthokozisi Gcabashe, Mthokozisi Zuma, Mlungisi Gwala, Njabulo Mbedu, Ndumiso Ncobela, Siyabonga Dlamini and Lihle Gumbi). In patience and your constructive sources of ideas and resources, my humble supervisors Dr. Rebecca Zengeni (University of KwaZulu-Natal) and Jon McCosh (Institute of Natural Resources), I say thank you. Your academic guidance, assistance and commitment throughout the study cannot be quantified.

I am extending my gratitude to staff (Ms Tezi Nala, Joe Buthelezi and Rajiv Singh) and colleagues (Nondumiso Sosibo, Nsikelelo Dlamini, Bonginkosi Vilakazi, Lindumusa Myeni and Bangani Dube) of the department of Soil Science; for their contribution, and assistance in one way or the other (laboratory work and consultations). My appreciation also goes to the Water Research Commission who admitted me into the project research titled “Up-scaling of rainwater harvesting and conservation on communal crop and rangeland through integrated crop and livestock production for increased water use productivity” under Water Research Commission Project Number K5/2177/4/. In respect to this, some of the information in the project are also contained in some specific deliverable reports submitted to Water research Commission between 2015 and 2016 through the Institute of Natural Resources (INR) in KwaZulu-Natal. I also acknowledged their financial support for this project. My sincere thanks also goes to Jon McCosh and Brigid Letty (Institute of Natural Resources) whom counted me worthy and incorporated into Water Research Commission project. This project provided the funding required for the fieldwork research projects. Thank you for your assistance in logistics and planning during my data collection, Msinga farmers (Mtungane Zulu, Xoshimpi Zulu and Mxheleni women’s group) and Eastern Cape farmers (mam’Quvile, mam’Mjali, Sokhombela, Beya and mum’Madosini). Thank you for time and effort in ensuring that this project become successful. I also appreciate all project team members under the leadership of Mr Jon McCosh (Brigid Lety., Gasa Nokulunga., Lynton Dedekind., Michael Malinga., Mawethu Tshabu., Zanele Shezi and Zinhle Ntombela), contributors (R. Zengeni, P Muchaonyerwa, J.J Botha and J.J Anderson). I cannot end this page without saying a word of appreciation to the Agricultural Research Council for funding the presentation of part of this work in the Combined Congress Conference held in Bela Bela in January 2017 and in the African Combined Congress held in Ratanga Junction in Cape Town in January 2018.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 CHAPTER ONE: GENERAL INTRODUCTION

Poverty is a challenge for South Africa's population. About half the population is classified as living in poverty while 25 % are extremely poor (Botha et al., 2003). This situation is even worse in rural areas. To address food insecurity, the agricultural sector plays a vital role in providing food and income for the majority of the population (Lema and Majule, 2009). Agriculture is therefore considered as a good tool for reducing poverty and to create jobs in rural areas (Botha et al., 2003). As a result, it is key to economic development as well as food security of the country (Majule, 2008). However, agricultural production is facing serious challenges of climate unreliability and variability (Lema and Majule, 2009). Climate variability and change is recognised through changes in rainfall patterns, amounts and intensities. Deficiencies in precipitation result in reductions in crop yields, and this is particularly true in regions where annual rainfall ranges from 300 to 500 mm (Mertz et al., 2009). This is usually the case for most rainfall regions within South Africa. Furthermore, South Africa is classified as a semi–arid and water-scarce country (Schulze and Maharaj, 1997). It is amongst other countries in sub-Saharan Africa that experiences limited precipitation over an extended period of time (Thomas et al., 2007). South Africa receives mean annual rainfall of less than 500 mm which is well below the global annual mean (Kahinda and Taigbenu, 2011). The rainfall also experiences an erratic distribution. In addition to this, less than 15 % of land in South Africa is arable. Thus, both low average rainfall and limited arable land make it difficult to successfully and efficiently use natural resources for food and fibre production (Botha et al., 2003).

Smallholder agriculture has experienced land degradation in many parts of Africa including South Africa. This is due to several factors including poor management coupled with over-utilisation of natural resources such as vegetation and soil (Hensley et al., 2000). Overgrazing on rangelands has resulted in loss of many grass species which impact on soil surface cover. This results in poor infiltration, increased runoff as well as severe soil erosion. Crop and livestock production in the communal farming regions of South Africa is mostly rain-fed, since most farming communities do not possess the necessary irrigation facilities to supplement rainfall. The reduction in water use efficiency is another additional challenge that South African communal farmlands are facing (Howell, 2001). This is due to several factors such as unproductive losses because of surface runoff and excessive soil evaporation due to bare soil surfaces. These losses lead to reduction in agricultural food production.

Farming communities in South Africa have reported declining crop yields over the years (Deng et al., 2006). There have also been reports of livestock mortality in Eastern Cape and in Kwa-Zulu Natal provinces. These mortalities as well as declining crop yields are a result of limited water availability under dry-land farming (Shackleton et al., 2001). It is therefore observed that communities are vulnerable to the challenges of both low and erratic rainfall. It is reported that the declining of rainfall occurrence is expected to be worse with time (Smithers and Schulze, 2003). To address the problem of limited water availability, different technologies have been introduced in dry land agriculture in order to improve the quality and quantity of yields (Deng et al., 2006a). These include advances in plant breeding, fertilizers and irrigation systems (Mupangwa et al., 2006a). However, Wang et al. (2009) suggested that despite all these technological innovations, climate variability remains a critical limiting factor in dry-land agricultural production. The main reason for this is that the majority of the communal farmers of South Africa are resource poor and cannot afford to implement the expensive technological advancements. Rainfall variability and a low rainfall supply reduce the quality and availability of water for crop growth and soil productivity (Wang et al., 2009). This in-turn reduces the productivity of agricultural ecosystems. Different rainwater harvesting techniques (RWH) such as in-field, ex-field and on farm rainwater harvesting that aim to supplement the limited rainfall events have been introduced in communal farming regions of South Africa (Hensley et al., 2000). Al-Shamiri and Ziadat (2012), defined RWH as the "concentration, collection, storage and use of rainwater runoff for both domestic and agricultural purposes". The different RWH techniques adopted so far include both in situ and ex situ RWH technology. A detailed description of the different techniques is given in chapter two.

Rainwater harvesting and conservation (RWH&C) techniques have not only been demonstrated to increase agricultural crop production but also to be environmentally sustainable (Botha et al., 2007). RWH improves soil water content and its availability for plant uptake (Li et al., 2000a). This improves the uptake of nutrients by plants as water serves as a transport medium for soil nutrients (Mbilinyi et al., 2005b). The aim of this research was to assess the impact of the contour ridge RWH technique on crop yields and soil productivity in comparison with the traditional farmers' practise. The traditional farmer practise in this study is referred to any practise that the farmer is employing on his or her field. The objectives of this study were as follows:

1. To determine the effect of RWH on soil physico-chemical properties in comparison with the traditional farmers' practice.

2. To determine soil moisture content at different positions of the contour in comparison with the control.

3. To assess crop yields under RWH in comparison with the traditional farmers’ practice.

2 CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Aridity and climatic uncertainty are the leading challenges to agricultural productivity in arid and semi-arid regions (Ammar et al., 2016). Farmers in these regions are heavily reliant on rain-fed agriculture as the dominant farming system. Variable rainfall, which is poorly distributed and is below average, is a challenge to farmers operating in these regions. South Africa is a water stressed country characterised by low, erratic and poorly distributed rainfall with high evaporation rates, and excessive runoff which result in soil losses (Kahinda et al., 2010). It receives an average annual rainfall of 500 mm. Regions that are considered to receive good rainfall in South Africa are few, and these are mostly along the south-eastern coastline (Baiyegunhi, 2015). The greater part of the interior and western part of the country is characterised as being arid or semi-arid. About 65 percent of South Africa receives an annual rainfall which is below 500 mm per annum (Thomas et al., 2011). This is regarded as the minimum for dry land agriculture. Furthermore, about 21.5% of South African regions receive less than 200 mm of annual rainfall (Affairs and Forestry, 1994). This confirms that South Africa is indeed experiencing water shortages due to low rainfall events.

Climate variability in South Africa has impacted significantly on both the availability and requirements for water (Botha et al., 2007). South Africa is currently experiencing rainfall shifts by way of a decrease in early summer rainfall i.e. from October to December and an increase in late summer rainfall (January to March) (Tadross et al., 2005). The majority of the South African population lives in rural areas that are mostly arid or semi-arid and marginal for crop production, except for a small portion that is under irrigation (Baiyegunhi, 2015). Hall (2007) stated that the practice of backyard gardens in rural communities adds up to 200 000 ha of land which doubles the area that requires irrigation. This area is huge enough for the production of food adequate for household food security. However, the major constraint is inadequate and fluctuating water availability, which affects agricultural productivity and profitability. This causes communal farmers to remain at subsistence level and in continuous poverty (Baiyegunhi, 2015). The collection and storage of water for later use has long been practiced in sub-Saharan Africa using indigenous knowledge systems. This practice is termed rainwater harvesting.

2.2 History and origin of rainwater harvesting

Domestic rainwater harvesting (RWH) was basically used on farms, schools and hospitals before improved water supply technologies became available (Suleman et al., 1995). This type of rainwater harvesting was mainly used for drinking as well as domestic use, but not really for agricultural purposes. The origin of rainwater harvesting is not easily traceable due to numerous related techniques that were independently developed in different regions of the world (Kahinda et al., 2007). In southern Jordan and southern Mesopotamia, RWH structures were believed to have been constructed over 9000 years ago and as early as 4500 BC respectively (Oweis and Hachum, 2006). In Ganzu province of China, rainwater wells as well as jars only existed 2000 years ago (GNADLINGER, 2000). About 100 years BC, rainwater harvesting was already a common technique in the Mediterranean and Middle East countries such as Egypt, Palestine, Iran, Iraq as well as in Greece (Smet and Moriarty, 2001). The main motive for rainwater harvesting was mostly for the collection of drinking water.

Other drivers for the origin of agricultural related RWH include population expansion, rural to urban migration and rainfall variability (Bennie and Hensley, 2001). This has been the case for South Africa. As the population begins to increase, the competition for natural resources such as water also increases. This results in a desperate need for the implementation of alternative technologies that will enhance an improved water supply for human consumption (Abu-Awwad and Shatanawi, 1997). Population expansion also led to a greater demand on agriculture in order to ensure food security. Rural to urban migration also contributed to population expansion as many people migrated from the rural to the urban areas thus causing an increased demand for water resources in the urban areas (Gao et al., 2014). Rainfall variability is also another factor that contributed to the origin of rainwater harvesting technologies. Rainfall variability is associated with the following major challenges (Gao et al, 2014):

(a) The poor spatial distribution and seasonality of rainfall that results in total crop failure.
(b) Relatively low stream flows in rivers.
(c) Permanent crop failure in dry-land agriculture.
(d) Drought and extreme soil loss
(e) Reduction of soil fertility

South African government institutions such as the department of agriculture or department of education have responded to a limited rainfall supply by donating water tanks to people for improved water storage (Dilley, 2000). However, there is a need for up scaling and out-scaling of rainwater harvesting techniques. It is not only the soil surface that can be used, but different structures can be used to successfully store water. These include the storage of rainwater from rooftops or courtyards. This form of storing rainwater is common in rural households, and is used for domestic purposes, gardening as well as small-scale agricultural productive activities (Baiyegunhi, 2015). The following section discusses different rainwater harvesting technologies that are available and currently used in different parts of Africa.

2.3 Overview of different rainwater harvesting techniques

Rainwater harvesting can be classified into two categories namely micro and macro catchment depending on the catchment area (Kahinda et al., 2008). In micro-catchment rainwater harvesting, runoff is collected from a small catchment area where sheet flow prevails over a short distance (Deng et al., 2006b). Macro-catchment rainwater harvesting on the other hand is characterized by runoff water collected from large natural catchments such as hills or mountains. Figure 2.1 illustrates the distinction between micro- and macro-catchment rainwater harvesting techniques.

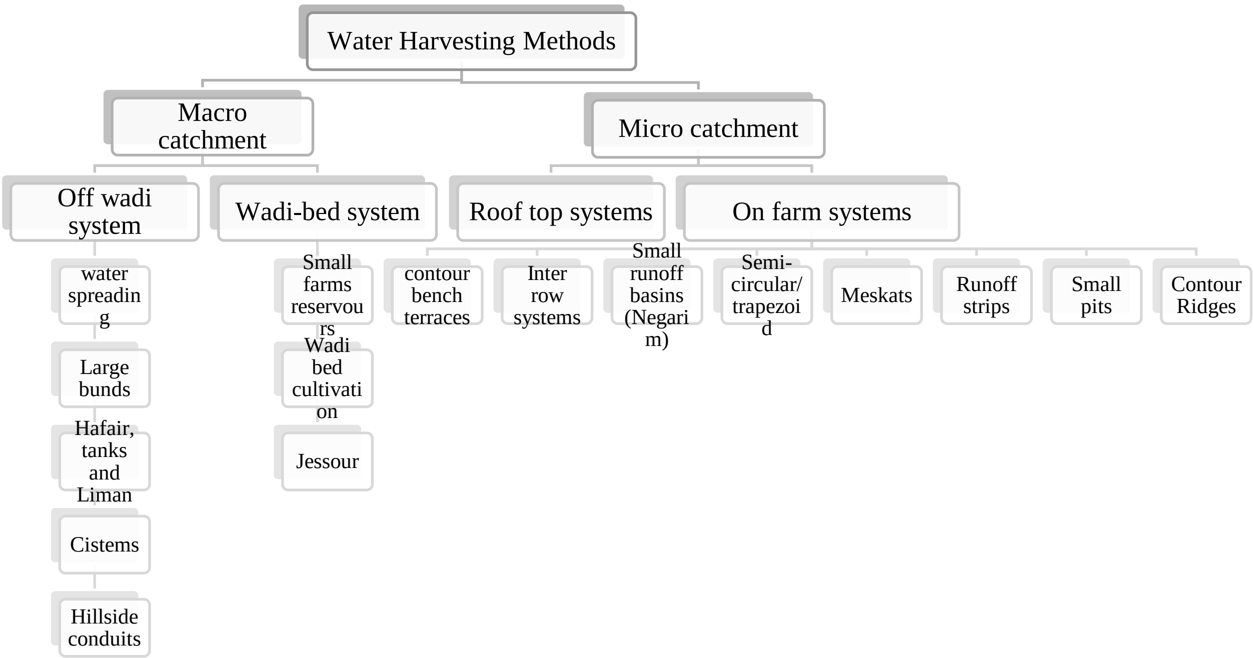

Figure 2.1: Different rainwater harvesting techniques (Oweis and Hachum, 2006)

The following section will discuss some of the techniques illustrated in Figure 2.1 in detail. However, not all the techniques displayed in the Figure will be discussed, only those that are common and have been adopted in South Africa are discussed.

As shown in Figure 2.1, micro catchment rainwater harvesting can further be divided into on-farm and rooftop system. Techniques of rainwater harvesting possible under on-farm are contour ridges, small pits, runoff strips as well as meskat. Under rooftop micro catchment rainwater harvesting, systems like semi-circular/ trapezoidal, small runoff basin, inter row as well as contour bench terraces are considered. Macro catchment and floodwater methods can also be subdivided into wadi-bed systems as well as off-wadi systems. Under wadi-bed, systems like small farm reservoirs, wadi-bed cultivation and jessour can be applied. Techniques like water-spreading, large bunds, hafair, tanks and liman, cisterns as well as hillside conduits can be considered under off-wadi system.

2.3.1 Micro-catchment rainwater harvesting

Micro-catchment rainwater harvesting systems include contour ridges, runoff strips and many others shown in Figure 2.1. These are characterised by having smaller runoff generating areas (Gao et al., 2014). The advantage of this system is its cost efficiency, as it is cheap and easy to implement. In the micro-catchment techniques, the cropped area is usually adjacent to a catchment area, which is located above the cropped area and is clear of vegetation in order to increase the runoff. This results in excess water being available for crop uptake, thereby reducing water stress during extremely dry conditions (Li and Gong, 2002). The micro-catchment system is ideal for crop production under arid and semi- arid regions for subsistence and large-scale farming. Micro-catchment rainwater harvesting is further subdivided into two categories, namely rooftop and courtyard system, and the on-farm system. Rooftop and courtyard rainwater harvesting is referred to as domestic rainwater harvesting (Kahinda et al., 2008). Here, water is collected from roofs of buildings then stored in tanks, jars and/or in underground systems as illustrated in Figure 2.2. These systems are generally used in cities, villages and on farmhouses for small-scale utilization in gardens or for household consumption. On-farm is different from courtyard rainwater harvesting in that in on-farm, runoff is collected in a catchment then used for agricultural purposes.

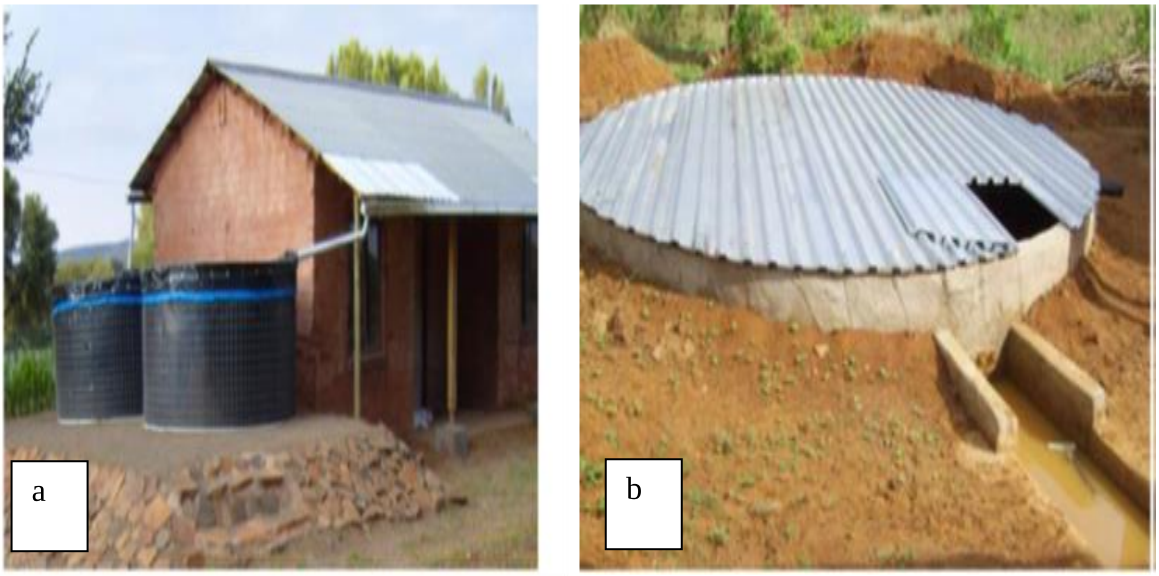

Figure 2.2: Rooftop (a) and courtyard (b) rainwater harvesting (Kahinda et al., 2008)

Table 2.1 gives the guidelines for application of micro-catchment rainwater harvesting. Contour ridges can be used when planting trees, vegetables as well as field crops. However, the soil depth should be above 500 mm while soil texture can be variable. This technique performs best at a slope between 4 and 12 % (Joseph, 2007). Different techniques with their associated crop type as well as suitable soil properties are outlined in Table 2.1.

Table 2.1: Guidelines for the application of some micro water harvesting techniques

Technique	Crop type	Soil Properties		
		Depth (mm)	**Texture (%)**	**Slope (%)**
Contour ridge	Trees, vegetables and veld	>1000 or	Variable	4-12
		500-1000+		
Tied ridging	Various Crops	500-1000+	Variable	1-50
Contour ridging with bunds	Various Crops	500-1000+	Variable	1-50
Shallow trenching	Various Crops	500-1000+	Variable	<4
Deep trenching	Trees, various crops and vegetables	>1000 or	Variable	<4
		500-1000+		
Basin tillage	Various crops and trees	500-1000+	Variable	4-12
Pot-holing	Veld, Trees and various crops	>1000	Variable	4-12
		500-1000+		
Runoff strip	Various crops	500-1000	Variable	2-4
In-field Rain Water Harvesting	Various crops	>700	20-60 % clay	1-7

Source: (Joseph, 2007)

On-farm rainwater harvesting can be further divided into runoff strips, bunds, contour ridges, terraces, planting pits and basins among others.

2.3.1.1 Runoff strips

Runoff strips which are sometimes referred to as vegetative filter strips (VFS) are either plants that are collectively planted downslope of the crop land or animal production facilities (Kahinda and Taigbenu, 2011). Their significance includes localised erosion protection and to filter nutrient sediments, organics, pathogens and pesticides from agricultural runoff before they reach receiving waters. Figure 2.3 shows how the runoff strips are used in the field. Ridges are constructed along the contours where strips are used to support crops in the drier regions. The upstream strip is used as the catchment area while the downstream is used to support crops (Kahinda and Taigbenu, 2011). The advantages of this system is that the surface is permanently covered with vegetation. This will increase the organic carbon content of the soil and reduce soil loss through erosion and surface evaporation. In areas where activities associated with livestock are high, the major pollutants in these areas includes nitrogen, phosphorus and sediments (Kahinda et al., 2007). This system is effective at removing these pollutants in surface runoff. This is achieved through changes in flow hydraulics that enhance the runoff and pollutants to infiltrate into the soil profile. It further enhances the deposition of total suspended solids through filtration of suspended sediments by vegetation and adsorption on soil and plant surfaces. The adsorbed pollutants are then trapped in the soil profile by a combination of physical, chemical and biological processes. The infiltrability status of the soil plays a significant role in this system as it decreases surface runoff, thereby reducing pollutant losses (Kahinda et al., 2010).

Figure 2.3: Runoff or vegetation filter strips (Barling and Moore, 1994)

2.3.1.2 Contour ridges

Contour ridges are among the soil conservation measures that improve mechanical protection of arable land from rill and gully erosion (Hagmann, 1996). Figure 2.4 shows pictures of contour ridges in a field experiment. This system can either be bunds or ridges constructed along a contour line, and separated from each other by a space of 5 to 20 m (Kahinda et al., 2007). This system is suitable for arid and semi-arid regions where the rainfall is not too high to cause extreme runoff and soil loss. An important consideration of this system is to ensure that bunds follow the line of the contour exactly. Failure to do this will result in the generation of runoff along the bund, which can result in its overtopping and breaking at lower points (McCosh et al, 2017). It is therefore required that good precision be ensured during contour construction. Contour ridges/bunds are suitable for slopes of between 4 to 12 % (Li et al., 2008), and they can also be made using stones which are then referred to as stone bunds. The advantage of this system is that contours are built once and there is no need to rebuild them unless they are damaged. It is also suitable for various slopes. The disadvantage is failure to align the ridges with the contour line will result in the system becoming ineffective due to overtopping and breaking of bunds at lower points.

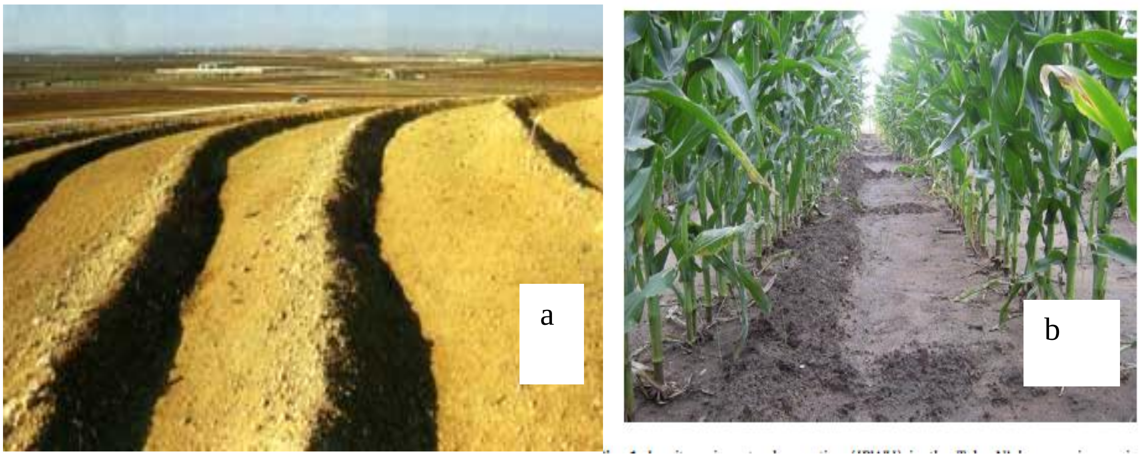

Figure 2.4: Contour ridges (a) and contour bunds (b) (Lema and Majule, 2009).

2.3.1.3 Contour bench terraces

Contour bench terraces is a system that employs level contour benches and ridges to provide erosion control and to retain, spread and infiltrate surface runoff (Mhizha et al., 2009). This system is similar to the contour ridges except that it is generally used on steeper slopes than those for contour ridges (Figure 2.5). It can be used for both soil and water conservation, as the terraces run across the slope to drain and release excess water safely (Li et al., 2000a). This system is well suited for steep slopes as it slows down the velocity of water and its erosive force. It also filters out and traps many of the suspended soil particles, which will ensure that particles are protected from being washed out of the field. Its disadvantage however is that it is only effective on steeper slopes and cannot be used on flat areas.

Figure 2.5: Contour bench terraces (Zingg and Hauser, 1959)

2.3.1.4 Planting pits and basin technique

Still under in-field rainwater harvesting is a technique called zai pits, (Figure 2.6). This is an old way of harvesting rainwater that was used in the past. It involves the digging of small planting pits measuring 20 - 30 cm in width, 10 - 20 cm in depth and are 60 - 80 cm apart (Kaboré and Reij, 2004). The word “zai” refers to small planting pits and was used by farmers in Bukina Faso where this system was first implemented (JIANG and LI, 2013). Zai pits are suitable on land that is infertile, has encrusted soils and receives low highly variable rainfall. Organic materials such as compost and manure can be added into the planting holes instead of spreading them all over the field. Water is also harvested inside the holes making it more available for the plant for a longer period. Thus this system concentrates both fertility and moisture to the rooting system of the crop. As a result, zai pits are suitable for dry fragile lands as a way of managing land degradation, soil infertility and low soil moisture (Kahinda et al., 2007). The disadvantage of this system is that high rainfall amounts could cause water logging of the pits.

Figure 2.6: Zai pits rainwater harvesting technique (Kahinda et al., 2007)

2.3.2 Macro-catchment rainwater harvesting

Macro-catchment or external catchment rainwater harvesting is a system that involves the collection of runoff water from large areas that are at a notable distance from where it is being used (Mupangwa et al., 2006b). This system involves the harvesting of water from catchments of areas ranging from 0.1 to thousands of hectares. These catchment areas can either be located near the cropped area or further distances away (JIANG and LI, 2013). Harvested rain water is usually used on cropped areas that are either terraced or on flat lands (Ren et al., 2008). Structures of diversion and distribution networks are usually used to convey runoff water when the catchment is large and located at a significant distance from cropped areas. In macro catchment rainwater harvesting, the runoff volumes and flow rates are higher than those of micro catchment systems. It is for this reason that macro catchment rainwater harvesting usually has problems associated with managing potentially demanding peak flows, which may lead to serious erosion and sediment deposition. Therefore, it is advisable that substantial channels and runoff control structures must be built. In cases where the macro catchments rainwater harvesting produces high volumes of runoff that cannot be stored in the soil profile; the harvested water is stored in dams or water holes. That is why small dams are normally constructed across rolling topography where creeks can be found.

The adoption of macro-catchment rainwater harvesting is frustrated by biophysical constraints such as the risk associated with the design of the system. This is because it is not easy to time and estimate the amount of runoff that is likely to be received each year. Sometimes the system receives high runoff volumes and flow rates, which results in serious soil losses. In that case substantial channels as well as runoff control structures such as stone bunds should be considered (Mzirai and Tumbo, 2010). The following section will be illustrating examples of macro catchment rainwater harvesting.

2.3.2.1 Hillside sheet or rill runoff utilisation

This system includes natural collection of runoff water from hilltops, sloping grounds, grazing land and/or highland areas to low lying flat areas. Figure 2.7 illustrates hill sheet flow rainwater harvesting (Hatibu and Mahoo, 1999). This system involves the construction of bunds on cropland, which form earth basins that assist in holding water while increasing infiltration into the soil. Earth basins are used to facilitate the distribution of water even if the cultivated area is on flat land (Gowing et al., 1999).

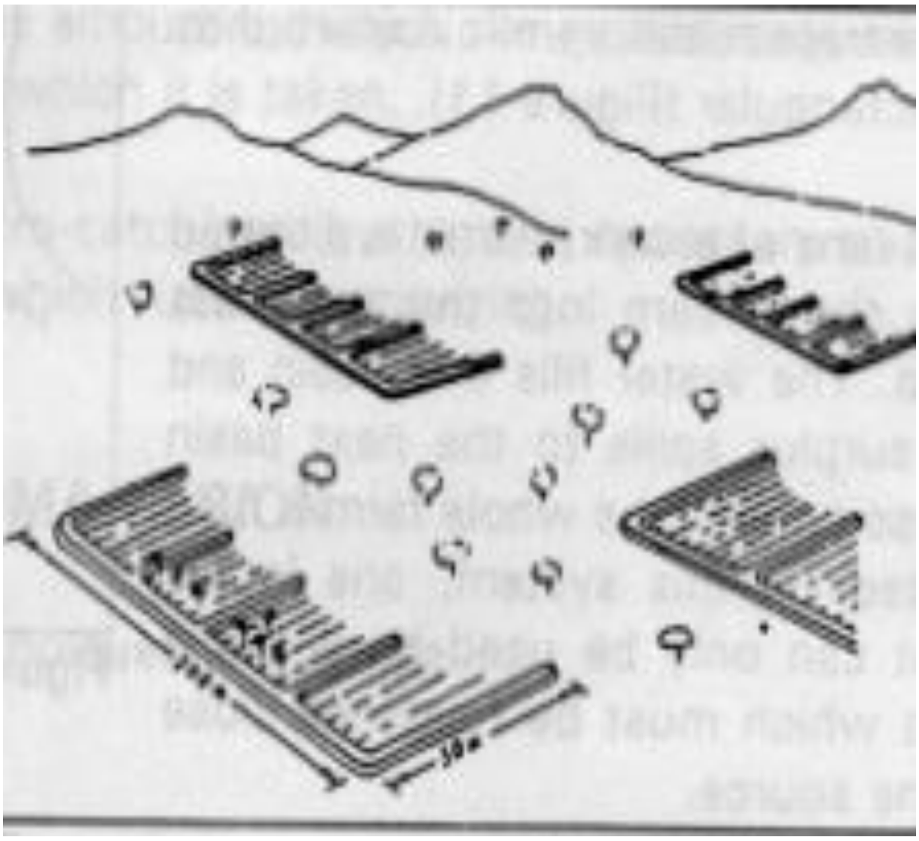

Figure 2.7: Hill sheet flow rainwater harvesting (Kahindra et al, 2007).

2.3.2.2 Floodwater harvesting within the stream bed

This system uses barriers such as permeable stone dams to reduce water flow and spread it on the adjacent plain, thereby enhancing soil infiltration rate. The wetted area is then used for crop production (Kahindra et al., 2011). Advantages of this system include the improvement of land management due to silting up of gullies with fertile deposits. It also increases crop production and erosion control because of harvesting and spreading of floodwater. Groundwater recharge is also enhanced. This system also reduces runoff velocities as well as the erosive potential of water. The major disadvantage of this system is the high labour cost during implementation and requirement for large quantities of stones (Jiang and Li., 2013). It is also suitable for areas receiving high volumes of rainfall only.

2.3.2.3 Ephemeral stream diversion

This system involves diverting water from its natural ephemeral stream and then conveying it to arable cropping areas as illustrated in Figure 2.8 (Kahindra et al., 2007). Li et al (2008a) suggested that two main methods are involved in this system. The first one involves the placing of cultivated fields closer to the ephemeral stream. This field is initially divided into open basins by the aid of structures such as trapezoidal, semi-circular or rectangular bunds (Li et al, 2008a). A weir is then used to divert water from the stream into the top most basin. The water then fills the basin and the surplus spills to the next basin until the whole farm is fully spread with water. The second system involves dividing the field into rectangular basins. Water is then diverted using a weir through a series of channels to the basins. The principle of flood irrigation is used in this system, so it can serve more than one farm which may be located far away from the inlet.

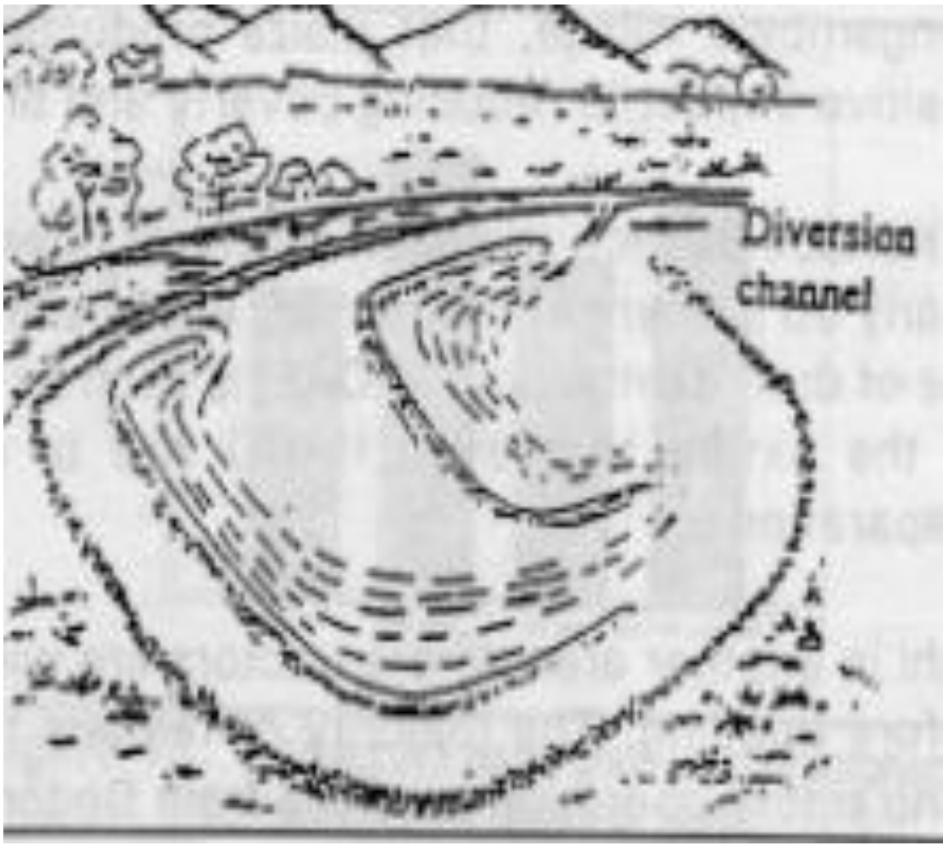

Figure 2.8: Ephemeral stream diversions with distribution canals (Li et al., 2008a)

2.4 Guidelines for selecting site for rainwater harvesting techniques

Biophysical factors such as landscape, slope, amount of rainfall and its distribution, slope type are key factors to consider when choosing a site for rainwater harvesting. Furthermore, social and cultural aspects of the area of concern should be given due consideration (Kahinda et al., 2007). These factors will affect the success or failure of the technique implemented. When these factors are well considered it will then be easy for end users to adopt the technology. A flow chart was developed which is useful when selecting a site for rainwater harvesting (Hatibu et al., 2006). Figure 2.9 shows how to qualify the site for rainwater harvesting. This is based on the slope gradient. Different slope gradients are suitable for different rainwater harvesting technology. The summary of what the Figure represents is described as follows:

The RWH techniques suitable for a land where crop production is being considered, and for slopes less than 8 % but where irrigation is not possible include contour, stone and trapezoidal bunds, as well as contour ridges. This is assuming that all biophysical factors such as soil texture, depth and rainfall are suitable for the implementation of rainwater harvesting. Under the same conditions but considering tree or forestation development, all micro catchment rainwater harvesting techniques can be considered. In the case of rangelands or fodder production under the same biophysical conditions as outlined before, contour bunds and semi-circular trees can be implemented using large scale mechanisation or hand dug on small scale respectively. On the other hand, when the slope is greater than 8 % and when considering crop production, water spreading bunds and permeable rock dams can be implemented.

Indigenous knowledge for selecting suitability of site for rainwater harvesting suggests that the site should have medium to low slope i.e. slopes less than 8 percent (Mbilinyi et al., 2005a). The reason for this is that soils in this type of slope are often deep enough for the implementation of rainwater harvest and hence less susceptible to erosion. However, there are technologies that can be implemented on steeper slopes. Figure 2.9 shows that spreading bunds and permeable rock dams can be considered in areas of steeper slopes. The problem with steeper slopes is that they are associated with high labour intensity, which is costly to subsistence farmers. For rainwater harvesting to be a success, the site must have access to runoff which is a function of its location along a toposequence (Mbilinyi et al., 2005a). This means farmers located downslope stand a good chance to successfully implement rainwater harvesting. In terms of soil properties, soils with high water holding capacity are well suitable for the implementation of rainwater harvesting so as to minimise erosion. Thus, loamy soil textures are the best for rainwater harvesting because of their high water holding capacity which allow better water seepage and percolation. Areas dominated by sandy textures are not suitable for implementation of rainwater harvesting (Mbilinyi et al., 2005a). This is because sandy soils cannot store water for long periods, as they have low infiltration rates and can easily be washed away when runoff is high. This will defeat the purpose of rainwater harvesting.

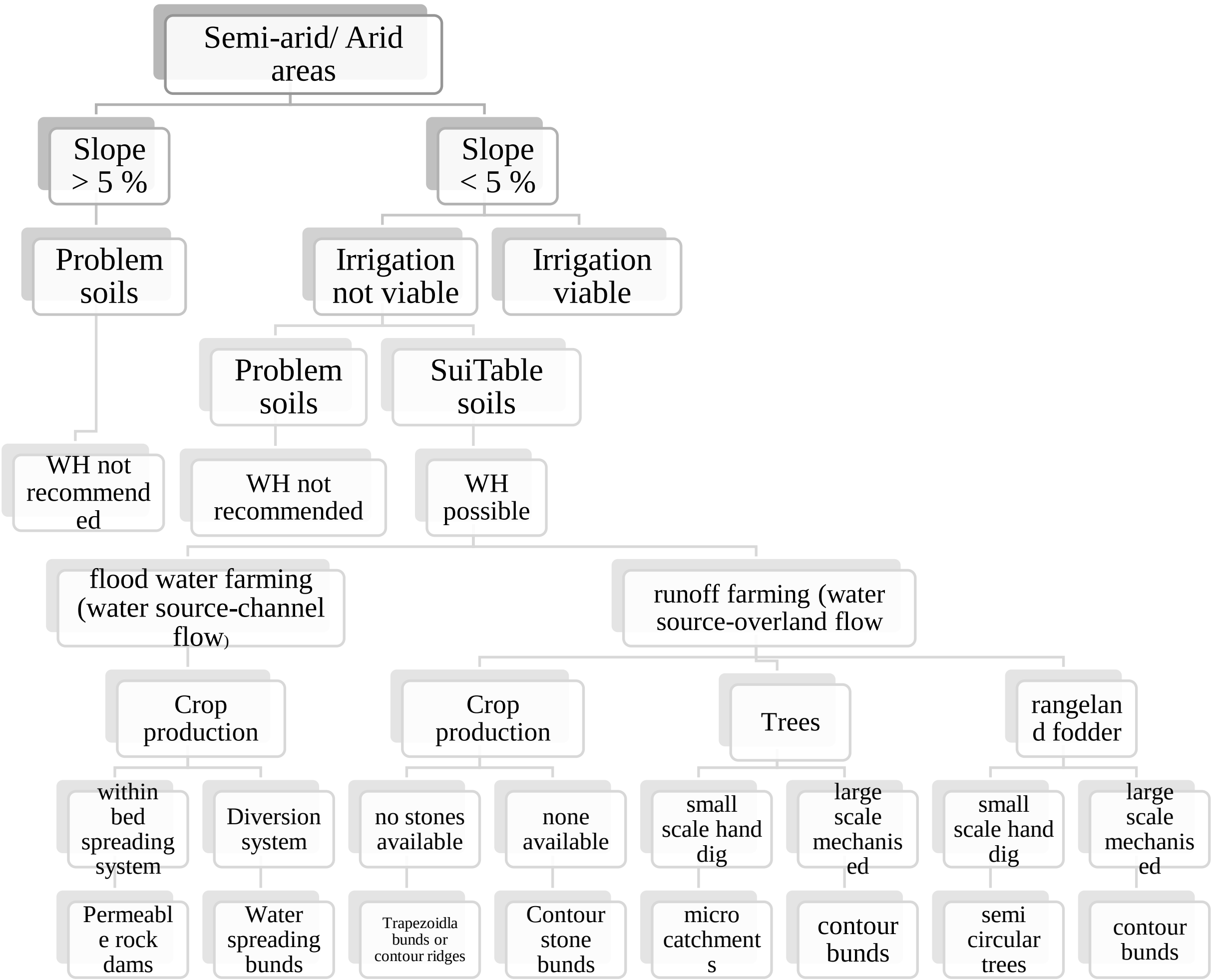

Figure 2.9: Flow chart for the selection of rainwater harvesting technique (Hatibu et al., 2006).

2.5 Challenges and opportunities for rainwater harvesting in South Africa.

South Africa has not yet successfully adopted rainwater harvesting techniques due to the often-prohibitive costs needed to construct RWH storage structures. Rural farmers also do not have the skills required for successful implementation of these technologies. Jiang et al. (2013) suggested that the main challenge to the adoption of rainwater harvesting is the ability to select suitable land that will allow for its implementation. Apart from this, there is also not enough literature on rainwater harvesting that relates its functioning and purpose for agricultural and domestic uses (Ren et al., 2008). Resource constrained farmers cannot afford to pay skilled personnel that will ensure correct implementation of the techniques. Rainwater harvesting also requires high labour input to implement initially and for its maintenance thereafter. Another limitation includes the unavailability of required machinery. Kahindra et al. (2008) stated that socio-economic studies of micro-basin tillage in Free State showed that it was hands on, and demanding high labour input. Since the rural communities do not have the means to pay for external labour, they then fail to implement and sustain rainwater-harvesting techniques.

The other challenge concerning implementation of rainwater harvesting in many countries including South Africa is that it is not included in water policies. Water management is usually based on renewable water, which is surface and groundwater with little consideration for rainwater (Kahindra et al., 2007). This will result in low quantities of water reaching people and ecosystems downstream, which will cause conflicts. The one last challenge for sustainable implementation of rainwater harvesting is the need for institutional support (Xiaolong et al., 2008). Kahindra et al. (2008) alluded to the fact that policy should consider establishing a body that co-ordinates rainwater harvesting. This body will focus on making the technology expand in terms of establishment and also guide how it can be practiced. It can be concluded that there is huge requirement for the government and non-governmental organisations to fund rainwater harvesting research and implementation (Kahindra et al., 2008).

2.6 Effect of rainwater harvesting on selected soil physical properties.

Soil physical properties are important parameters in crop production as they determine the amount of water that will be available for plant uptake (Horneck et al., 2011). These include bulk density, aggregate stability, porosity and hydraulic conductivity among others (Brady and Weil, 2000). Factors such as the addition of organic matter, changing the land use from conventional to minimum or zero tillage directly affects soil physical properties (Horneck et al., 2011). Al-Seekh and Mohammad (2009) studied the effect of stone terraces and contour ridges on soil moisture. They found that soil moisture content was about 45 percent higher in both rainwater harvesting techniques compared with the control. The reason for this was a reduced surface runoff which led to increased infiltration and soil moisture stored in the profile under stone terraces and contour ridges (Al-Seekh and Mohammad, 2009). The increase in soil moisture due to rainwater harvesting was also observed in the study where contour bunds were used as the rainwater harvesting technique in arid areas of Central Australia (Dunkerley, 2002). Botha et al. (2007) conducted another study that supports these findings where soil moisture was improved because of introducing rainwater harvesting, when mulching technology was used to harvest rainwater. They associated the increase in soil moisture content to the fact that mulch cover reduces surface water loss through evaporation during low rainfall events and therefore the water is stored in the soil profile for the used by the plants.

Shreshtha et al. (2007) in their study found that stone terraces and contour bunds decreased soil bulk density and increased aggregate stability since they were also coupled with mulching. The increase in aggregate stability where mulch was added to the soil was associated with the mulching effect, i.e., mulching improves the soil’s resistance to external disruptive forces further enhancing the stability of soil aggregates (Mulumba and Lal, 2008). This will equally decrease the bulk density of the soil. In another study where contour ridges were used as rainwater harvesting, it was found that aggregate stability also increased where contour ridges were used compared to the control (Shrestha et al., 2007). Furthermore, Hummad et al. (2004) conducted a study where stonewalled terracing technique was assessed to see its effect on soil-water conservation and wheat production. They found that aggregate stability as a measure of water stable aggregate (WSA) was 2-2.5 times higher in the stone-walled terracing plot compared with non-stonewalled terracing plot. The improved aggregate stability was considered as an important factor in controlling surface runoff and soil erosion.

2.7 Soil chemical properties and fertility as influenced by rainwater harvesting

Chemical as well as fertility status of the soil is affected by many factors including soil water (Bulluck et al., 2002). This further affects crop performance. Singh et al (2012) evaluated the effect of rainwater harvesting (i.e. contour and box trenches) combined with afforestation on soil properties, tree growth and restoration of degraded hills. They did their initial measurements on soil pH, electric conductivity, organic carbon, ammonium and nitrate-N, extractable phosphorus, soil water dynamics and texture in 2005 then final measurements in 2010. They found an increase in soil pH, organic carbon, electric conductivity, ammonium nitrogen (NH_4^+), nitrate (NO_3-N) and extractable phosphate (PO_4-P) down the slope of their study sites (Singh et al., 2012). This was not attributed to the rainwater harvesting but rather to mass movement of material from the upper to lower slope. This resulted in the accumulation of salts and nutrients transported along with water from upper to lower slope positions (Singh et al., 2012). Yong et al (2006) also observed similar trends of nutrient accumulation from upper slope to lower slope. The greatest increase in SOC was observed in the 10-20 % slope, and this was associated with the effect of rainwater harvesting, as it enabled soil water retention and nutrient mobilization that enhanced vegetation cover as well as turnover of roots and litter (Singh et al., 2012). Another study done in semi-arid China where mulch coupled with no till practice was used as a form of rainwater harvesting suggested an increase in soil organic carbon by 2.7 % compared with the conventional tillage practice where maize crop was planted (Liu et al., 2009). Al-Seekh and Mohammad (2009) also obtained a 5 % increase in soil organic carbon in their study where they studied the effect of harvesting rainwater on runoff, sediments and soil properties. These two studies indicate that the rainwater harvesting technique improves soil organic carbon.

Based on this literature, it can therefore be concluded that the benefits of rainwater harvesting include crop yield increases, improved soil fertility especially when it is mixed with soil conversation techniques such as mulching, minimum and zero tillage, (Blevin et al, 1983). However, another short-term study to assess the impact of stone bench terraces on soil properties and crop response in the Peruvian Andes suggested no effect of this technique on soil fertility (Posthumus and Stroosnijder, 2010). The results from this study showed no significant differences in soil chemical nutrients between rainwater harvesting and control plots. They indicated that a change in soil chemical properties could not be expected since the study was run over short period, i.e. over a period of two growing seasons.

2.8 Crop yields as affected by rainwater harvesting

There are studies that have proven that rainwater harvesting improves crop yields and thus promotes food security to rural farmers. A study by Botha et al (2003) in Taba Nchu area in Free State province of South Africa is one example where in-field rainwater harvesting significantly improved maize and sunflower production in homestead gardens. Their treatments included organic mulch in basins and bare surfaces in runoff area (ObBr), organic mulch in basin and organic mulch on runoff area (ObOr), organic mulch in basin and stone mulch on runoff area (ObSr) and stone mulch in basin and stone mulch in runoff area (SbSr). The rainwater-harvesting treatments above were compared with conventional tillage (CON) practice. They measured seed and biomass yield and the results obtained from their study indicated that ObSr, treatment was 15 % higher than the CON treatment for maize seed yield while ObOr was 5 % higher than the CON for maize biomass yield. The seed yields obtained for sunflower followed the order ObSr > ObOr > ObBr > SbSr > CON. However, no significant difference was observed between treatments for biomass yield for both maize and sunflower crops in their study. An improvement in seed yields under RWH treatments compared to the CON plot was an evidence that rainwater harvesting has the potential to improve crop yields and thus food security. In another study in India, ridge-furrow tillage was tested against conventional tillage in a sub humid area that is prone to drought during the production of sweet sorghum (Wang et al., 2009). They found that ridge furrow over-performed the control plot by 15 percent for both grain and biomass yields.

Another study conducted in the Mediterranean where stone-walled terraces were compared with a non-stonewalled terrace control for wheat production, showed that rainwater harvesting was 43 % higher than the control plot for both grain yield and dry matter yields (Hammad et al., 2004). Similar results where plastic mulch treated with several treatments that aimed at reducing surface evaporation were used during the sorghum production, found improvement in sorghum biomass yield when compared to the control (Wang et al., 2009). Based on these findings, it can be concluded that rainwater harvesting technologies can be considered as an alternative for farmers operating under dry land agriculture in arid and semi-arid regions to improve their crop production and household food security (Li et al., 2000b). In another study done by Posthumus and Stroosnijder (2010), where the short-term impact of bench terraces as rainwater harvesting technique on soil properties and maize yields was studied. They found that though there was no evidence that soil fertility was improved as a result of this technique, water productivity was improved, which resulted in average grain yield being higher where bench terraces was employed compared with the control plot. This study was conducted for only two growing seasons.

2.9 Level of adoption of rainwater harvesting in South Africa

Rainwater harvesting is mostly adopted in areas of high population such as in China where cost of developing surface or groundwater reserves are restricting. It has been hugely adopted in arid and semi-arid regions. However, its adoption is very low in South Africa due to the high cost and skill requirement for this technology. The only rainwater harvesting technique that is common in South Africa is the trapping of rainwater using the rooftop system for domestic use. South African departments such as human settlement have adopted this method by providing households with tanks for rainwater harvesting purposes across all of its nine provinces. About 1 % of South Africa's rural inhabitants are currently using domestic rainwater harvesting as their main water source (Kahindra et al., 2007). The department of agriculture and rural development has also adopted the rooftop and courtyard rainwater harvesting methods in supporting small-scale farmers in rural areas that are facing drought. While the department of education has implemented this technique by providing schools with rainwater harvesting tanks in an effort to curb rainfall variability and water shortage experienced throughout the country.

In-field rainwater harvesting techniques such as contour ridges are mostly implemented at household level in the backyard while the ex-field rainwater harvesting such as contour terracing, percolating tanks etc. is not very common. Eastern Cape is one province that has considered use of contour ridges in their homestead gardens. In Kwa-Zulu Natal, most rural farmers use contour bunds to harvest rainwater in their gardens especially when planting sweet potatoes (Baiyegunhi., 2015). This is due to the high water consumption required by sweet potatoes. Kahindra et al. (2007) stated that the Agricultural Research Council of South Africa initiated a programme of in-field rainwater harvesting in Taba Nchu area for over a decade. The technique has not extended beyond small plots around homestead garden due to the high costs required to scale it out. It can be concluded that the adoption of rainwater harvesting is still uncommon in South Africa, despite its positive impacts on agriculture and homestead food security.

3 CHAPTER THREE: MATERIALS AND METHODS

3.1 Introduction

This chapter outlines the methods and materials used for the study and will provide detailed descriptions of the sites used, experimental layout and design, as well as the soil and plant variables measured. The study was conducted in homestead gardens of Kwa-Zulu Natal (KZN) province under Msinga local municipality and in Eastern Cape Province (EC) under Tsolo local municipality. The KZN sites lie from latitude 28.5608° S to 29.0549°S and from longitude 30.4358°E to 30.6085°E. While Eastern Cape sites lie between latitude 31.3194°S to 31.0638°S and longitude 28.7548°E to 28.3345°E. The study was set up as five on-farm field trials namely Madosini, Beya, Mjali, Quvile and Sokhombe in Tsolo, and three field trials in Msinga (Mntungane, Xoshimpi and Mxheleni). Initially, five homestead gardens were selected in both provinces to participate in this project. However, two homesteads in KZN withdrew and were eliminated due to farmers' inability to cope with research expectations.

3.2 Site Description

3.2.1 Msinga research area in KwaZulu-Natal Province

Msinga is one of the four local municipalities constituting Umzinyathi district (Figure 3.1). The agricultural production potential in uMsinga is largely affected by poor soil fertility and unfavourable climate (Baiyegunhi, 2015). The mean annual precipitation for uMsinga ranges from 300 to 500 mm while the mean annual minimum and maximum temperatures are 11.7^{o}C and 26.7^{o}C respectively. There is rampant land degradation due to soil erosion caused by overgrazing (Camp, 1997). The limited rainfall also causes soil to be dry and become susceptible to de-flocculation due to animal hooves. This results in high soil losses through wind or water erosion.

These conditions often fail to support rain-fed agriculture, resulting in persistent crop failures and subsequent food shortages since the area is semi-arid. The altitude ranges from 641 to 800 m above sea level. While the slope ranges from 5- 15 %. However, the dominant terrain unit is valley with a slope of less than 5 percent (Camp, 1999). There are also several hills and mountains dominated by bushveld and mixed thornveld (Camp, 1997). These are characterised by acacia species such as *Acacia karoo, Acacia nilotica, Acacia tortilis* as well as other species like *Brocia albitrunca, Schotia brachypetala.* The bio-resource unit (BRU) for Msinga trial sites are Sb2 and Tb6. This coding is based on the rainfall, altitude as well as the vegetation type of that area. Thus, in Sb2, S represents rainfall of between 601-650 mm, b is an altitude of 641 to 800 mm and the number 2 represents dry coast forest, thorn and palm veld vegetation type. The T in Tb6 represents rainfall of 300 to 500 mm, b is altitude of 451 to 900 m while number 6 shows that this is the sixth occurrence of the TB code (Camp, 1999).

Igneous rocks such as dolerite and granite characterize the geology of the area. The dominant parent material within the study area is dolerite and shales (Hardy and Camp, 1999). These give rise to soil forms such as shortlands and glenrosa (Soil Classification working group, 1991). The soils are dark brown (7.5 YR 4/4) in appearance at the surface and yellowish red (5 YR 4/6) at depth. They are shallow, duplex with moderate to poor drainage that presents erosion hazard if not managed properly (Camp, 1997). Three experimental sites were selected namely Xoshimpi, Mtungani and Mxheleni which all fall under Msinga municipality of Umzinyathi district. Xoshimpi and Mntungane are both located in the same village and Mxheleni site is about 5 km north-west of Xoshimpi and Mntungane sites. Figure 3.1 below represents the location of study sites in KZN.

3.2.2 Tsolo research area in Eastern Cape Province

In the Eastern Cape, the study was conducted in Tsolo local municipality. The study location is presented in Figure 3.1 below. This area is located between Qumbu and uMtata towns (Hammond-Tooke, 1968). The five homestead gardens selected were Madosin, Beya, Mjali, Quvile and Sokhombela. Tsolo has annual precipitation ranging from 600 to 700 mm and mean annual temperature of 16°C (Hammond-Tooke, 1968). The natural vegetation is tall grassveld and trees such as *Acacia tortilis*, *Brocia albitrunca and Schotia brachypetala* (Hammond-Tooke, 1968), with soils being generally deep and well drain Shortlands. The dominant parent material is dolerite (Group, 1991).

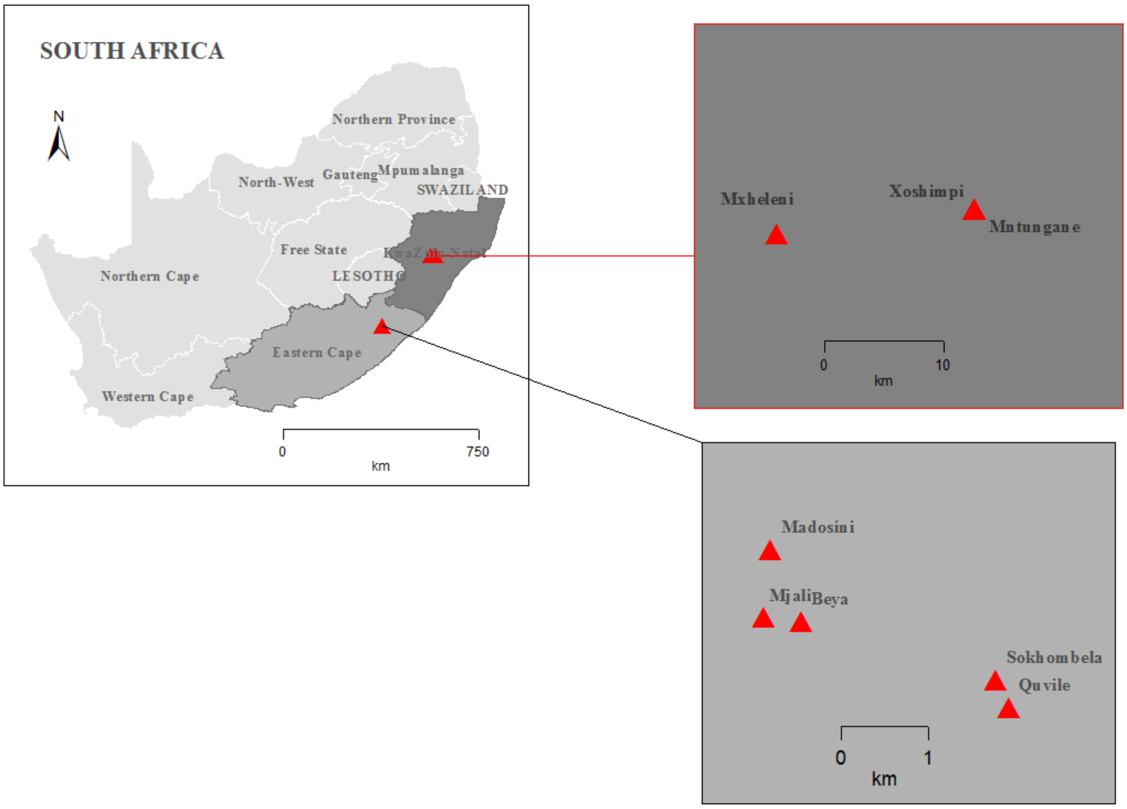

Figure 3.1: Map showing location of study sites in KZN and Eastern Cape provinces.

3.3 Experimental Design

The study was designed as randomised complete block design, that compared two treatments i.e. rainwater harvesting (RWH, using contour bunds) with the traditional farmer practice (control) over two seasons (2013/14 and 2014/2015) in the two study areas (KZN and EC). Three contour bunds in the RWH were randomly selected for sampling during the study period and were considered as replicates of each other for statistical analysis. In the control treatment which was adjacent to the RWH treatment, three 5 x 5 metres were selected for soil sampling and crop harvesting. These plots in the control treatment were considered as replicates of each other. A detailed treatment factors are discussed in the subsequent sections.

The plot size for all study sites in KZN was maintained at 0.4 ha. A rainwater harvesting (RWH) treatment plot comprising of contour bunds and ridges was set up at each site and this was compared with an adjacent control plot. The control treatment was where the farmers were allowed to practice their own preferable method of farming which in this study all farmers preferred broadcasting of seeds in the control plot both in KZN and in EC. Contour ridges were used as the RWH technique at Xoshimpi and Mntungane sites, while stone bunds were used at Mxheleni. A detailed explanation of how contours were developed is outlined in section 3.3.1 below. Figure 3.2 shows the field layout at Mntungane site where contour ridges were developed. There were five selected homestead gardens in Eastern Cape where research was done namely Quvile (0.30 ha), Sokhombela (0.31 ha), Mjali (0.30 ha), Beya (0.32 ha) and Madosini (0.30 ha).

Figure 3.2: Field layout showing animal traction at Mntungane site in KZN

3.3.1 Development of Contours on research sites

Contour ridges were developed using a dumpy level. Three main contours were developed as a guide for the establishment of the other remaining contours guided by a catchment to storage ratio of 2: 1 across all the research sites. The catchment refers to an area between two contours ridges while the storage (sometimes referred to as basin) is the area below each contour ridge where water collects and is stored. This means that the spacing between contour ridges was 2 m and the length of the contour was kept at 1 m. In the RWH treatment, the planting rows followed the contour while in the control they were broadcast randomly over the whole field. Animal traction was used to develop the contours across all KZN sites (Figure 3.2). The contour design was the same in both KZN and Eastern Cape sites. The Mxheleni site used both stone and contour bunds. For all the KZN and Eastern Cape sites, the control and RWH plot lay adjacent to each other on one field site.

3.3 Crop Planting

In the RWH treatment, maize was planted on each side of the contour ridge at inter and intra-row spacing of 1 x 0.22 m, giving a plant population of 30 000 plants per hectare. The open pollinated yellow maize variety SC 506 was used in all plots at a seed application rate of 30 000 seeds ha^{-1} under RWH. Lime ammonium nitrate (LAN) and Mono-ammonium phosphate (MAP) were applied at planting. Thus the fertilizer recommendations for KZN suggested that

LAN should be applied at 140 kg.ha^{-1} across all sites. However, MAP was applied at a rate of 60, 50 and 45 kg.ha^{-1} at Xoshimpi, Mntungane and Mxheleni sites respectively in KZN. The Eastern Cape sites on the other hand had a uniform application for both LAN and MAP of 140 kg.ha^{-1} and 20 kg.ha^{-1} respectively. Farmers were requested to assist with weeding without the use of any herbicides during the course of the study.

3.4 Field data collection and laboratory analysis

3.4.1 Soil sampling and preparation for initial and final site characterisation

Soil samples were taken prior to planting to characterize soil chemical and physical properties of the study sites in 2013. They were collected from three selected contour bunds in the RWH treatments and in three 5 x 5 meter plots in the control treatment. Samples were taken at 0 - 10, 10 - 20 and 20 - 30 cm depths using a bucket auger. Collected samples were transported to the milling room in well-labelled plastic bags where they were air-dried and ground with pestle and mortar to pass through a 2 mm sieve for the analyses of pH, electric conductivity, exchangeable bases, micronutrients and particle size distribution. Aggregate stability and bulk density samples were collected separately. Aggregate stability samples were taken as clods using the spade to avoid shearing effect of a soil auger; while bulk density samples were taken using stainless steel core cylinders. Bulk density samples were taken at 0-10 cm depth only while aggregate stability samples were collected at 0-10, 10-20 and 20-30 cm depth intervals. Particle size was only analysed during initial site characterisation to determine the soil texture.

Another set of samples were collected at harvest in 2015 for a second analysis of chemical and physical properties. This was done in order to see if there were any changes in soil physico-chemical properties from those measured during initial site characterisation in 2013. There was periodic monitoring of gravimetric soil moisture content at different stages of maize growth throughout the course of the 2014/15 growing season as outlined in section 3.4.2 below.

3.4.2 Soil moisture determination at different stages of maize growth

Soil moisture content was periodically monitored at different stages of maize growth (i.e. planting, establishment, vegetative growth, tasselling and harvest) to determine if rainwater harvesting was effective at improving soil moisture; at sampling depths of 0-10, 10-20, 20-30, 30-60 cm or until the limiting horizon was encountered. KZN sites had shallow soils so they were sampled up to 60 cm depth, while Eastern Cape sites had deeper soil and were sampled up to 120 cm depth. In the RWH plots, samples were also collected from different contour positions, which were runoff collecting area, below and above ridge as illustrated in Figure 3.3.

Due to high volume of samples for the monitoring of soil moisture content, study sites were considered as replicates of each other during statistical analysis.

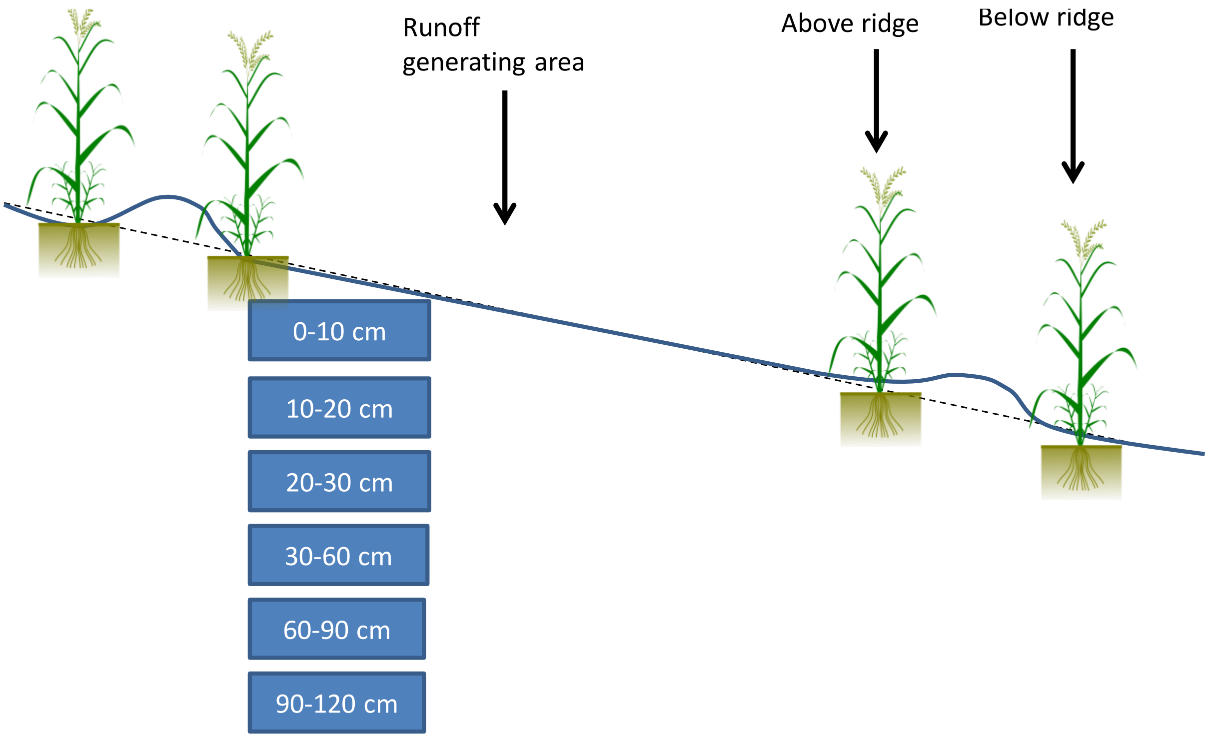

Figure 3.3: Sampling for gravimetric soil moisture at different contour positions

3.5 Soil laboratory analyses

3.5.1 Particle size distribution

Particle-size analysis was done using the sieve and double pipette method (Gee and Bauder, 1986). Soil (20 g) was weighed for each sample in a 100 mL beaker then 50 mL of calgon solution (35.7g of sodium hexametaphosphate and 7.9 g of sodium carbonate made up to 1L with deionised water) was added, and the mixture treated for 3 minutes with ultrasonic probe at maximum output. The probe tip was immersed about 13 mm into the liquid but not too close to the bottom of the beaker to avoid breakage. Dispersed samples were washed through a 0.053 mm sieve into a 1 L measuring cylinder with distilled water, then topped to the mark. The soil fraction coarser than 0.053 mm (sand fraction) was transferred into a 250 mL beaker then dried in an oven at 105 ^{o}C overnight, after which it was transferred to a nest of sieves arranged in apertures of 0.500 mm, 0.250 mm, 0.106 mm and pan, then shaken for 5 minutes. The mass of each empty sieve was recorded accurately and then again recorded with the sand fraction. The clay and silt fraction were analyzed in the sedimentation column. Different settling times were used guided by the temperature of sedimentation. After the appropriate settling time, fine silt was sampled at 100 mm and clay was sampled at 75 mm below the surface. After plunging the sedimentation column, 20 ml of the soil suspension was pipetted using a double pipette into a pre-weighed 50 mL beaker and placed in an oven at 105 ^{o}C overnight. The following day, beakers were removed from the oven, allowed to cool in a desiccator and re-weighed. Proportions of sand, silt and clay were calculated and expressed as percentages of the total then used to determine soil textural class using the textural triangle.

3.5.2 Aggregate stability

The Emerson's stability test was used for analyzing aggregate stability through mean weight diameter. Clods were sampled using a spade at 0-10, 10-20 and 20-30 cm depth only. The clods were then air dried at atmospheric temperature. Clods (3 to 5 mm in size) were oven-dried at 40 ^{o}C for 24 hours, in order to prevent contrasts in humidity and to make the sample conditions uniform (Bissonnais, 1996). These were then weighed, with initial weight in the range of 5-10 g. Deionized water (50 ml) was poured into a 100 ml beaker and the aggregates were placed inside. Slaking was observed visually for 10 minutes and then excess water from the beaker was removed using a pipette. Aggregates were then transferred into a 50 µm sieve which was immersed in ethanol. Soil fraction greater than 50 µm was passed through a set of 6 sieves with apertures of 2000, 1000, 500, 200, 50 µm and pan. The weight of the fraction smaller than 50 µm was inferred by difference with initial weight (Amezketa, 1999). Mean weight diameter (MWD) was then calculated in mm units (Haynes and Francis, 1993). Calculation of MWD was based on a formula derived from Henin et al., (1958) and improved by Haynes (1993).

$$\text{MWD} = \sum(d * w)$$

d – Mean diameter between size fractions

w – Proportion by weight of size fraction

3.5.3 Bulk Density

Soil sampling for bulk density was only done at 0-10 cm depth and was determined using the core method as described by Blakes (1965). The soil core was oven dried at 105^{o}C until a constant weight was reached. The height and diameter of the cores used was measured, and the mass of the soil core after oven drying was recorded. The volume of the core was given by the formula $V=\pi r^2 h$ where r is the radius and h is the height of the soil core. Bulk density was then computed as follows:

$$\frac{Ms\ (kg)}{V(cm3)}$$

Ms - mass of the soil core after oven drying

V – volume of soil core

3.5.4 Soil pH, micronutrients and exchangeable bases

Soil pH was measured at 1: 5 (soil: solution) ratio and the suspension was stirred for two minutes and left to stand for an hour before measuring pH using the pH 210 standard pH meter. Micronutrients (copper, manganese, iron and zinc) were extracted using 1 % EDTA by weighing 5 grams of soil samples into centrifuge tubes, then adding 50 ml of 1 % EDTA. The mixture was shaken for an hour before it was filtered through Whatman no. 5 filter paper. The filtrate was analysed with an inductively coupled plasma optical emission spectrometer i.e. ICP-OES 720 Varian describe by the non-affiliated soil analysis work committee (Committee, 1990). The basic cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+) were extracted using ammonium acetate (NH_4OAc). Samples were placed in centrifuge tubes and 50 ml of 1M NH_4OAc solution was added. The mixture was shaken on a reciprocal shaker at 180 oscillations per minute for 30 minutes. The suspension was filtered through Whatman no. 5 filter paper before analysing using a Varian (AA280FS) atomic absorption spectrophotometer (Thomas, 1982).

3.5.5 Gravimetric soil moisture determination

Soil moisture was determined by weighing about 10g of soil of each sample before and after oven dried to constant mass at 105° C, then calculated using the formula below:

$$\frac{Mass\ of\ wet\ soil(g) - Mass\ of\ dry\ soil(g)}{Mass\ of\ dry\ soil(g)}$$

3.6 Plant yield

Three 5 x 5 m plots were harvested in June, six months after planting. This was done under both control and RWH treatments. Maize was harvested 1 cm above the ground. Maize cobs were separated from the stalk. The maize stalk was then oven dried at 60 ^{o}C until constant weight and weighed for dry matter yield. Maize cobs were air dried until constant weight for the determination of grain yield.

3.7 Statistical Analysis

Measured soil and crop variables were subjected to an analysis of variance (ANOVA) test using Genstat 17th edition (VSN International, UK). Treatment means were separated using the least significant difference (LSD) at 5% probability level.

4 CHAPTER FOUR: RESULTS

4.1 Introduction

This chapter presents results that were collected during the course of the study. It begins with site characterization which details soil forms and the initial soil physico-chemical properties of the study sites. This is followed by results from the physical and chemical analyses of the soils at the research sites taken during the course of the study to determine whether rainwater harvesting had an impact on soil properties. The results also include seasonal soil moisture results taken at different stages of maize growth (before planting, at establishment, vegetative growth, tasseling and harvesting), as well as at different positions of the contour (runoff generation area, below and above ridge) in comparison with the control plots. Moisture results for the KZN sites at harvesting stage could not be obtained due to complete crop failure because of drought. At the Eastern Cape sites, soil moisture results at tasselling were inconsistent so they were excluded from the seasonal moisture trends. This resulted in both the KZN and Eastern Cape sites having gravimetric moisture monitored for only four stages of growth. Finally, the chapter presents results on maize dry matter and grain yields. Due to the complete crop failure at the KZN research sites in both seasons, data on crop yields was not determined.

4.2 Site descriptions

4.2.1 KZN site descriptions

The KZN sites had shallow soils with an effective rooting depth of less than 30 cm (Table 4.1). The dominant soil forms at Mntungane and Xoshimpi sites were Shortlands. The Clovelly soil form was also found at Xoshimpi though it was not as abundant as Shortlands. Mxheleni was however dominated by the Swartland soil form. All sites were basically shallow with Xoshimpi and Mxheleni sites having a total soil depth of 80 cm, while Mntungane had a total depth of 75 cm. All KZN sites had clay loam textures with medium slope classes (5-15%).

Table 4.1: Dominant soil forms and their characteristics for KZN sites

Sites	Soil Forms	% Clay	% Silt	% Sand	Soil Texture Class	Total Soil Depth (cm)	Effective rooting depth (cm)	Slope Class
Xoshimpi	Shortlands and Clovelly	29	30	41	Clay Loam	80	20	Medium
Mntungane	Shortlands	27	38	45	Clay Loam	75	25	Medium
Mxheleni	Swartland	25	32	48	Loam	80	20	Medium

4.2.2 Eastern Cape site descriptions

In the Eastern Cape, soils were deep at all the sites with total soil depths greater than 120 cm and effective rooting depth ranges of 45-60 cm (Table 4.2). Shortlands soil form was dominant at Beya, Quvile and Sokhombela sites; while Mjali had Hutton and Madosini had Dundee soil form. Three of the sites (Mjali, Sokhombela and Quvile) fell under medium slope, while Beya and Madosini had gentle slopes. Beya, Mjali and Quvile had clay loam textures while Madosini and Sokhombela sites had sandy clay loams.

Table 4.2: Dominant soil forms and their characteristics for Eastern Cape sites

Sites	Soil Forms	%Clay	%Silt	%Sand	Soil Texture Class	Soil Depth (cm)	Effective rooting depth (cm)	Slope Class
Madosini	Dundee	23	27	50	Sandy Clay Loam	120	45	Gentle
Beya	Shortlands	21	39	40	Loam	120	60	Gentle
Mjali	Hutton	36	19	45	Clay Loam	120	55	Medium
Quvile	Shortlands	36	21	43	Clay Loam	120	60	Medium
Sokhombela	Shortlands	29	27	44	Sandy Clay Loam	120	45	Medium

4.3 Comparison of soil physical properties before planting (2013) and at harvest (2015) at the research sites

4.3.1 Physical soil properties at KZN sites

4.3.1.1 Aggregate stability in KZN sites before planting (2013) and at harvest (2015)

Table 4.3 shows aggregate stability presented as mean weight diameter (MWD) of aggregates. It varied across sites ($p < 0.001$) in both seasons ($p = 0.029$) and with rainwater harvesting ($p < 0.001$; appendix A). In 2013, MWD followed the order Xoshimpi = Mntungane > Mxheleni at all depths in the control, while in the RWH treatment it was Mntungane = Mxheleni > Xoshimpi across all depths. The control plots had higher MWD than the RWH treatments at Mntungane and Xoshimpi across all depths, while no significant differences were observed between the control and RWH treatment at Mxheleni.

In the 2015, there were no significant differences in MWD recorded in the control plots across all depths at Mntungane and Xoshimpi, while RWH had higher MWD than the control at

Mxheleni (Table 4.3). The RWH treatment thus followed the order Mxheleni > Mntungane = Xoshimpi in MWD across all depths. A closer look at the seasonal trends suggest that RWH improved MWD across all sites (especially at Mxheleni) in 2015 compared to 2013 ($p = 0.029$). The control only recorded better MWD in 2015 than 2013 at Mxheleni, while it remained unchanged at the other two sites.

Table 4.3: Aggregate stability before planting (2013) and at harvest (2015) for KZN sites

Sites	Treatments	Soil Depth (cm)	MWD 2013 (mm)	MWD 2015 (mm)
Mtungane	**Control**	**0-10**	2.4^{c}	2.3^{ab}
		10-20	2.1^{cb}	2.4^{ba}
		20-30	2.1^{cb}	2.3^{ab}
	RWH	**0-10**	1.9^{b}	2.5^{ba}
		10-20	1.8^{ba}	2.4^{ba}
		20-30	1.7^{ba}	2.2^{ab}
Mxheleni	**Control**	**0-10**	1.9^{b}	2.7^{b}
		10-20	1.4^{a}	2.5^{ba}
		20-30	1.6^{ab}	2.5^{ba}
	RWH	**0-10**	1.9^{b}	4.1^{c}
		10-20	1.7^{ba}	4.2^{c}
		20-30	1.5^{ab}	4.0^{c}
Xoshimpi	**Control**	**0-10**	2.5^{c}	2.2^{ab}
		10-20	2.5^{c}	2.1^{ab}
		20-30	2.4^{c}	2.0^{a}
	RWH	**0-10**	1.5^{ab}	2.2^{ab}
		10-20	1.4^{a}	2.2^{ab}
		20-30	1.4^{a}	2.1^{ab}
$LSD_{p<0.05}$ Site*Treatment* Depth			**0.5**	**0.7**

MWD – Mean weight diameter in mm,

Means with the same letterscript are not significantly different, those with different letterscripts are statistically different for each season.

4.3.1.2 Bulk density in KZN sites before planting (2013) and at harvest (2015)

Bulk density values for KZN sites were only taken at 0-10 cm depth (Table 4.4). Mntungane had the highest bulk density compared to the other two sites in 2013, while Xoshimpi had highest and Mxheleni lowest density values in 2015 (p = 0.037; Appendix B). There were no significant differences in bulk density between the RWH treatment and control across most sites in each season. Seasonal variations showed bulk density to be generally higher in 2015 compared to 2013 (p = 0.003; Appendix B).

Table 4.4: Bulk density before planting (2013) and at harvest (2015) for KZN sites.

Sites	Treatments	Bulk Density 2013 (g cm^{-3})	Bulk Density 2015 (g cm^{-3})
Mtungane	Control	1,19^{b}	1,38^{b}
	RWH	1,18^{b}	1,21^{ab}
Mxheleni	Control	0,73^{a}	1,12^{a}
	RWH	1,13^{b}	1,04^{a}
Xoshimpi	Control	0,99^{ba}	1,62^{b}
	RWH	0,74^{a}	1,63^{b}
LSD$_{p<0.05}$ Site*Treatment		**0,32**	**0,34**

Means with the same letterscript are not significantly different, those with different letterscripts are statistically different for each season.

4.3.2 Physical properties at Eastern Cape sites

4.3.2.1 Aggregate stability in EC sites before planting (2013) and at harvest (2015)

Table 4.5 shows the variation of aggregate stability for Eastern Cape sites before planting (2013) and at harvest (2015). MWD varied across sites ($p<0.001$; Appendix C) in both seasons ($p<0.001$; Appendix C). Quvile and Sokhombela sites had the highest while Beya and Mjali had moderate and Madosini the lowest MWD in both the control and RWH plots across all depths and seasons. There were no significant differences in MWD between RWH treatment and control at Beya, Madosini, Mjali and Sokombela in 2013, while RWH had higher MWD than the control at Quvile. The RWH treatment recorded higher MWD than the control plots at all sites in 2015 however ($p < 0.01$; appendix C). Soil depth did not have a significant effect on MWD across all treatments. Seasonal observations were that the MWD was higher in 2015 than 2013 in the RWH plots at most sites.

Table 4.5: Aggregate stability before planting (2013) and at harvest (2015) for Eastern Cape sites

Sites	**Treatments**	**Soil Depth (cm)**	**MWD 2013 (mm)**	**MWD 2015 (mm)**
Beya	**Control**	**0-10**	2.4^{c}	2.5^{cb}
		10-20	2.1^{bc}	2.2^{bc}
		20-30	2.1^{bc}	2.1^{b}
	RWH	**0-10**	2.5^{c}	3.7^{ed}
		10-20	2.4^{c}	3.6^{ed}
		20-30	2.2^{cb}	3.6^{ed}
Madosini	**Control**	**0-10**	1.9^{b}	1.7^{a}
		10-20	1.4^{a}	1.6^{a}
		20-30	1.6^{ab}	1.6^{a}
	RWH	**0-10**	1.9^{b}	2.7^{c}
		10-20	1.7^{ba}	2.6^{c}
		20-30	1.5^{a}	2.5^{cb}
Mjali	**Control**	**0-10**	2.5^{c}	2.5^{cb}
		10-20	2.5^{c}	2.4^{cb}
		20-30	2.4^{c}	2.4^{cb}
	RWH	**0-10**	2.5^{c}	3.8^{e}
		10-20	2.4^{c}	3.7^{ed}
		20-30	2.4^{c}	3.3^{d}
Quvile	**Control**	**0-10**	3.7^{d}	3.0^{dc}
		10-20	3.7^{d}	3.0^{dc}
		20-30	3.6^{d}	2.9^{cd}
	RWH	**0-10**	4.4^{e}	4.5^{f}
		10-20	4.4^{e}	4.4^{f}
		20-30	4.2^{e}	4.4^{f}
Sokhombela	**Control**	**0-10**	3.5^{d}	3.4^{de}
		10-20	3.5^{d}	3.4^{de}
		20-30	3.5^{d}	3.4^{de}
	RWH	**0-10**	3.5^{d}	5.3^{g}
		10-20	3.4^{d}	5.3^{g}
		20-30	3.5^{d}	5.3^{g}
LSD$_{p<0.05}$ Site*Treatment* Depth			**0,49**	**0,46**

Means with the same letterscript are not significantly different, those with different letterscripts are statistically different for each season.

4.3.2.2 Bulk Density in EC sites before planting (2013) and at harvest (2015)

Bulk density was not affected by the site, water harvesting or depth but only differed across seasons (p = 0.002; appendix D) in EC (Table 4.6). In 2013 RWH increased bulk density at Beya, while in 2015 the control had higher density values that RWH at Madosini and Sokhombela. RWH improved bulk density at Sokhombela, Beya, Mjali and Quvile since they recorded lower density values in 2015 than 2013, while Madosini, Beya and Sokhombela had higher density values in 2015 than 2013 in the control.

Table 4.6: Bulk density before planting (2013) and at harvest (2015) for Eastern Cape

Sites	Treatments	Bulk Density 2013 (g cm^{-3})	Bulk Density 2015 (g cm^{-3})
Madosini	**Control**	$1,4^{ab}$	$1,8^{c}$
	RWH	$1,4^{ab}$	$1,5^{b}$
Beya	**Control**	$1,2^{a}$	$1,4^{ba}$
	RWH	$1,9^{b}$	$1,4^{ba}$
Mjali	**Control**	$1,8^{b}$	$1,5^{bc}$
	RWH	$1,6^{b}$	$1,5^{bc}$
Quvile	**Control**	$1,2^{a}$	$1,3^{ba}$
	RWH	$1,5^{ba}$	$1,3^{ab}$
Sokhombela	**Control**	$1,4^{ba}$	$2,6^{d}$
	RWH	$1,4^{ba}$	$1,1^{a}$
$LSD_{p<0.05}$ Site*Treatment		**0,42**	**0,32**

Means with the same letterscript are not significantly different; those with different letterscripts are statistically

4.4 Comparison of soil chemical properties before planting (2013) and at harvest (2015) at the research sites.

4.4.1 Chemical properties at KZN sites

4.4.1.1 Soil pH

Table 4.7 shows soil pH in water for KZN sites before planting (2013) and at harvest (2015). Soil pH differed across sites ($p = 0.021$; Appendix E) in both seasons ($p < 0.001$; Appendix E). However, the soil depth and water harvesting did not have a significant effect on pH. In 2013 no significant differences in pH were recorded across sites, depths or RWH treatment. In 2015 however, Xoshimpi site had the lowest pH in the control plots across depths, with the control having significantly lower pH than the RWH at this site. A comparison of seasons showed pH to be generally higher in 2015 than 2013 across treatments.

Table 4.7: Soil pH before planting (2013) and at harvest (2015) for KZN sites

Sites	Treatments	Soil Depth (cm)	pH (water) 2013	pH (Water) 2015
Xoshimpi	**Control**	**0-10**	6^{a}	6.8^{b}
		10-20	6.3^{ab}	6.1^{a}
		20-30	6.4^{ba}	6.2^{a}
	RWH	**0-10**	6.7^{b}	7.7^{c}
		10-20	6.4^{ab}	7.3^{c}
		20-30	6.4^{ab}	7.2^{cb}
Mntungane	**Control**	**0-10**	6.3^{ab}	6.9^{b}
		10-20	6.5^{ba}	7.8^{c}
		20-30	6.2^{ab}	6.5^{ba}
	RWH	**0-10**	7^{b}	7.5^{c}
		10-20	6.7^{b}	6.5^{ba}
		20-30	7.1^{b}	7.1^{cb}
Mxheleni	**Control**	**0-10**	6.4^{ba}	7.5^{c}
		10-20	6.3^{ab}	7.5^{c}
		20-30	6.6^{ba}	6.7^{b}
	RWH	**0-10**	6.7^{b}	7.7^{c}
		10-20	6.5^{ba}	7.6^{c}
		20-30	6.2^{ab}	6.5^{ba}
LSD$_{p<0.05}$ Site*Treatment* Depth			**0.66**	**0.5**

Means with different letterscript in a column indicate significant differences at $p < 0.05$.

4.4.1.2 Micronutrients

The concentrations of both Cu and Mn varied significantly across sites ($p < 0.001$; Appendices Fi and iii), while water harvesting, growing season and depth had no effect on these nutrients (Table 4.8). The Mxheleni site recorded the lowest while Mntungane had the highest Cu amounts in both seasons, treatments and across all depths. In the case of Mn, Xoshimpi had the highest Mn in both seasons and across all treatments. No clear site differences were recorded for Mn in 2013, while Mntungane had the lowest Mn in 2015 in the control plot.

Fe on the other hand only had a significant seasonal effect shown by a huge increase in Fe in 2015 across all treatments ($p<0.001$; Appendix Fii). Mxheleni had the lowest Fe amount in the control in 2013, while no clear trend among sites was observed in 2015 (Table 4.8). Finally, Zn was not affected by any of the treatment factors (Table 4.8)

Table 4.8: Micronutrients before planting (2013) and at harvest (2015) for KZN sites

Sites	Treatments	Soil Depth (cm)	Cu 2013	Cu 2015	Fe 2013	Fe 2015	Mn 2013	Mn 2015	Zn 2013	Zn 2015
			mg/kg							
Xoshimpi	**Control**	**0-10**	0.2^{c}	0.19^{d}	6.3^{b}	26.2^{cb}	37.7^{d}	33.2^{d}	$0,5^{a}$	0.6^{a}
		10-20	0.17^{b}	0.22^{e}	6.9^{b}	32.7^{e}	31.1^{c}	37.9^{d}	$0,4^{a}$	0.6^{a}
		20-30	0.2^{c}	0.19^{d}	6.3^{b}	26.9^{cb}	37.6^{d}	33.3^{d}	$0,5^{a}$	0.5^{a}
	RWH	**0-10**	0.18^{b}	0.22^{e}	5.9^{b}	30.1^{d}	31.1^{c}	38.5^{d}	$0,4^{a}$	0.7^{a}
		10-20	0.2^{c}	0.19^{d}	5.9^{b}	26.6^{cb}	37.6^{d}	32.9^{d}	$0,5^{a}$	0.6^{a}
		20-30	0.17^{b}	0.22^{e}	5.9^{b}	31.5^{ed}	31.7^{c}	37.9^{d}	$0,4^{a}$	0.7^{a}
Mntungane	**Control**	**0-10**	0.44^{e}	0.55^{f}	19.2^{d}	29.7^{c}	29.2^{cb}	4.5^{a}	$0,4^{a}$	1.9^{a}
		10-20	0.4^{d}	0.54^{f}	1.2^{a}	36.6^{f}	12.9^{a}	4.8^{a}	$0,4^{a}$	1.4^{a}
		20-30	0.4^{d}	0.55^{f}	3.2^{ab}	27.2^{c}	28.9^{cb}	3.8^{a}	$0,4^{a}$	1.5^{a}
	RWH	**0-10**	0.4^{d}	0.18^{cd}	1.2^{a}	25.4^{ab}	12.7^{a}	35.3^{d}	$0,4^{a}$	0.6^{a}
		10-20	0.4^{d}	0.17^{c}	3.2^{ab}	20.3^{a}	28.9^{cb}	36.3^{d}	$0,4^{a}$	0.6^{a}
		20-30	0.4^{d}	0.39^{f}	3.3^{ab}	25.1^{b}	12.9^{a}	14.1^{b}	$0,4^{a}$	9.1^{b}
Mxheleni	**Control**	**0-10**	0.1^{a}	0.04^{a}	1.5^{a}	27.5^{c}	27.7^{bc}	23.6^{c}	$0,5^{a}$	1.2^{a}
		10-20	0.1^{a}	0.06^{b}	1.3^{a}	37.6^{f}	25.2^{b}	28.8^{dc}	$0,4^{a}$	1.7^{a}
		20-30	0.04^{a}	0.04^{a}	1.6^{a}	30.4^{d}	28.0^{bc}	23.5^{c}	$0,5^{a}$	1.3^{a}
	RWH	**0-10**	0.1^{a}	0.06^{b}	1.2^{a}	32.0^{ed}	25.2^{b}	29.4^{dc}	$0,4^{a}$	1.7^{a}
		10-20	0.04^{a}	0.04^{a}	15.4^{c}	27.6^{c}	27.9^{bc}	23.8^{c}	$0,5^{a}$	1.2^{a}
		20-30	0.1^{a}	0.06^{b}	15.2^{c}	39.2^{g}	12.9^{a}	29.3^{dc}	$0,4^{a}$	1.7^{a}
$LSD_{p<0.05}$ Site*Treatment* Depth			**0,02**	**0,02**	**0,02**	**0,02**	**4.3**	**6.7**	**0.11**	**2.46**

Means with different letterscript in a column indicate significant differences at $p<0.05$.

4.4.1.3 Exchangeable bases

The concentrations of Ca varied significantly across sites and depths ($p < 0.001$; Appendix Gi), while water harvesting had no effect on this nutrient (Table 4.9). In 2013, Ca followed the following trend in both the control and RWH treatment Mxheleni > Mntungane > Xoshimpi. Ca amounts also increased in 2013 at 10-20 cm depth at two of the sites in the control (Mxheleni and Xoshimpi), while it decreased at these same sites and depth in the RWH treatment. In 2015 on the other hand, Ca was highest at Mxheleni in both the control and RWH treatment, while there was no clear trend with depth. Seasonal variations showed that there were significantly lower amounts of Ca in the control in 2013 than in 2015 while no clear seasonal Ca differences were recorded under RWH.

In the case of Mg, Mxheleni had the highest Mg in 2013 in the control, while it also had highest and Xoshimpi had lowest Mg in 2015 in the RWH treatment ($p < 0.001$; Appendix Gii). There was a rise in Mg amount at 10-20 cm depth under the control and a drop at the same depth under the RWH treatment at Xoshimpi and Mntungane in 2013 ($p < 0.001$; Appendix Gii). The opposite was recorded in 2015 where a drop was observed at 10-20 cm under the control and a rise was recorded at the same depth under RWH treatment for these two sites (Table 4.9). The 2015 season generally recorded higher Mg than 2013 across all sites ($p < 0.001$; Appendix Gii).

Na however had a significant site ($p = 0.032$; Appendix Giii) and seasonal effect ($p = 0.016$), particularly in 2015 where Mxheleni recorded the highest Na concentration (Table 4.9). The depth and water harvesting had no significant effect on Na amounts. A closer look at seasonal effect suggests that Na was higher in 2013 compared with 2015 (Table 4.9).

Finally, K only varied significantly across sites ($p = 0.002$; appendix Giv) and depth ($p = 0.031$) while water harvesting and growing season had no effect on the concentration of this element. The Xoshimpi site recorded the highest while Mxheleni had the lowest K amounts in both seasons and across all treatments. While there was no clear trend of K with depth in 2013; in 2015 there was an increase in K at 10-20 cm for Mxheleni and Mntungane in the control. This same element decreased at 10-20 cm depth at the same sites in the RWH treatment.

Table 4.9: Exchangeable bases before planting (2013) and at harvest (2015) for KZN sites

Sites	Treatments	Soil Depth (cm)	Ca 2013	Ca 2015	Mg 2013	Mg 2015	Na 2013	Na 2015	K 2013	K 2015
			cmol$_c$/Kg							
Xoshimpi	**Control**	**0-10**	8.0^{a}	15.0^{b}	5.2^{a}	7.5^{c}	4.0^{ba}	0.14^{ab}	1.3^{c}	1.4^{e}
		10-20	15.0^{bc}	12.8^{ba}	7.0^{c}	5.2^{a}	2.7^{a}	0.09^{a}	1.4^{d}	1.3^{d}
		20-30	8.0^{a}	15.1^{b}	5.3^{a}	7.5^{c}	4.0^{ba}	0.13^{ab}	1.3^{c}	1.4^{e}
	RWH	**0-10**	15.0^{bc}	9.2^{a}	7.1^{c}	5.1^{a}	2.7^{a}	0.09^{a}	1.4^{d}	1.3^{d}
		10-20	8.0^{a}	15.1^{b}	5.1^{a}	7.5^{c}	4.1^{ba}	0.10^{a}	1.3^{c}	1.4^{e}
		20-30	15.0^{bc}	9.6^{ab}	5.7^{b}	5.1^{a}	2.7^{a}	0.14^{ab}	1.4^{d}	1.3^{d}
Mntungane	**Control**	**0-10**	12.7^{b}	14.5^{b}	5.0^{a}	7.6^{c}	3.7^{a}	0.12^{a}	1.2^{b}	0.9^{c}
		10-20	14.6^{bc}	13.9^{b}	6.9^{c}	6.9^{b}	4.2^{b}	0.14^{ab}	0.6^{a}	1.4^{e}
		20-30	12.6^{b}	14.5^{b}	5.1^{a}	7.5^{c}	3.7^{a}	0.10^{a}	1.2^{b}	0.9^{c}
	RWH	**0-10**	14.6^{bc}	13.1^{ba}	6.9^{c}	6.9^{b}	4.0^{ba}	0.10^{a}	0.6^{a}	1.4^{e}
		10-20	17.4^{c}	14.7^{b}	5.0^{a}	7.5^{c}	3.7^{a}	0.14^{ab}	1.2^{b}	0.9^{c}
		20-30	23.5^{d}	13.6^{b}	6.9^{c}	6.9^{b}	4.0^{ba}	0.11^{a}	0.6^{a}	1.4^{e}
Mxheleni	**Control**	**0-10**	17.4^{c}	25.2^{c}	7.2^{c}	7.6^{c}	3.9^{a}	0.38^{d}	0.6^{a}	0.6^{a}
		10-20	23.5^{d}	17.3^{b}	7.3^{c}	7.3^{c}	4.0^{ba}	0.24^{c}	0.6^{a}	0.7^{b}
		20-30	17.4^{c}	25.2^{c}	7.3^{c}	7.6^{c}	3.9^{ba}	0.11^{a}	0.6^{a}	0.6^{a}
	RWH	**0-10**	23.5^{d}	17.3^{b}	7.2^{c}	7.4^{c}	4.0^{ba}	0.10^{a}	0.6^{a}	0.7^{b}
		10-20	17.4^{c}	25.2^{c}	7.2^{c}	7.6^{c}	3.9^{ba}	0.18^{b}	0.6^{a}	0.6^{a}
		20-30	23.5^{d}	17.3^{b}	7.3^{c}	7.4^{c}	4.1^{ba}	0.13^{ab}	0.6^{a}	0.7^{b}
LSD$_{p<0.05}$ Site*Treatment* Depth			**3.1**	**4.4**	**0.5**	**0.3**	**1.5**	**0.06**	**0.1**	**0.06**

Means with different letterscript in a column indicate significant differences at $p<0.05$.

4.4.2 Chemical properties at EC sites

4.4.2.1 Soil pH

Table 4.10 shows soil pH in water for Eastern Cape before planting (2013) and at harvest (2015). Soil pH differed across sites ($p < 0.001$; appendix H) in both seasons ($p = 0.029$). However, the soil depth and water harvesting did not have a significant effect on it. In 2013, soil pH was highest at Madosini and Mjali sites, but lowest at Quvile across all treatments. In 2015, soil pH was lowest at Mjali in the control while there were no clear differences in the RWH treatments. There was a general drop in pH as one moved from the 2013 to 2015 season.

Table 4.10: Soil pH before planting (2013) and at harvest (2015) for EC sites

Sites	**Treatments**	**Soil Depth (cm)**	**pH (water) 2013**	**pH (Water) 2015**
Madosini	**Control**	**0-10**	7.8^{c}	7.1^{dc}
		10-20	7.7^{c}	7.0^{dc}
		20-30	7.6^{c}	6.4^{b}
	RWH	**0-10**	7.7^{c}	7.3^{d}
		10-20	7.7^{c}	7.0^{dc}
		20-30	7.6^{c}	6.7^{cb}
Beya	**Control**	**0-10**	7.1^{bc}	7.3^{d}
		10-20	7.1^{bc}	6.9^{cd}
		20-30	7.0^{b}	6.8^{c}
	RWH	**0-10**	7.1^{bc}	7.4^{d}
		10-20	7.1^{bc}	6.7^{cb}
		20-30	7.1^{bc}	6.8^{c}
Mjali	**Control**	**0-10**	7.5^{c}	6.8^{c}
		10-20	7.5^{c}	5.5^{a}
		20-30	7.5^{c}	5.4^{a}
	RWH	**0-10**	7.6^{c}	7.3^{d}
		10-20	7.5^{c}	7.2^{d}
		20-30	7.5^{c}	5.4^{a}
Quvile	**Control**	**0-10**	6.4^{a}	7.4^{d}
		10-20	6.4^{a}	7.3^{d}
		20-30	6.3^{a}	7.3^{d}
	RWH	**0-10**	6.6^{a}	6.9^{cb}
		10-20	6.5^{a}	6.7^{cb}
		20-30	6.5^{a}	6.4^{bc}
Sokhombela	**Control**	**0-10**	7.5^{c}	7.3^{d}
		10-20	7.4^{cb}	7.2^{d}
		20-30	7.4^{cb}	6.9^{cb}
	RWH	**0-10**	7.4^{cb}	6.9^{cb}
		10-20	7.3^{cb}	6.9^{cb}
		20-30	7.3^{cb}	6.9^{cb}
$LSD_{p<0.05}$ Site*Treatment* Depth			**0.39**	**0.39**

Means with different letterscript in a column indicate significant differences at $p<0.05$.

4.4.2.2 Micronutrients

The results for micronutrients (Cu, Zn, Mn and Fe) for EC sites before planting (2013) and at harvest (2015) are presented in Table 4.11. The concentration of Cu differed across sites ($p = 0.006$; Appendix Ii), depths and seasons ($p < 0.001$). In 2013, Beya recorded the highest while Madosini had the lowest Cu amounts under both RWH and control plots across all depths. It was difficult to discern a clear trend of Cu with depth in 2013. The site patterns were also difficult to see in 2015, but there was a general decrease of Cu with depth in the control plots at Mjali, Madosini and Sokhombela, while it increased with depth in the RWH treatment at Quvile and Beya. There was a significant increase in soil Cu amount in 2015 compared to 2013.

Zn only showed significant differences across sites ($p < 0.001$; Appendix Iii), while there were no significant seasonal, depth and water harvesting effects (Table 4.11). In 2013, the Sokhombela and Mjali sites recorded higher Zn in the control while no significant differences were observed across sites in the RWH treatment. There were no clear site differences of Zn in 2015 however.

Mn significantly differed across sites, depths and seasons ($p < 0.001$; Appendix Iiii), but rain water harvesting did not have a significant effect on it (Table 4.11). Mjali and Sokhombela sites had the highest Mn in 2013. It was difficult to see a clear trend of Mn with depth however in this season. In 2015 Sokhombela and Beya sites also recorded the highest while Madosini had the lowest Mn amount. There was an increase in Mn at the 10-20 cm depth at Beya (both treatments) and Mjali (control only) in 2015. Overall, the 2015 season recorded higher amounts of Mn than 2013 at most of the sites (Table 4.11).

The concentration of Fe in the soil was also significantly affected by site, season ($p < 0.001$; appendix Iiv) and depth ($p = 0.029$). Mjali had the highest while Madosini had the lowest Fe concentration in 2013 (Table 4.11). There were no significant differences of Fe with depth in this season however. In 2015, Quvile had the highest and Madosini the lowest Fe in the RWH treatment; while Beya had the lowest Fe in the control. Most of the sites (serve for Beya in the control) had more Fe in 2015 than in 2013.

Table 4.11: Micronutrients before planting (2013) and at harvest (2015) for EC sites

Sites	**Treatments**	**Soil Depth (cm)**	**Cu 2013**	**Cu 2015**	**Zn 2013**	**Zn 2015**	**Mn 2013**	**Mn 2015**	**Fe 2013**	**Fe 2015**
			mg/kg							
Madosini	**Control**	**0-10**	2.1^{a}	10.0^{b}	0.9^{ab}	1.3^{a}	2.8^{ba}	5.8^{bc}	25.6^{a}	32.5^{ab}
		10-20	2.7^{a}	10.1^{b}	0.9^{ab}	1.5^{a}	2.6^{ba}	2.6^{ab}	25.2^{a}	50.8^{ef}
		20-30	2.1^{a}	8.6^{a}	0.9^{ab}	1.3^{a}	2.6^{ab}	3.9^{ba}	25.3^{a}	47.6^{ed}
	RWH	**0-10**	2.1^{a}	7.9^{a}	0.9^{ab}	1.3^{a}	2.8^{ba}	0.9^{a}	25.3^{a}	33.8^{cb}
		10-20	2.1^{a}	11.5^{b}	0.8^{ab}	1.6^{a}	1.6^{ab}	2.1^{ab}	25.7^{a}	30.7^{b}
		20-30	2.1^{a}	3.2^{a}	0.6^{ab}	1.8^{a}	2.5^{ab}	1.8^{ab}	25.3^{a}	43.3^{de}
Beya	**Control**	**0-10**	7.5^{c}	9.5^{b}	1.3^{ba}	1.3^{a}	3.9^{b}	6.9^{cb}	38.1^{b}	14.3^{a}
		10-20	7.8^{c}	35.3^{d}	1.2^{ba}	1.8^{a}	3.7^{ba}	8.8^{c}	37.4^{b}	10.7^{a}
		20-30	6.8^{c}	36.2^{d}	1.0^{ba}	1.4^{a}	3.6^{ba}	7.7^{cb}	38.2^{b}	15.9^{a}
	RWH	**0-10**	7.7^{c}	9.3^{a}	1.3^{ba}	1.5^{a}	3.7^{ba}	7.5^{cb}	38.1^{b}	61.3^{g}
		10-20	7.7^{c}	10.9^{b}	0.9^{ab}	1.3^{a}	3.6^{ba}	8.0^{b}	38.2^{b}	54.8^{f}
		20-30	7.7^{c}	13.8^{b}	1.3^{ba}	1.3^{a}	2.3^{ab}	4.5^{b}	37.3^{b}	12.1^{a}
Mjali	**Control**	**0-10**	6.0^{cb}	17.4^{c}	1.3^{ba}	1.0^{a}	3.5^{ba}	5.8^{bc}	45.1^{c}	42.6^{de}
		10-20	5.8^{cb}	9.9^{b}	1.8^{b}	1.4^{a}	4.9^{b}	8.5^{c}	46.5^{c}	64.8^{g}
		20-30	6.4^{cb}	6.8^{a}	1.4^{ba}	1.7^{a}	4.8^{b}	6.8^{cb}	46.5^{c}	36.5^{c}
	RWH	**0-10**	6.1^{cb}	12.1^{b}	1.5^{b}	1.3^{a}	4.1^{b}	7.1^{cb}	45.8^{c}	58.3^{f}
		10-20	5.9^{cb}	9.4^{a}	1.3^{ba}	1.3^{a}	4.7^{b}	6.9^{cb}	45.3^{c}	41.7^{dc}
		20-30	6.6^{c}	9.2^{a}	1.3^{ba}	1.4^{a}	4.6^{b}	7.2^{cb}	45.8^{c}	64.8^{g}
Quvile	**Control**	**0-10**	5.8^{cb}	13.1^{b}	1.1^{ba}	1.3^{a}	3.4^{ba}	4.7^{bc}	34.0^{b}	46.1^{ed}
		10-20	5.5^{bc}	9.3^{a}	0.8^{ab}	1.1^{a}	2.8^{ba}	7.3^{cb}	35.9^{b}	69.4^{h}
		20-30	6.8^{c}	13.1^{b}	0.9^{ab}	1.6^{a}	3.0^{ba}	4.9^{bc}	35.7^{b}	42.4^{d}
	RWH	**0-10**	5.7^{cb}	9.8^{b}	0.5^{a}	1.0^{a}	2.9^{ba}	7.8^{cb}	35.97^{b}	70.5^{h}
		10-20	5.2^{bc}	15.5^{b}	0.8^{ab}	1.1^{a}	2.9^{ba}	5.6^{bc}	35.9^{b}	44.7^{de}
		20-30	5.8^{cb}	15.5^{b}	0.6^{ab}	1.0^{a}	1.3^{a}	3.6^{ba}	35.8^{b}	74.1^{h}
Sokhombela	**Control**	**0-10**	6.8^{c}	11.5^{b}	1.6^{b}	1.9^{a}	4.4^{b}	10.9^{c}	36.7^{b}	47.7^{ed}
		10-20	4.7^{b}	8.4^{a}	1.3^{ba}	2.2^{a}	4.5^{b}	8.3^{c}	36.8^{b}	62.4^{g}
		20-30	6.3^{cb}	9.4^{a}	1.4^{b}	2.4^{a}	5.9^{b}	9.8^{c}	36.8^{b}	40.3^{dc}
	RWH	**0-10**	5.5^{bc}	10.3^{b}	1.3^{ba}	2.1^{a}	2.6^{ba}	7.0^{cb}	36.87^{b}	65.4^{g}
		10-20	4.7^{b}	7.9^{a}	1.3^{ba}	2.2^{a}	4.5^{b}	9.9^{c}	36.7^{b}	48.0^{e}
		20-30	6.7^{c}	10.7^{b}	1.2^{ba}	1.4^{a}	4.5^{b}	8.9^{c}	36.8^{b}	66.5^{g}
LSD$_{p<0.05}$ Site*Treatment* Depth			**1.8**	**6.3**	**0.9**	**1.7**	**2.6**	**3.5**	**6.2**	**5.5**

Means with different letterscript in a column indicate significant differences at $p < 0.05$.

4.4.2.3 Exchangeable bases

The results for exchangeable Ca, Mg, Na and K are presented in Table 4.12. The concentrations of Mg and Na show no significant differences across sites, treatments, depths and seasons. Ca differed across sites and depths ($p < 0.001$; appendix Jii), while it showed no significant seasonal and water harvesting effects (Table 4.12). In 2013, Beya recorded the highest, while Sokhombela followed by Mjali had the lowest Ca amounts under both RWH and control plots across all depths (Table 4.12). There was not much difference of Ca amounts observed with depth in 2013 across sites. The site and depth patterns were highly variable in 2015.

K on the other hand varied significantly across sites ($p = 0.004$; appendix Jiv) and with water harvesting treatments ($p = 0.018$), while season and depth had no effect on the amount of this element. In 2013, Quvile site had the highest while Beya and Mjali had the lowest K values in all treatments. In 2015, no clear site differences in K were observed in the control, while Madosini had the lowest and Beya the highest amount of K in RWH treatment. No clear depth effect was observed in both seasons.

Table 4.12: Exchangeable bases before planting (2013) and at harvest (2015) for EC

Sites	Treatments	Depth (cm)	Ca 2013	Ca 2015	Mg 2013	Mg 2015	Na 2013	Na 2015	K 2013	K 2015
			$\mathrm{cmol_c/Kg}$							
Madosini	**Control**	**0-10**	7.7^{g}	11.1^{h}	1.8^{ab}	2.5^{ab}	0.1^{a}	0.07^{a}	0.5^{a}	0.4^{a}
		10-20	7.9^{h}	5.3^{ab}	2.0^{ab}	2.0^{ab}	0.1^{a}	0.1^{a}	1.0^{cd}	1.0^{ab}
		20-30	7.8^{h}	6.4^{bc}	1.8^{ab}	1.8^{ab}	0.1^{a}	0.09^{a}	1.0^{cd}	1.8^{e}
	RWH	**0-10**	7.9^{h}	4.6^{ab}	1.9^{ab}	1.7^{ab}	0.1^{a}	0.09^{a}	1.0^{cd}	0.2^{a}
		10-20	7.9^{h}	7.9^{fg}	1.7^{ab}	1.7^{ab}	0.2^{a}	0.1^{a}	1.0^{cd}	1.3^{bc}
		20-30	7.9^{h}	7.9^{fg}	2.8^{ab}	2.7^{bc}	0.2^{a}	0.1^{a}	1.0^{cd}	0.2^{a}
Beya	**Control**	**0-10**	9.2^{hi}	8.3^{a}	1.3^{ab}	1.3^{ab}	0.1^{a}	0.2^{a}	0.8^{b}	1.2^{ab}
		10-20	9.2^{hi}	8.1^{fg}	2.8^{ab}	2.7^{bc}	0.1^{a}	0.1^{a}	1.1^{c}	1.0^{ab}
		20-30	9.2^{hi}	11.4^{h}	1.2^{ab}	1.2^{ab}	0.1^{a}	0.2^{a}	0.8^{b}	1.1^{ab}
	RWH	**0-10**	9.3^{hi}	7.3^{ef}	2.6^{ab}	2.5^{ab}	0.1^{a}	0.1^{a}	1.1^{c}	1.5^{d}
		10-20	9.2^{hi}	8.1^{fg}	0.4^{a}	0.39^{a}	0.1^{a}	0.2^{a}	0.8^{b}	1.4^{de}
		20-30	9.2^{hi}	18.9^{h}	3.0^{ab}	2.8^{bc}	0.1^{a}	0.1^{a}	1.1^{c}	1.4^{de}
Mjali	**Control**	**0-10**	4.7^{c}	7.9^{fg}	3.0^{ab}	2.9^{bc}	0.1^{a}	0.1^{a}	0.8^{b}	0.9^{ab}
		10-20	4.9^{d}	5.9^{bc}	3.4^{bc}	3.3^{bc}	0.1^{a}	0.1^{a}	0.9^{bc}	0.8^{b}
		20-30	4.7^{c}	7.5^{ef}	2.0^{ab}	1.9^{ab}	0.1^{a}	0.1^{a}	0.8^{b}	0.9^{ab}
	RWH	**0-10**	4.7^{c}	4.3^{ab}	1.7^{ab}	1.6^{ab}	0.1^{a}	0.1^{a}	0.9^{bc}	1.5^{d}
		10-20	4.7^{bc}	8.3^{g}	2.2^{ab}	2.3^{ab}	0.1^{a}	0.1^{a}	0.8^{b}	1.2^{bc}
		20-30	4.7^{b}	5.7^{ab}	3.1^{ab}	2.9^{ab}	0.1^{a}	0.1^{a}	0.9^{bc}	1.1^{ab}
Quvile	**Control**	**0-10**	6.7^{e}	7.6^{ef}	2.7^{ab}	2.6^{bc}	0.1^{a}	0.2^{a}	1.7^{f}	1.1^{ab}
		10-20	6.8^{g}	8.2^{fg}	3.5^{bc}	3.4^{c}	0.1^{a}	0.2^{a}	1.6^{ef}	1.3^{c}
		20-30	6.8^{g}	7.4^{ef}	1.1^{ab}	0.9^{ab}	0.1^{a}	0.1^{a}	1.6^{ef}	1.1^{ab}
	RWH	**0-10**	6.8^{fg}	8.3^{g}	2.7^{ab}	2.6^{ab}	0.1^{a}	0.2^{a}	1.5^{ef}	1.0^{ab}
		10-20	6.8^{f}	6.6^{bc}	2.2^{ab}	2.1^{ab}	0.1^{a}	0.1^{a}	1.7^{f}	1.2^{ab}
		20-30	6.7^{e}	8.3^{g}	2.0^{ab}	1.8^{ab}	0.1^{a}	0.2^{a}	0.5^{a}	1.4^{cd}
Sokhombela	**Control**	**0-10**	4.4^{a}	8.1^{fg}	1.7^{ab}	1.6^{ab}	0.1^{a}	0.09^{a}	1.2^{d}	0.9^{ab}
		10-20	4.4^{a}	3.2^{a}	2.3^{ab}	2.2^{ab}	0.1^{a}	0.2^{a}	1.2^{d}	1.0^{ab}
		20-30	4.4^{a}	7.3^{ef}	2.0^{ab}	1.8^{ab}	0.1^{a}	0.1^{a}	1.3^{de}	1.2^{ab}
	RWH	**0-10**	4.4^{a}	4.4^{ab}	1.1^{ab}	1.0^{ab}	0.1^{a}	0.2^{a}	1.3^{de}	1.2^{ab}
		10-20	4.4^{a}	6.9^{de}	1.8^{ab}	1.4^{ab}	0.1^{a}	0.1^{a}	1.2^{d}	1.4^{de}
		20-30	4.4^{a}	3.6^{ab}	2.0^{ab}	2.0^{a}	0.2^{a}	0.2^{a}	1.3^{de}	1.4^{cd}
LSD$_{p<0.05}$ Site*Treatment* Depth			**0.04**	**0.04**	**1,8**	**2.3**	**0,08**	**0,09**	**0,2**	**0,4**

Means with different letterscript in a column indicate significant differences at p<0.05.

4.5 Seasonal variations of gravimetric soil moisture at different contour positions and stages of maize growth for KZN and EC research sites in the 2014/15 season.

4.5.1 KZN soil moisture

Figure 4.1 shows the seasonal variations of soil moisture at different contour positions and stages of maize growth for KZN sites. The rainwater harvesting treatment had significantly higher soil moisture content compared to the control, at all contour positions, ($p < 0.001$; Appendix K). The below ridge position generally had the highest soil moisture followed by above ridge, runoff then control plot respectively. Soil moisture content generally increased with increasing soil depth ($p < 0.001$; Appendix K), but did not significantly vary with the stage of maize growth across all sites.

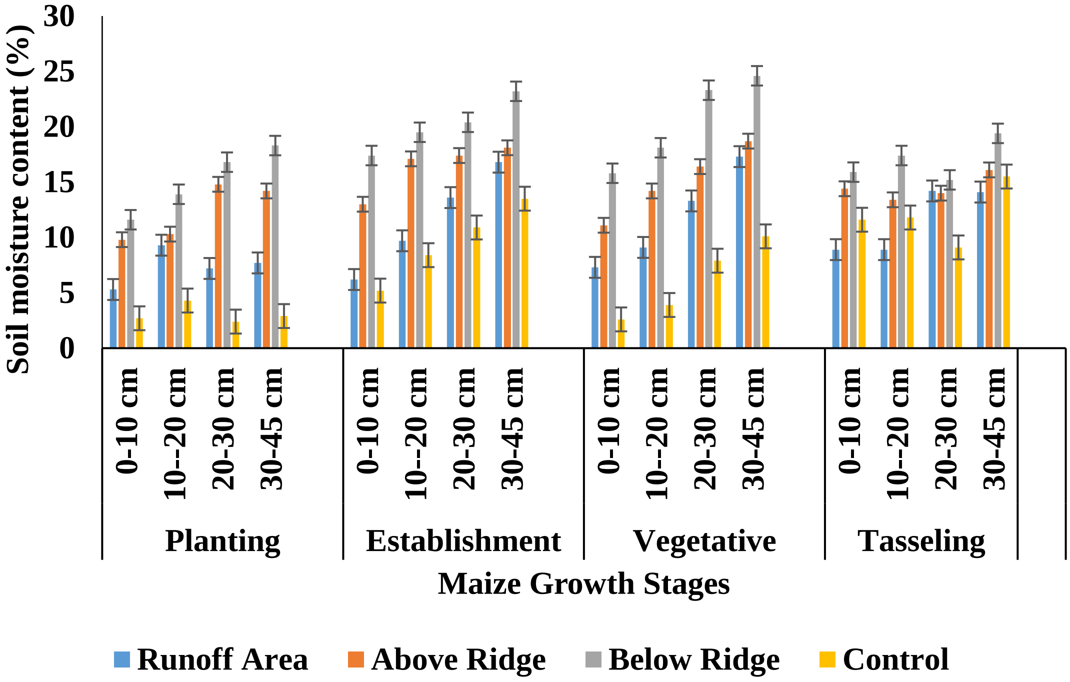

Figure 4.1: Variation of soil moisture content for KZN sites.

4.5.2 Eastern Cape soil moisture.

Figure 4.2 shows that the RWH treatment had significantly higher soil moisture compared with the control ($p<0.001$; Appendix L) in Eastern Cape, with the below ridge component having the highest soil moisture followed by above ridge, runoff and control positions respectively. Soil moisture generally increased with increasing soil depth ($p < 0.001$; appendix L). It was also affected by the stage of maize growth ($p < 0.001$; appendix L), being highest at planting followed by establishment, vegetative then finally harvesting.

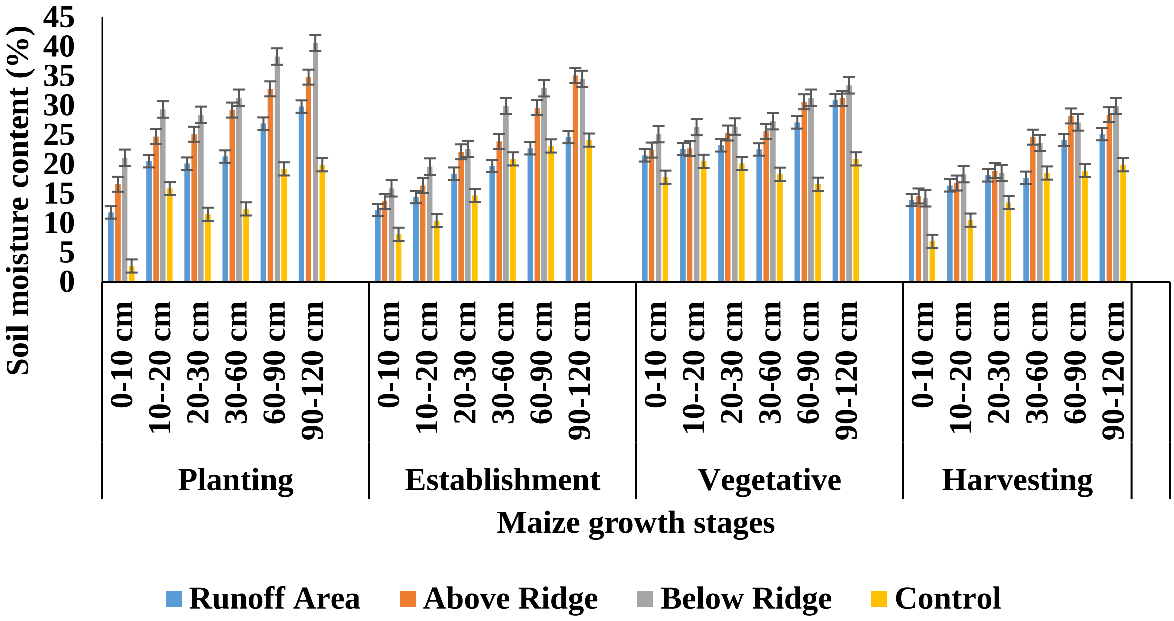

Figure 4.2: Variation of soil moisture content for Eastern Cape sites.

4.6 Grain and dry matter yields at EC in 2015

Figure 4.3 shows the variation of grain and dry matter yields for Eastern Cape sites in 2015. Grain yield varied across sites (p = 0.047; Appendix M) and with water harvesting (p = 0.020). It was highest at Mjali, then lowest at Sokhombela in the RWH treatment, but followed the order Quvile > Beya > Mjali > Sokhombela > Madosini in the control. Grain yield was significantly higher in the RWH treatment compared with the control at Madosini and Mjali sites while it was significantly lower than the control at Quvile site. No significant differences in grain yield were recorded between the control and RWH treatment at Beya and Sokhombela sites.

The dry matter yield also varied significantly across sites (p = 0.013; Appendix N) and with water harvesting (p = 0.025). The order for the dry matter yield was Mjali > Madosini >Quvile = Sokhombela > Beya in the control and Mjali > Sokhombela > Beya > Madosini > Quvile under RWH. Rainwater harvesting gave higher dry matter yield compared with the control at Beya, Mjali and Sokhombela while it was lower at Madosini. No significant differences in dry matter yield were observed between treatments at Quvile.

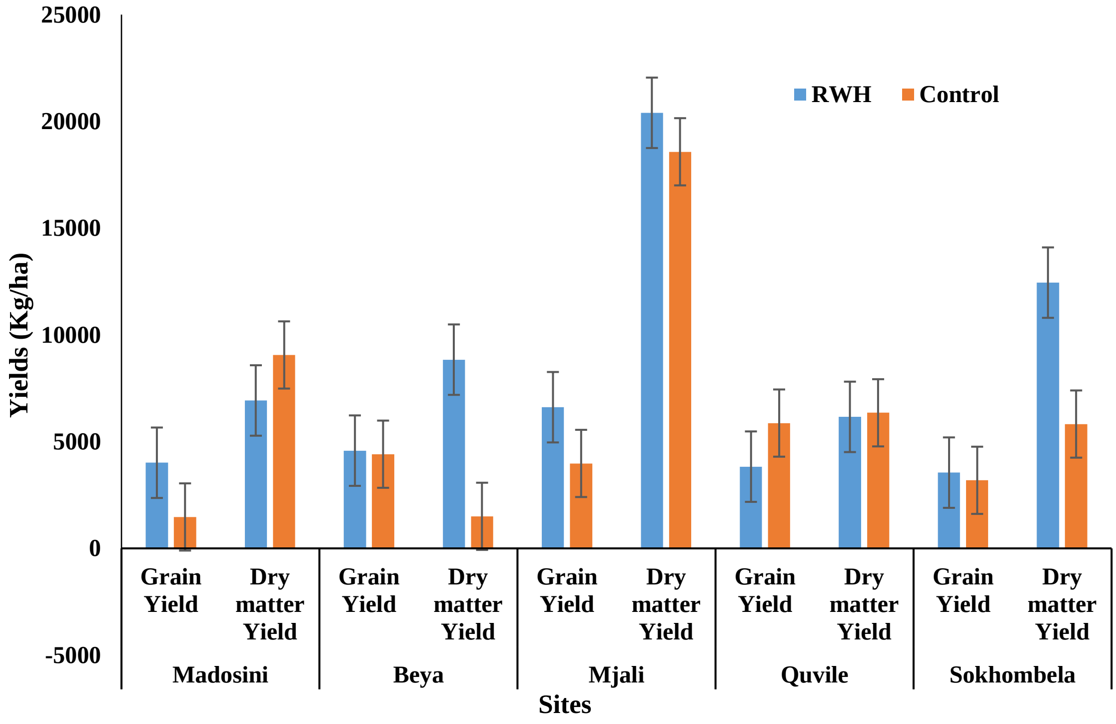

Figure 4.3: Grain and dry matter yield at different Eastern Cape sites in 2015

5 CHAPTER FIVE: GENERAL DISCUSSION, CONCLUSION & RECOMMENDATIONS

5.1 Introduction

The aim of this chapter is to discuss the main findings from the study as outlined by the initial objectives of this study. It will further highlight the conclusions drawn and recommendations made from this research.

5.2 Discussion

Findings from this study suggests that rainwater harvesting improved soil aggregate stability at Mxheleni site only in Kwa-Zulu Natal; while it was improved across all the study sites in Eastern Cape. This was informed by higher MWD in the RWH treatment compared with the traditional farming practice in 2015 than the 2013 season at these sites. However, in KZN there were no significant differences in bulk density between the RWH treatment and control plots across most sites in each season. On the other hand, seasonal variations showed bulk density to be generally higher in 2015 compared to 2013. Improved bulk density through rainwater harvesting was observed at Sokhombela, Beya, Mjali and Quvile in EC, since they recorded lower density values in 2015 than 2013. In a similar study done by Li et al (2000), they found that rainwater harvesting improved both bulk density and aggregate stability, as was the case in EC. This was further supported by Xiaolong et al (2008) in their study on the effect of rainwater harvesting on spring corn production. Improved aggregate stability with simultaneous decrease in bulk density is desirable since it promotes the infiltration rate of soil and protect it from erosion (Barthes and Roose, 2002). It is however; not very clear why sites in KZN that had seemingly good aggregate stability had undesirably high density values. It is possible that the bulk density samples from KZN were taken in areas where the soil was compacted due to the action of animal hooves and tractor wheels which were used during the construction of contours. Kuht et al (2012) suggested that the use of heavy agricultural machinery could lead to soil compaction, which if not managed could possible lead to serious soil degradation. Shah et al (2017), further alluded that both the use of heavy agricultural machinery and hoofing by animals could lead to soil compaction. According to Bissonnais (1996), poor soil aggregation coupled with higher bulk density could promote aggregate breakdown as well as the detachment of soil fragments by rain in areas under semi-arid regions.

This will destroy soil structure which negatively impacts soil water retention, as poor soil structure promotes the reduction of soil pores that are active in the retention of gases and moisture within the soil continuum (Kasangaki et al, 2003).

Soil pH was not affected by rainwater harvesting across all sites in KZN and Eastern Cape. This was informed by RWH plots having similar pH results with the traditional farmer practice. However, seasonal variations showed increasing pH at KZN while it decreased in Eastern Cape as one moved from 2013 to 2015. Generally, an increase in soil moisture could results in a decrease in soil pH (Adejumobi et al, 2014). This, especially could hold true for Eastern Cape sites as higher annual rainfall was recorded in 2015 compared with those obtained in 2013 (Appendix P). Therefore, the differences in the amount of recorded annual rainfall could cause the pH to drop because of possible high amount of soil moisture which could results in a drop in soil pH as one move from 2013 to 2015 (Wang and Jong, 1998). In KZN sites, an opposite trend was observed with regards to rainfall. Higher amounts of rainfall were received in 2013 compared with those obtained in 2015 (Appendix O). As a result, soil pH values were recorded lower in 2013 than those recorded in 2015 for all KZN sites. This is again could be associated with Adejumobi et al (2014) observations mentioned in the preceding section. Helyar and Porter (1989) described the mechanism that results in dropping soil pH because of an increase in soil moisture. In their description, they stated that as soil water increases, it results in possible leaching of basic elements such as calcium, magnesium and potassium. These basic elements are then replaced by acidic elements such as hydrogen, aluminium and manganese (Bolan et al, 2003). This mechanism was supported in this study by a drop in soil pH when research sites received higher rainfall and an increase in soil pH when study sites received lower rainfall.

This study showed no effect of rainwater harvesting on soil micronutrients in both KZN and Eastern Cape sites. Seasonal effects were significant for Fe as it increased in 2015 in both areas. Iron was also found to be higher at Mntungane and Xoshimpi sites in KZN. This could be associated with the soil form found at these sites which is Shortlands that is dominated by the haematite mineral with high Fe content (Inman-Bamber et al, 1993). When this soil form receives adequate moisture, Fe is easily released as an abundant element (Meyer et al, 1983). The same reason may apply to the EC sites as they were dominated by Hutton soil form and Shortlands also associated with high Fe mineralogy. Furthermore, in the Eastern Cape, Cu and Mn also increased in 2015, while Zn decreased in 2015 at KZN. The mobility of Cu and Mn is favoured at soil pH less than 5 (Mdlambuzi, 2014). However, the mobility of these elements could not be associated with pH in this study. This is because even though there was a slightly drop in soil pH in 2015 in the EC sites, the drop was still not less than 5 where the mobility of these elements is promoted. However, Weil et al (2016) stated that the availability of these elements in soils i.e. Cu and Mn could also be favoured under the conditions of increasing soil moisture content. The increase in soil moisture content under the RWH treatment due to high rainfall received in 2015 compared with that received in 2013 for EC sites (Appendix P) under the RWH treatment could therefore be associated with an increase in the concentration of these elements in these sites.

Rainwater harvesting did not have a significant effect on basic cations serve for Mg and K that had variable trends among treatments in KZN and EC respectively. There was a rise in Mg levels while Na amounts dropped in 2015 at KZN. According to Shaw and Thorbum (1985), when soil moisture content increases either through irrigation or heavy precipitation, it promotes the mobility of micro nutrients that form complexes with basic cations and results in the leaching of these basic cations making them less available in the soil. This was supported by Xu et al (2010) who explained that if more moisture is received by the soil through irrigation or rainfall, it can result in a drop in the soil pH towards acidic. This observation was clearly supported by findings in the Eastern Cape sites in 2015 and in KZN sites in 2013 where higher rainfall was received and yet some basic elements were less available in the soil. According to the soil forms that were obtained across all study sites, the dominant soil form was well drained Shortlands and Hutton. These soils are usually developed from dolerite which is an igneous rock. According to Mayland and Wilkinson (1989), soils that are formed from igneous rocks contain substantial amounts of ferromagnesian mineral, which means that they contain vast amounts of iron and magnesium. It is that reason that high amounts of Mg and Fe under RWH treatment were obtained in this study.

In the Eastern Cape where the control exhibited lower concentration of K compared with RWH, was contrary to most of water conservation studies as lower concentrations of this element could only be expected under RWH since it promotes the leaching of basic elements. Therefore, we could rather expect RWH plot to have lower concentration of these element since this technique aimed at increasing soil moisture and therefore promotes the acidic conditions that will promote the mobility of micronutrients that will form complexes with basic elements making them less available in the RWH. However, Nelson (1968) stated that the lower soil temperature could affect the availability of K in the soil. The low quantities of K obtained under the RWH compared with those under the control could only be associated with the soil temperature. The soil samples in 2015 were collected at harvest in July where soil exhibited low temperature, which resulted in RWH treatment exhibiting lower concentrations of K than the control as the RWH treatment had lower soil temperature compared with the control.

Higher soil moisture was found on all the different positions of the contour compared with control plot. This implies that RWH effectively conserved soil moisture (Botha et al., 2007). Improved soil moisture results in good crop yields as it enhances the easy flow of essential plant nutrients, making them readily available for plant uptake (Tardieu et al., 1991). The highest soil moisture was obtained below the ridge of the contour across all sites in Kwa-Zulu Natal and Eastern Cape. This suggests that rainwater collects from the runoff area and is deposited below the ridge of the contour. Higher accumulation of rainwater below the ridge could promote plant growth. As a result, it is recommended that plants be grown along the contours so that they enjoy the benefits of higher moisture content in this region. The growing of plants along the contour was also recommended by Botha (2006). Higher soil moisture was obtained during the vegetation and establishment stages of maize growth in KZN and at planting in the Eastern Cape. This could be due to the fact that rainfall amounts were highest at planting in EC compared to other stages of maize growth.

Results from this study show that the contour ridge rainwater harvesting technique is suitable for arid and semi-arid regions through its effect of improving soil moisture reserves. It might not be suitable in humid regions for the same reasons, as the higher moisture reserves under contours would induce heavy leaching of basic cations resulting in decreases in soil pH towards acidic levels (Helyar and Porter, 1989). This acidity will consequently favour the sorption and precipitation of elements such as P and exchangeable bases while micronutrients Fe, Mn etc. become more available at low pH (McBride, 1994). However, this could not be possible in dry areas such as those from arid and semi-arid regions. Furthermore, higher soil moisture found at deeper soil depths across all study sites implies that water percolates down the soil profile and accumulates in the lower depths (Iqbal et al., 2005).

Higher grain yields at Madosini and Mjali and dry matter yield at Beya, Mjali and Sokhombela under RWH than the control plot suggests that RWH through contour farming can be adopted to improve maize crop production in low yielding rain-fed areas. Many studies have shown that RWH technology is designed specifically for subsistence farmers who are located in marginal semi-arid ecotopes with high risk of drought, coupled with duplex soils and high runoff losses (Hensley et al., 2011). Farmers like those that were part of this study can be able to attain better crop yields through contour farming than what they obtain using their conventional farming practices. Mzezewa et al (2011) at the university of Venda research farm conducted another study where the grain yield of sunflower was compared between the in-field rainwater harvesting (IRWH) and other tillage systems. Results from this study indicated that grain yield was 56 % higher in IRWH than under other tillage systems. Botha et al (2003) and Botha et al (2012) obtained similar results where grain yields of sunflower and maize crops were improved because of RWH. Oweis and Hachum (2006), also measured the maize dry matter yield under water harvesting and supplemental irrigation for improved water productivity of dryland farming system. They found that where water harvesting structures i.e. contour ridges and bunds were constructed there was higher dry matter yield compared to where no water harvesting structures were constructed. Based on these findings from the literature, it can be concluded that rainwater harvesting could improve both grain and dry matter yield.

5.3 Implications, recommendation and conclusions for further studies

Climate variability poses a great threat to agricultural food production in rural areas of arid and semi-arid regions. Technologies that will assist the less privilege farmers in these regions are demanding attention to researchers. Studies have shown that rainwater harvesting can address the issue of rainfall variability in these regions by conserving limited water resource for crop production. It is therefore recommended that farmers especially those that are resource poor in these regions are supported by all means, especially with financial investments and required skills for the successful implementation of RWH in order to improve crop production under unfavourable climatic conditions. It has been proven in several studies that rainwater harvesting can improve the livelihood and food security of those communities that have adopted it (Botha et al, 2003).

It is therefore recommended, based on the findings from this study that farmers should improve their traditional way of farming by incorporating rainwater harvesting in crop production. This is because rainwater harvesting does not only conserve water but also conserves the fragile soil resource while maintaining higher crop yields. However, this will require capital investment to cover the labour requirements needed to implement and maintain contours. This is especially true for rural communities since most of the farmers there are elderly people who will not be able to supply the labour required for successful implementation and maintenance of rainwater harvesting. Apart from the unfavourable socio-economic status of farmers who participate in rural farming, contour farming also requires skilled personnel that can ensure accurate installation of the contours, otherwise they will end up causing accelerated soil losses through erosion if not installed properly. It is therefore equally significant that government departments such as agriculture and rural development should come on board to support the implementation of rainwater harvesting technology since it has potential to promote crop production under a variable climate.

Conclusions drawn from our study is that that RWH through use of contours, improved soil aggregate stability, soil moisture content as well as grain and dry matter yields compared to the traditional farmer practice. However, the trends for the effect of RWH on other soil parameters such as bulk density, micronutrients and exchangeable bases were inconsistent and highly variable to draw meaningful conclusions. Better soil fertility trends might have been observed if the experiment had been allowed to run over a longer period of time. The recommendation is therefore to advise farmers to adopt contour farming, since it has the ability to conserve soil moisture, improved aggregate stability and consequently enhance crop yields. The higher plant biomass produced under rainwater harvesting can also be incorporated into the soil after crop harvest to enhance residual soil fertility for the next crop, as well as improve soil carbon reserved. The biomass produced could also be given as fodder to animals especially during drought years when pastures are unproductive.

Farmers could also become more food secure as a result of better grain yield gains under rainwater harvesting. Future research must aim at studying the performance of contour ridges under more seasons, and possibly with a combination of other conservation techniques such as crop rotation, residue mulch or the use of cover crops etc. to gain a more holistic insight as to the benefits of different rainwater harvesting techniques, under rural dry-land farming conditions.

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7 List of Appendices

7.1 Appendix A. An analysis of variance of aggregate stability for KZN

Variate: Mean Weight Diameter

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.2657	0.1328	1.26	
Rep.*Units* stratum					
Treatment	1	1.5325	1.5325	14.48	<.001
Site	2	25.7755	12.8877	121.76	<.001
Season	1	0.5201	0.5201	4.91	0.029
Depth	2	0.11839	0.05919	1.70	0.205
Treatment* Season	1	23.75654	23.75654	684.20	<.001
Treatment*Depth	2	0.10414	0.05207	1.50	0.245
Season*Season*Depth	2	0.12246	0.06123	1.76	0.195
Treatment*Season*Depth*Site	2	0.13587	0.06794	1.96	0.165
Residual	22	0.76387	0.03472		
Total	35	73.06648			

7.2 Appendix B. Analysis of variance of bulk density for KZN

Variate: Bulk Density

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.56740	0.28370	3.99	
Rep.*Units* stratum					
Site	2	0.54739	0.27369	3.85	0.037
Treatment	1	0.21302	0.21302	2.99	0.098
Season	1	0.77213	0.77213	10.86	0.003
Site*Treatment	2	0.10724	0.05362	0.75	0.482
Site* Season	2	0.07627	0.03813	0.54	0.592

Treatment* Season	1	0.48424	0.48424	6.81	0.016
Site*Treatment*Season	2	0.12650	0.06325	0.89	0.425
Residual	22	1.56483	0.07113		
Total	35	4.45901			

7.3 Appendix C. Analysis of variance of aggregate stability for Eastern Cape sites

Variate: Mean Weight Diameter (mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.8106	0.4053	3.36	
Replicate.*Units* stratum					
Site	4	82.9955	20.7489	171.93	<.001
Treatment	1	6.7311	6.7311	55.78	<.001
Season	1	49.1871	49.1871	407.59	<.001
Depth	2	6.583	3.292	0.41	0.418
Site *Treatment	4	68.647	17.162	2.12	0.090
Site *Depth	8	47.070	5.884	0.73	0.669
Treatment*Depth	2	2.708	1.354	0.17	0.847
Site*Treatment*Depth*Season	8	14.513	1.814	0.22	0.985
Residual	58	470.615	8.114		
Total	89	666.126			

7.4 Appendix D. Analysis of variance of bulk density for Eastern Cape

Variate: Bulk Density

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.6545	0.8272	6.55	
Rep.*Units* stratum					
Site	4	0.4379	0.1095	0.87	0.493

Treatment	1	0.2010	0.2010	1.59	0.215
Season	1	1.4104	1.4104	11.16	0.002
Site*Treatment	4	0.2301	0.0575	0.46	0.768
Site*Season	4	1.3848	0.3462	2.74	0.043
Treatment*Season	1	0.0505	0.0505	0.40	0.531
Site*Treatment*Season	4	0.1187	0.0297	0.23	0.917
Residual	38	4.8003	0.1263		
Total	59	10.2882			

7.5 Appendix E. Analysis of variance of pH (Water) for KZN

Variate: Soil pH (Water)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.5112	0.7556	4.83	
Rep.*Units* stratum					
Site	2	0.05120	0.02560	0.164	0.021
Treatment	1	0.0417	0.0417	0.27	0.609
Depth	2	0.0357	0.0179	0.11	0.892
Season	1	49.1871	49.1871	407.59	<.001
Site*Treatment	2	0.0668	0.0334	0.21	0.809
Site*Depth	4	0.2311	0.0578	0.37	0.829
Treatment*Depth*Season	2	0.0102	0.0051	0.03	0.968
Site*Treatment*Depth* Season	4	0.3325	0.0831	0.53	0.713
Residual	34	5.3158	0.1563		
Total	53	8.057			

7.6 Appendix F. Analysis of variance of micronutrients for KZN

(i) Variate: Cu

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	319.04	159.52	5.06	
Rep.*Units* stratum					
Site	2	9559.76	4779.88	151.54	<.001
Treatment	1	12.92	12.92	0.41	0.524
Season	1	0.02	0.02	0.00	0.980
Depth	2	75.14	37.57	1.19	0.310
Site*Treatment	2	39.41	19.70	0.62	0.538
Site*Season	2	22.80	11.40	0.36	0.698
Treatment*Growing season	1	9.58	9.58	0.30	0.583
Site*Depth	4	80.99	20.25	0.64	0.634
Treatment*Depth	2	23.92	11.96	0.38	0.686
Season*Depth	2	5.29	2.64	0.08	0.920
Site*Treatment*Season	2	44.12	22.06	0.70	0.500
Site*Treatment*Depth	4	34.69	8.67	0.27	0.893
Site*Season*Depth	4	22.62	5.65	0.18	0.948
Treatment*Season*Depth	2	20.32	10.16	0.32	0.726
Site*Treatment*Season*Depth	4	19.54	4.89	0.15	0.960
Residual	70	2207.90	31.54		
Total	107	12498.06			

(ii) Variate: Fe

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	158.99	79.49	3.18	
Rep.*Units* stratum					
Site	2	151.95	75.98	3.04	0.054
Treatment	1	62.53	62.53	2.50	0.118
Season	1	15253.45	15253.45	610.54	<.001
Depth	2	42.22	21.11	0.84	0.434
Site*Treatment	2	145.32	72.66	2.91	0.061
Site*Season	2	92.73	46.37	1.86	0.164
Treatment*Season	1	389.20	389.20	15.58	<.001

Site*Depth	4	25.36	6.34	0.25	0.906
Treatment*Depth	2	3.68	1.84	0.07	0.929
Growing season*Depth	2	8.31	4.16	0.17	0.847
Site*Treatment*Season	2	30.77	15.38	0.62	0.543
Site*Treatment*Depth	4	41.41	10.35	0.41	0.798
Site*Season*Depth	4	21.34	5.33	0.21	0.930
Treatment*Growing season*Depth	2	3.21	1.61	0.06	0.938
Site*Treatment*season*Depth	4	10.62	2.66	0.11	0.980
Residual	70	1748.86	24.98		
Total	107	18189.95			

(iii) Variate: Mn

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	577.61	288.80	6.14	
Rep.*Units* stratum					
Site	2	4820.96	2410.48	51.26	<.001
Treatment	1	97.34	97.34	2.07	0.155
Season	1	35.54	35.54	0.76	0.388
Depth	2	10.25	5.13	0.11	0.897
Site*Treatment	2	300.32	150.16	3.19	0.047
Site*Season	2	153.42	76.71	1.63	0.203
Treatment*Season	1	1132.12	1132.12	24.08	<.001
Site*Depth	4	69.14	17.28	0.37	0.831
Treatment*Depth	2	32.71	16.35	0.35	0.707
Season*Depth	2	194.30	97.15	2.07	0.134
Site*Treatment*Season	2	146.77	73.39	1.56	0.217
Site*Treatment*Depth	4	136.80	34.20	0.73	0.576
Site*Season*Depth	4	107.43	26.86	0.57	0.684
Treatment*Season*Depth	2	61.41	30.71	0.65	0.524
Site*Treatment*Season*Depth	4	36.52	9.13	0.19	0.941
Residual	70	3291.65	47.02		
Total	107	11204.28			

(iv) Variate: Zn

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.00002	0.00001	0.00	
Replicate.*Units* stratum					
Site	1	0.2565	0.2565	1.01	0.326
Treatment	1	0.01361	0.01361	0.21	0.068
Depth	2	1.72072	0.86036	13.53	0.151
Season	1	3.69921	3.69921	58.19	0.215
Site* Treatment	2	0.05901	0.02950	0.46	0.635
Site*Depth	4	2729894.	682474.	9.16	0.064
Site*Season	2	140.957	70.479	28.28	0.057
Treatment*Season	1	210.143	210.143	84.33	0.104
Treatment*Depth	2	0.618	0.309	0.12	0.884
Season*Depth	2	92.467	46.233	18.55	0.614
Site*Treatment*Season	2	6.683	3.341	1.34	0.268
Site*Treatment*Depth	4	72.214	18.054	7.24	0.058
Site*Season*Depth	4	59.570	14.893	5.98	0.814
Treatment*Season*Depth	2	11.941	5.971	2.40	0.099
Site*Treatment*Season*Depth	4	23.723	5.931	2.38	0.060
Residual	70	174.432	2.492		
Total	107	20282.437			
Treatment*Season		0.12960	0.12960	2.04	0.167
Depth*Season	2	0.13877	0.06939	1.09	0.353
Treatment*Depth*Season	2	0.13115	0.06557	1.03	0.373
Residual	22	1.39852	0.06357		
Total	35	7.29060			

7.7 Appendix G. Analysis of variance of exchangeable bases for KZN

(i) Variate: Ca

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	102398.	51199.	0.69	
Rep.*Units* stratum					
Site	2	61692236.	30846118.	413.93	<.001
Treatment	1	81697.	81697.	1.10	0.299
Season	1	769559.	769559.	10.33	0.002
Depth	2	3301442.	1650721.	22.15	<.001
Site*Treatment	2	784342.	392171.	5.26	0.007
Site*Season	2	144367.	72184.	0.97	0.385
Treatment*Season	1	24661819.	24661819.	330.94	<.001
Site*Depth	4	2729894.	682474.	9.16	<.001
Treatment*Depth	2	158631.	79315.	1.06	0.350
Growing season*Depth	2	292563.	146282.	1.96	0.148
Site*Treatment*Season	2	6000784.	3000392.	40.26	<.001
Site*Treatment*Depth	4	956182.	239045.	3.21	0.018
Site*Season*Depth	4	782443.	195611.	2.62	0.042
Treatment*Season*Depth	2	1827107.	913553.	12.26	<.001
Site*Treatment*Season*Depth	4	3309118.	827279.	11.10	<.001
Residual	70	5216390.	74520.		

Total 107 112810972.

(ii) Variate: Mg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	5016.3	2508.2	2.60	
Rep.*Units* stratum					
Site	2	415825.3	207912.7	215.32	<.001
Treatment	1	135.0	135.0	0.14	0.710
Season	1	157250.5	157250.5	162.86	<.001
Depth	2	119262.5	59631.2	61.76	<.001
Site*Treatment	2	88453.0	44226.5	45.80	<.001

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Site*Season                      2     84502.9     42251.4     43.76   <.001
Treatment*Season
                                 1    479433.5    479433.5    496.52   <.001
Site*Depth                       4     13665.0      3416.2      3.54   0.011
Treatment*Depth                  2      1451.0       725.5      0.75   0.475
Season*Depth                     2      1452.2       726.1      0.75   0.475
Site*Treatment*Season
                                 2    223663.3    111831.7    115.82   <.001
Site*Treatment*Depth             4      1412.5       353.1      0.37   0.832
Site*Season*Depth
                                 4      4594.3      1148.6      1.19   0.323
Treatment*Season*Depth
                                 2     13046.4      6523.2      6.76   0.002
Site*Treatment*Season*Depth
                                 4      7066.2      1766.5      1.83   0.133
Residual                        70     67590.7       965.6

Total    107      1683820.
```

(iii) Variate: Na

```
 Source of variation    d.f.     s.s.     m.s.    v.r.     F pr.

Rep stratum                      2       691.8       345.9      2.46

Rep.*Units* stratum
Site                             2       868.6       434.3      3.08   0.032
Treatment                        1       112.7       112.7      0.80   0.374
Season                           1       264.0       264.0      1.87   0.016
Depth                            2        89.6        44.8      0.32   0.729
Site*Treatment                   2        15.2         7.6      0.05   0.947
Site*Season                      2       191.4        95.7      0.68   0.510
Treatment*Season
                                 1       486.1       486.1      3.45   0.067
Site*Depth                       4       538.3       134.6      0.96   0.437
Treatment*Depth                  2         0.7         0.4      0.00   0.997
Season*Depth                     2        26.8        13.4      0.10   0.909
Site*Treatment*Season   2   4632.0      2316.0       16.45     0.581

Site*Treatment*Depth             4        11.6         2.9      0.02   0.999
Site*Season*Depth
                                 4         8.0         2.0      0.01   1.000
Treatment*Season*Depth
                                 2       338.3       169.2      1.20   0.307
Site*Treatment*Season*Depth
                                 4       635.1       158.8      1.13   0.351
Residual                        70      9857.6       140.8

Total                          107     18767.8
```

(iv) Variate: K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	441018.	220509.	6.08	
Replicate.*Units* stratum					
Site	4	639724.	159931.	4.41	0.002
Treatment	1	739956.	739956.	20.41	0.541
Season	1	212.	212.	0.01	0.939
Depth	2	5357978.	2678989.	73.89	0.031
Site*Treatment	4	661988.	165497.	4.56	0.002
Site*Season	4	4868.	1217.	0.03	0.998
Treatment*Season	1	6151.	6151.	0.17	0.681
Site*Depth	8	460717.	57590.	1.59	0.135
Treatment*Depth	2	181804.	90902.	2.51	0.086
Growing Season*Depth	2	1324.	662.	0.02	0.982
Site*Treatment*Season	4	6076.	1519.	0.04	0.997
Site*Treatment*Depth	8	622810.	77851.	2.15	0.037
Site*Growing Season*Depth	8	7315.	914.	0.03	1.000
Treatment*Season*Depth2	2782.	1391.	0.04	0.962	
Site*Treatment*Season*Depth	8	5989.	749.	0.02	1.000
Residual	118	4278004.	36254.		
Total	179	13418715.			

7.8 Appendix H. Analysis of variance of pH (water) for Eastern Cape

Variate: pH Water

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.15176	0.07588	1.31	
Replicate. *Units* stratum					
Site	4	33.13045	8.28261	142.64	<.001
Treatment	1	0.12027	0.12027	2.07	0.155
Depth	2	0.03211	0.01605	0.28	0.759
Season	1	0.5201	0.5201	4.91	0.029

Site *Treatment	4	0.53350	0.13338	2.30	0.070
Site *Depth	8	0.10222	0.01278	0.22	0.986
Treatment*Depth	2	0.03140	0.01570	0.27	0.764
Site *Treatment*Depth	8	0.17402	0.02175	0.37	0.930
Residual	58	3.36777	0.05807		
Total	89	37.64349			

7.9 Appendix I. Analysis of variance of micro nutrients for Eastern Cape

(i) Variate: Cu

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	159.37	79.69	0.98	
Replicate.*Units* stratum					
Site	4	1223.64	305.91	3.77	0.006
Treatment	1	12.51	12.51	0.15	0.695
Depth	2	2535.62	1267.81	15.64	<.001
Season	1	2017.50	2017.50	24.89	<.001
Site * Treatment	4	23.29	5.82	0.07	0.990
Site * Depth	8	1001.35	125.17	1.54	0.149
Treatment * Depth	2	35.95	17.98	0.22	0.801
Site *Season	4	324.32	81.08	1.00	0.410
Treatment * Season	1	13.39	13.39	0.17	0.685
Depth *Season	2	897.47	448.73	5.54	0.005
Site * Treatment *Depth	8	117.11	14.64	0.18	0.993
Site * Treatment * Season	4	21.41	5.35	0.07	0.992
Site * Depth*Season	8	862.24	107.78	1.33	0.235
Treatment * Depth *Season	2	29.81	14.90	0.18	0.832
Site * Treatment*Depth*Season	8	150.29	18.79	0.23	0.984
Residual	118	9564.54	81.06		
Total	179	18989.82			

(ii) Variate: Fe

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.8108	0.4054	3.49	
Replicate.*Units* stratum					
Site	4	9.7896	2.4474	21.05	<.001
Treatment	1	0.0140	0.0140	0.12	0.729
Depth	8	0.4980	0.0622	0.54	0.828
Season	1	0.0005	0.0005	0.00	0.946
Site*Treatment	4	1.9840	0.4960	4.27	0.003
Site*Depth	8	1.1501	0.1438	1.24	0.284
Treatment*Depth	2	0.0634	0.0317	0.27	0.762
Site* Season	1	0.0005	0.0005	0.00	0.946
Depth* Season	2	0.0648	0.0324	0.28	0.757
Site*Treatment*Depth	8	2.4921	0.3115	2.68	0.010
Site*Treatment* Season	4	0.2801	0.0700	0.60	0.662
Site*Depth* Season	8	0.8366	0.1046	0.90	0.520
Treatment*Depth* Season2	0.1565	0.0783	0.67	0.512	
Residual	118	13.7214	0.1163		
Total	179	53.9792			

(iii) Variate: Mn

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	14.979	7.490	2.59	
Replicate.*Units* stratum					
Site	4	357.559	89.390	30.86	<.001
Treatment	1	8.266	8.266	2.85	0.094
Depth	2	189.897	94.949	32.78	<.001
Growing Season	1	367.985	367.985	127.05	<.001
Site *Treatment	4	28.784	7.196	2.48	0.047
Site *Depth	8	70.838	8.855	3.06	0.004
Treatment *Depth	2	20.826	10.413	3.60	0.031
Site * Season	4	92.772	23.193	8.01	<.001
Treatment * Season	1	0.292	0.292	0.10	0.751
Depth * Season	2	17.680	8.840	3.05	0.051
Site *Treatment *Depth	8	33.414	4.177	1.44	0.186
Site *Treatment * Season	4	25.969	6.492	2.24	0.069
Site *Depth * Season	8	42.097	5.262	1.82	0.080

Treatment *Depth * Season	2	5.958	2.979	1.03	0.361
Site *Treatment*Depth* Season	8	13.828	1.728	0.60	0.779
Residual	118	341.780	2.896		
Total	179	1632.926			

(iv) Variate: Zn

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	464.40	232.20	2.88	
Replicate.*Units* stratum					
Site	4	8938.00	2234.50	27.69	<.001
Treatment	1	364.15	182.08	2.26	0.109
Depth	2	588.29	294.15	3.64	0.209
Season	8	448.29	56.04	0.69	0.696
Site * Treatment	4	1309.43	327.36	4.06	0.004
Site * Depth	1	4644.03	4644.03	57.54	<.001
Treatment * Depth	2	3.25	1.63	0.02	0.980
Site * Season	4	5827.04	1456.76	18.05	<.001
Treatment * Season	1	2449.94	2449.94	30.36	<.001
Site * Treatment * Depth	8	47.39	5.92	0.07	1.000
Site * Treatment * Season	4	1106.05	276.51	3.43	0.011
Site * Depth * Season	8	395.28	49.41	0.61	0.766
Treatment *Depth * Season	2	0.55	0.28	0.00	0.997
Site *Treatment *Depth * Season	8	61.15	7.64	0.09	0.999
Residual	118	9523.38	80.71		
Total	179	38671.46			

7.10Appendix J. Analysis of variance of exchangeable bases for Eastern Cape

(i) Variate: Ca

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	518019.	259009.	1.70	
Replicate.*Units* stratum					
Site	4	7447771.	1861943.	12.23	<.001
Treatment	1	201451.	201451.	1.32	0.252
Depth	2	2909315.	1454657.	9.56	<.001
Season	1	537019.	537019.	3.53	0.063
Site*Treatment	4	870087.	217522.	1.43	0.229
Site*Depth	8	998289.	124786.	0.82	0.587
Treatment*Depth	2	233028.	116514.	0.77	0.467
Site* Season	4	480053.	120013.	0.79	0.535
Treatment* Season	1	219724.	219724.	1.44	0.232
Depth* Season	2	3097915.	1548957.	10.18	<.001
Site*Treatment*Depth	8	2629711.	328714.	2.16	0.035
Site*Treatment* Season	4	860343.	215086.	1.41	0.234
Site*Depth* Season	8	2317692.	289712.	1.90	0.066
Treatment*Depth* Season	2	233824.	116912.	0.77	0.466
Site*Treatment*Depth* Season	8	2660694.	332587.	2.19	0.033
Residual	118	17959703.	152201.		
Total	179	44174637.			

(ii) Variate: Mg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	518019.	259009.	1.70	
Replicate.*Units* stratum					
Site	41	19.57	19.57	1.48	0.227
Treatment	1	201451.	201451.	1.32	0.252
Depth	2	70.97	35.48	2.68	0.073
Season	1	537019.	537019.	3.53	0.063
Site*Treatment	4	870087.	217522.	1.43	0.229
Site*Depth	8	998289.	124786.	0.82	0.587
Treatment*Depth	2	233028.	116514.	0.77	0.467

Site* Season	4	480053.	120013.	0.79	0.535
Treatment* Season	1	219724.	219724.	1.44	0.232
Depth* Season	2	3097915.	1548957.	10.18	<.001
Site*Treatment*Depth	8	2629711.	328714.	2.16	0.035
Site*Treatment* Season	4	860343.	215086.	1.41	0.234
Site*Depth* Season	8	2317692.	289712.	1.90	0.066
Treatment*Depth* Season	2	233824.	116912.	0.77	0.466
Site*Treatment*Depth* Season	8	2660694.	332587.	2.19	0.033
Residual	118	17959703.	152201.		
Total	179	44174637.			

(iii)Variate: Na

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	518019.	259009.	1.70	
Replicate.*Units* stratum					
Site	41	19.57	19.57	1.48	0.227
Treatment	1	201451.	201451.	1.32	0.252
Depth	2	70.97	35.48	2.68	0.073
Season	1	537019.	537019.	3.53	0.063
Site*Treatment	4	870087.	217522.	1.43	0.229
Site*Depth	8	998289.	124786.	0.82	0.587
Treatment*Depth	2	233028.	116514.	0.77	0.467
Site* Season	4	480053.	120013.	0.79	0.535
Treatment* Season	1	219724.	219724.	1.44	0.232
Depth* Season	2	3097915.	1548957.	10.18	0.121
Site*Treatment*Depth	8	2629711.	328714.	2.16	0.035
Site*Treatment* Season	4	860343.	215086.	1.41	0.234
Site*Depth* Season	8	2317692.	289712.	1.90	0.066
Treatment*Depth* Season	2	233824.	116912.	0.77	0.466
Site*Treatment*Depth* Season	8	2660694.	332587.	2.19	0.033
Residual	118	17959703.	152201.		

Total	179	44174637.

(iv) Variate: K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	5402.	2701.	0.60	
Replicate.*Units* stratum					
Site_	4	72572.	18143.	4.05	0.004
Treatment	1	25923.	25923.	5.78	0.018
Depth	2	38530.	19265.	4.30	0.106
Season	1	14714.	14714.	3.28	0.073
Site*Treatment	4	139696.	34924.	7.79	<.001
Site*Depth	8	28576.	3572.	0.80	0.607
Treatment*Depth	2	1549.	775.	0.17	0.842
Site* Season	4	42350.	10587.	2.36	0.057
Treatment* Season	1	141.	141.	0.03	0.860
Depth* Season	2	410999.	205500.	45.82	<.001
Site*Treatment*Depth	8	47395.	5924.	1.32	0.240
Site*Treatment* Season	4	190944.	47736.	10.64	<.001
Site*Depth* Season	8	35907.	4488.	1.00	0.439
Treatment*Depth* Season	2	19384.	9692.	2.16	0.120
Site*Treatment*Depth* Season	8	30358.	3795.	0.85	0.564
Residual	118	529187.	4485.		
Total	179	1633628.			

7.11 Appendix K. Analysis of variance of gravimetric moisture content for KZN

Variate: Gravimetric soil moisture for all sites

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.02769	0.01385	0.81	
Rep.*Units* stratum					
Contour position	3	0.41255	0.13752	8.01	<.001
Growth Stage	3	0.05574	0.01858	1.08	0.359
Depth	3	0.40726	0.13575	7.91	<.001
Treatment*Growth Stage	9	0.16390	0.01821	1.06	0.396
Treatment*Depth	9	0.12714	0.01413	0.82	0.596
Growth Stage*Depth	9	0.15310	0.01701	0.99	0.451
Treatment*Growth Stage*Depth	27	0.41783	0.01548	0.90	0.609
Residual	126	2.16282	0.01717		
Total	191	3.92803			

7.12 Appendix L. Analysis of variance of gravimetric moisture for Eastern Cape

Variate: GMC

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	4	0.152660	0.038165	6.19	
Rep.*Units* stratum					
Contour position	3	0.327563	0.109188	17.71	<.001
Growth Stage	4	0.329796	0.082449	13.37	<.001
Depth	5	1.311653	0.262331	42.54	<.001
Treatment*Growth Stage	12	1.067489	0.088957	14.42	<.001
Treatment*Depth	15	0.066818	0.004455	0.72	0.763
Growth Stage*Depth	20	0.181323	0.009066	1.47	0.086

Treatment*Growth Stage*Depth	60	0.180400	0.003007	0.49	1.000
Residual	476	2.935448	0.006167		
Total	599	6.553149			

7.13 Appendix M. Analysis of variance of grain yield for Eastern Cape

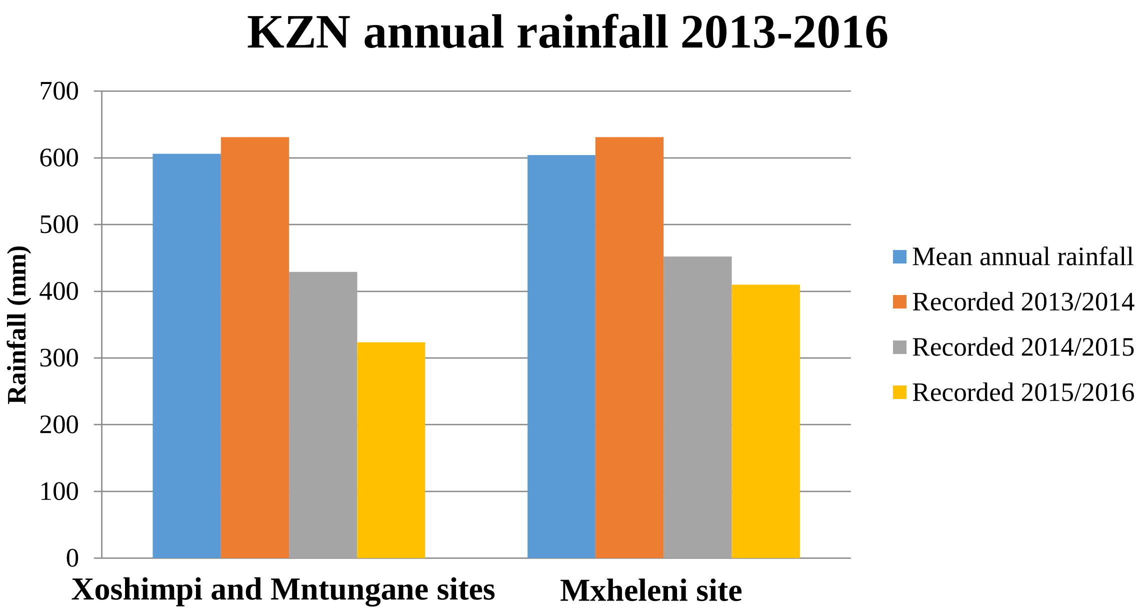
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	10995106.	5497553.	2.42	
Rep.*Units* stratum					
Treatment	1	4015912.	4015912.	1.77	0.020
Site	4	27101338.	6775334.	2.99	0.047
Treatment*Site	4	22541591.	5635398.	2.48	0.080
Residual	18	40831048.	2268392.		
Total	29	105484996.			

7.14Appendix N. A general analysis of variance of dry matter yield for Eastern Cape

Variate: Dry matter yield

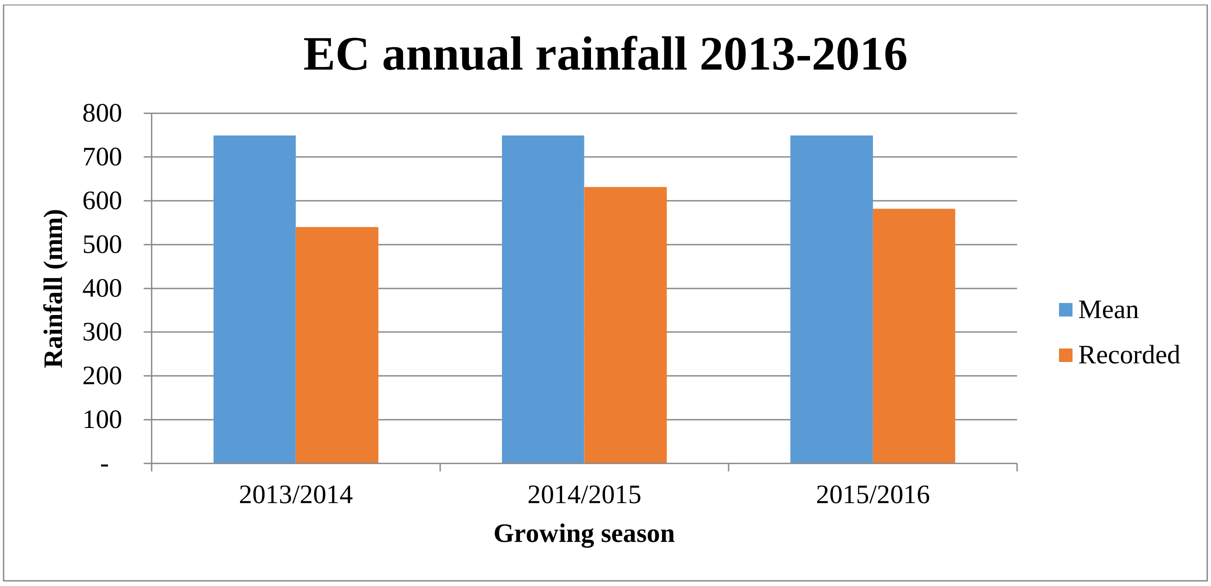
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.223	6.116	0.99	
Rep.*Units* stratum					
Treatment	1	8.576	8.576	1.39	0.025
Site	4	5.079	1.270	2.06	0.012
Treatment*Site	4	1.920	4.800	0.78	0.553
Residual	18	1.109	6.159		
Total	29	2.017			

7.15 Appendix O. Annual mean rainfall for KwaZulu-Natal (2013-2016)



Source: McCosh et al., 2017

7.16 Appendix P. Annual mean rainfall for Eastern Cape sites



Source: McCosh et al., 2017